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Impact of COVID-19 Pandemic on Indian Agriculture: A Review

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Abstract

The rise and spread of Covid-19 pandemic affected all parts of the human society by creating massive socio-economic panic across all the sectors including agriculture, tourism, commerce, shipping, manufacturing and tertiary sectors across the world. The agricultural and food sector were considered as the most crucial part of the developing economics across the globe, which was completely exposed during the Covid-19 pandemic. It has an undesirable and prominent influence on agriculture and allied sectors in India. The pandemic lockdown has resulted in the agrarian crisis across the nation by influencing and disrupting the food demand, food supply and value chain of various agricultural goods and commodities. In the country like India where majority of the population, approximately 140 million, depends directly or indirectly on agriculture and food sectors as the primary source of their income the impact due to the Covid-19 pandemic created an imbalance and affected the economy of the nation. Containing an analysis and detailed review based on articles, scientific reports, publications, organizational statements, and press releases, this review article addresses an inclusive assessment and highlights the effects of Covid-19 pandemic on agriculture and food systems. An effort has been made to understand its impact on food supply, food demand, food prices, food security and national economy. The need of the hour is to promote effective solutions in order to control critical factors such as food production, food supply, food demand, price hikes, food security and supply chain resilience. Since the urbanization and population will have tremendous growth in the coming decades, epidemics may be more frequent and we need to ensure contingency plans and mitigation strategies, especially for agricultural and food systems.

Keywords

Covid-19; Agriculture; Food supply chain; Food security

Introduction

In China, the first confirmed case of SARSCoV-2 (Covid-19), chronic respiratory infection, was reported in Wuhan, the capital of Hubei Province, in December 2019 (Singhal, 2020). On January 12, 2020, WHO named this new virus as the 2019 novel corona virus (2019-nCoV) (Lu, Stratton and Tang, 2020; Lu *et al*., 2020). On confirming SARS-CoV-2 cases in Wuhan, Chinese authorities declared a lockdown in the city to constrain the spread of the disease to other cities and countries (Lv *et al.*, 2020). The spread of viral infection to other countries and states was caused by immigration and emigration of various infected people from China to other countries and provinces (Steffens, 2020). The Corona virus disease (Covid-19) is a relatively new strain that was reported in 2019 and was not previously recognized by humans on Earth. As of 7 April 2020, the Covid-19 had infected more than 1.2 million people, killed more than 72,000 and spread across the world (WHO, 2020). The World Health Organization (WHO) on 30 January 2020 declared the Covid-19 spread as a Public Health Emergency of International Concern (Team, 2020). The recent outbreak of the virus rapidly spread across the world, and the World Health Organization (WHO) declared it as global pandemic in March 2020 (Cucinotta and Vanelli, 2020). Compared to the various previous epidemics that the world has suffered from, Covid-19 has been viewed with alarming conditions seriously affecting public health and quarantine recommendations for its detrimental effects on human enterprises and productivity, disrupting national and global economies (Hanashima and Tomobe, 2012). The Covid-19 pandemic is often referred to as the "Black Swan Event", which happens as a miracle incident not considered occurring normally and these events were distinguished from its previous incidents of greatest incompatibility and acute illnesses (Trevino, 1986). The rapid rise and spread of Covid-19 along with its several detrimental consequences induced pandemic control through territory lockdowns, travel and tourism bans, social distancing and many other restrictions that are imposed on the people's movements and migrations affecting adversely the economy of all countries across the globe. Worldwide, the pandemic has prominently affected food systems, food supply particularly agricultural inputs and output markets, food processing, food value chains, food demand, consumer economy (Mehrolia, Alagarsamy and Solaikutty, 2021) and unemployment, in return, aggravating poverty, and food and nutrition insecurity. The FAO report, "State of Food Security and Nutrition in the World", estimates that the Covid-19 pandemic could add about 130 million people worldwide suffering from chronic hunger and malnutrition in 2020 (FAO *et al*., 2020). The main aim of the lockdown was to restrain social interaction and mobility of individuals. The restricted ability for movements also limits the ability to gather a large mass of individuals in an area with a relative high density of consumers and retailers such as shopping centers, malls, town centers, etc., preventing unprecedented public health concern leading to social and economic crises (Kraemer *et al*., 2020). When there is an outbreak of contagious disease, it results into starvation and famine at a higher rate (Burgui, 2020). The Covid-19 pandemic would almost certainly have a global economic effect unlike anything seen since the Great Depression of the 1930s (He and Harris, 2020).

India is a diversified country having high population density of more than one billion, contributing 18 per cent to the world's population, which makes it second most populous country in the world. The adverse impact of communicable disease such as

Covid-19 is severe in India as compared with other countries. The first Covid-19 positive case was identified in Kerala in India on 27 January 2020. Since then, it started spreading at an alarming rate. In order to prevent its spread, the Government of India had announced a nationwide lockdown on 24 March 2020. The lockdown had adversely affected all the segments of the Indian society. Agriculture is one of the priority sectors severely affected by the lockdown. If a nation's agricultural sector is confronted with challenges, the population's well-being will be affected (Tambi *et al*., 2021). The strict lockdown measures resulted in the restrictions of major economic activities such as production, exports, commerce, logistics, processing, manufacturing, etc., thereby, affecting food supply, food demand, food prices and supply value chain leading to enormous uncertainties with respect to economic growth and socio-economic livelihoods of people.

Methodology

This paper is based on the desk review of recent data on Covid-19 pandemic concerning agriculture, including various published and unpublished literature from different sources along with web-based resources. The method involves reviewing the published and unpublished research articles to determine the impact of Covid-19 pandemic on agriculture and its critical consequences around the world. Google Scholar and Research Gate were the primary databases used for obtaining comprehensive and systematic data from various journals, articles, conference proceedings, scientific reports published by different organizations, and the books. The information collected was systematically analyzed for logical discussion and conclusion.

Results and Discussion

Current Scenario of Indian Agriculture

Agriculture is the prominent sector of the Indian economy. It contributes nearly one-sixth to the Indian national income that is about 17 per cent to the country's GDP and also provides employment opportunities to over 60 per cent of the population directly or indirectly associated to agricultural sector in India. The estimated annual growth (in real terms) from 2014–15 to 2018–19 in agriculture and allied sectors was 2.9% (Government of India, 2020). In terms of the world's agriculture, India produces more than one-fifth of global production of paddy and pulses. Similarly, it contributes to more than 20 per cent of global production of many horticultural crops such as okra, cauliflower, banana, mango and papaya (FICCI, 2020). It acts as the priority sector helping in ensuring food security of the nation along with influencing the growth and development of secondary and tertiary sector of the economy. While the Indian economy contracted by 23.9% in the first quarter of 2020–21, agriculture was the only sector to register a positive growth of 3.4% (ET, 2020). Agricultural growth and development help in enhancing agricultural production and productivity, thereby, reducing poverty directly by raising farm incomes and indirectly by creating employment opportunities, reducing food prices, increasing per capita food availability and ensuring food security (NABARD, 2020). More emphasis on agriculture sector promotes development of the economy. In other words, a flourishing agricultural sector is a boon for most other sectors of the Indian economy.

Impact of Covid-19 on Agriculture Sector of India

The nationwide lockdown across the country has severely affected the production and supply of goods and services that are inadequate to meet the existing demand. Many economic units are on the verge of shutting down; people became unemployed by losing their jobs and wages. When lockdowns are imposed, people are restricted to venture out to purchase various goods and services resulting in reduced consumption along with lower demand (FICCI, 2020). The Covid-19 pandemic has adversely affected the agricultural sector since the farmers had faced a lot of difficulties in every aspect of farming involving production process such as purchase of inputs due to delays in transport and logistics services especially at ports causing smallholders to suffer farm losses (Okolie and Ogundeji, 2022), sowing, accessing labor, harvesting, processing, marketing and exporting of agricultural commodities (NABARD, 2020).The impacts of the pandemic on agriculture and food systems resulting in the instability caused by a shock and related behavioural modifications leading to occasional price spikes, market supply disruptions, and food shortages (Table 1) (FAO, 2020).

Table 1: Impact of Covid-19 Pandemic on Sectors of Agriculture

Sector	*Impact*
Production	Non-availability of raw inputs
	Increase in cost of production
	Shortage of labor and farm inputs (seeds, fertilizers, agrochemicals, farm equipment, etc.)
	Demand deficit
	Wastage of food due to improper food management (perishables and semi-perishables)
Processing	Shutting down of the units
	Lack of adequate supply of raw materials
	Low demand due to lockdown
	Low income and unemployment of employees
	Inflation in price of raw commodities
Retailing	Panic buying among consumers
	Shortage of food products
	Disruptions in demand and supply
	Inaccessibility of goods and services
	Logistics and storage facilities
Consumption	Change in consumer consumption pattern
	Food insecurity for lower income groups
	Change in consumer behavioral pattern
	Low purchasing parity
	Change in consumers preference

The disruptions in the demand and supply chains lead to the shrinking market facilities and falling output prices. With respect to a consumer, it can lead to uneven rise in retail prices. Consumers are adversely affected with the access to adequate quantities of food at reasonable prices. The absence of adequate quantities of food caused by either demand slowdowns or supply shocks resulting in abrupt hikes in retail food

pricing leading to the rise in hunger, malnourishment and nutritional insecurity particularly among the vulnerable groups. In the agriculture and food sector, the various demand and supply factors translated into some types of impacts (Lusk, 2020). The various factors affecting agricultural production such as shifting of consumer demands due to income shocks, reduction in the need for high value food products results into enhancing food insecurity (Amare *et al.*, 2020). The epidemic has affected the livelihood and intensity of farmers' adoption of sustainable agricultural practices (SAP) (Martey *et al*., 2022). Disruptions in the food supply and value chain are more acute especially for perishable items like fruits and vegetables (Mahajan and Tomar, 2020). The pandemic is severely influencing the food and agricultural supply chain in three big perspectives that include food supply, food demand and food prices (FAO, 2020a). Thus, the impact of Covid-19 pandemic has tremendously affected three major components of agriculture and food sectors that include food supply, food demand and food prices as illustrated in figure 1 and that are closely associated with eradication of poverty, hunger, nutritional security and promoting national food security.

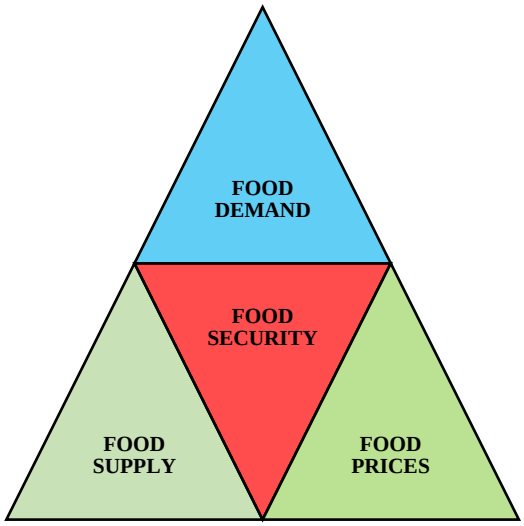

Figure 1: Three major components of food security

Impact of Corona Virus (Covid-19) on Food Supply

The food supply involves certain activities such as farming, harvesting, processing, and its distribution for the purpose of marketing such as whole selling and retailing. Food supply needs a time-bound action and implementation in order to achieve optimum quality of goods and services. In order to optimize production, quality agricultural inputs are required such as seeds, fertilizer, agrochemicals, etc. During the Covid-19 pandemic, the nationwide lockdown resulted in transportation restrictions, closure of industries and international borders affecting input supplies across the nation (Aday and Aday, 2020). The shortage of labour was observed because of their migration to hometowns in order to mitigate the pandemic conditions (Nandi and Swamikannu, 2020). A survey reports that 45% of the migrants returned home during lockdown (Imbert, 2020). The closing of the various national and international borders was a strategy used by many countries in order to control the risk and spread of contaminants. Although various production activities of major staple crops are being

highly mechanized in the developed nations are not affected adversely whereas the more labour-intensive crops such as fruits and vegetables require huge involvement of work force and human labour, thus, being more vulnerable to the effects of Covid-19 (Laborde *et al.*, 2020). Manufacture, reining, distribution and transportation are the various activities which altogether act as the fragments of the food supply associating with the farming landscape to the user's table. Ensuring food supply does not get disrupted and it strives to flourish well (Chen *et al.*, 2020). The Covid-19 pandemic outbreak resulted in enforcement of corresponding preventive lockdowns that acted as a new challenge. During the first and second quarters of 2020, food supply chains were outlined production and transportation fell sharply and household income was adversely affected (FAO, 2020a, 2020b, 2020c, 2020d). Many other worldwide efforts have been made in order to control the pandemic by restraining movement and interactions of people resulting in negative economic effects linked with the functioning of agricultural systems responsible for food supply (Siche, 2020; Timilsina *et al.*, 2020). The international trade of agricultural goods and commodities almost came to a halt whereas the domestic trade networks were severely affected due to the lockdown. Due to the travel restrictions, the movement of goods from the farmer's fields to the nearest market was affected. Thus, the disruptions in food supply and logistics during the pandemic remained acute. As accurate forecasting of food supply became difficult, various firms became risk-averse due to the bullwhip effect where the supplies declined far more than that was necessary.

Impact of Corona Virus (Covid-19) on Food Demand

The demand for the food depends on the mindset of the customers or consumers who further depend on certain attributes such as their socio-economic conditions, patterns of consumption, consumer's attitude, behaviors etc. along with various other environmental conditions, such as drought, flood, ecological disturbances and Covid-19 pandemic affecting significantly the food demand. Food demand can be addressed as consumer's interest and abilities to purchase specific goods and services within a given time frame (Gottheil, 2013). The demand for the food depends on the price of food stuffs, income level of the consumers, socio-demographic situation, consumption pattern, shopping preferences and time constraints (Bakalis *et al.*, 2020; Cranfield, 2020). During the initial phase of Covid-19 pandemic, consumers did resort to panic buying and stockpiling of food items during the lockdown in March 2020. Large-scale stockpiling of foods affected the recurrent stock outs leading to uncertainty over the availability of essential food products in the future as a cause of panic buying (Keane and Neal, 2021). Many consumers hoarded basic food items during the pandemic along with cleaning and sanitary products to ensure the availability of grocery essentials when required (Castelló and Casasnovas, 2021). It has been studied that stockpiling is driven by the expectations over future price fluctuations (Mela, Jedidi and Bowman, 1998). Similarly, at further phase there was steep fall in the demand for food items due to the loss of jobs, accessibility and unemployment. The huge reduction in demand for eatery and commercial food services due to certain factors including handling of foods, production capacity of food along with other agricultural products that have an adverse influence on the farmers output reduction (Brewin, 2020; Ceballos, Cranfield, 2020; Kannan and Kramer., 2020; Poudel and Subedi, 2020). On a general basis there was an uneven distribution of food resulting in shortages of some foods in certain areas and oversupply of certain other foods in

different areas. During the Covid-19 pandemic restrictions many consumers preferred to take away food or use home delivery facilities due to closure of restaurants (Bakalis *et al.*, 2020; Shahidi, 2020). Along the same time, most of the consumers were concerned about the critical effects of Covid-19 on their mental and physical health due to which they look for specific food products and confectionaries to improve their health and mood (Hughes, 2020; Muscogiuri, Barrea and Savastano, 2020). However, keeping the distribution chain alive was necessary by utilization of effective supply management strategies in order to meet the consumer demands (De Sousa Jabbour *et al.*, 2020). Thus, as the consumers play a vital role in food supply chain, changes in consumer's attitude, decision making behaviour and consumption pattern gets strongly affected during Covid-19 pandemic outbreak.

Impact of Corona Virus (Covid-19) on Food Prices

The demand and supply of major agricultural commodities declined in India after the lockdown. The challenges in the food demand and supply chains during the Covid-19 pandemic resulted in the fluctuations in prices of various agricultural goods and commodities. Major studies were done on demand and supply shocks and are analyzed along with price movements in agriculture after the lockdown (Narayanan and Shah, 2020; Rawal and Verma, 2020). The major cause for the price inflation during Covid-19 outbreak involves the demand for food, panic purchase, hoarding and back stocking of goods. Other factors affecting may include shortage of labourers, shutting down of food processing plants, inefficient marketing platforms, disruptions in the global supply chain due to travel restrictions (Sen, 2020). The gap between the wholesale and retail prices of various agricultural commodities increased during the lockdown which may be due to demand collapse or overwhelmed supply shocks. Many consumers may also expect prices to rise in the near future when a supply shock is seen but retail prices are yet adjusted in upward trend (Jaravel and O'Connell, 2020). Fluctuations in food prices are obvious consideration in the underdeveloped and developing countries constituting of both income of farmers and purchasing parity of the consumers (Bellemare, 2015; Barrett, 2020). The selling cost of major agricultural goods and commodities has increased due to constraints in logistics associated with the pandemic (Hahn, 2020). Therefore, various stringent measures such as increase in the communication networks and strengthening logistics facilities are the key factors in establishing efficient food supply chain system, market access and promoting economic stability.

Impact of Corona Virus (Covid-19) on Food Security

Food security can be explained as a process of ensuring the availability and accessibility of optimum quantity of nutrient-rich foods to various communities. It describes about how foods are handled, prepared, and stored following various protocols for effective food control systems, which are essential for protecting consumer's health and safety. The primary goal of food security is to ensure enhancements in food accessibility in order to enable adequate food distribution starting from the households to low-income line. Food security refers to an individual or groups who have unlimited access to healthy food sufficient to improve their living conditions (Rosales and Mercado, 2020). The potential impact of Covid-19 pandemic on food security can be further summarized in the form of distortions in food supply

and demand, uneven hike in food prices, unemployment, poor economic conditions, low investments in the agriculture and food sectors, thereby, affecting government expenditures and financial assistance towards the farmers growth and improvement (Udmale, Pal and Szabo, 2020). According to the Food and Agriculture Organization (FAO), about 135 million people across the world were experiencing extreme levels of food insecurity before the pandemic outbreak (FAO, 2020a). The Covid-19 pandemic outbreak has a detrimental impact on agricultural food systems affecting major food supply chain and disrupting food security in the economically vulnerable region around the world (Alvi and Gupta, 2020; FAO, 2020c; Schmidt, 2020a). In a post-pandemic scenario, the World Food Programme (WFP) has forecasted that the number of individuals facing acute food insecurity may rise from 135 million to 265 million (WFP, 2020). Thus, the food security was adversely affected during the Covid19 pandemic outbreak that can be mitigated through policy reforms, financial growth and nutritional assistance programs. . The government can opt for a staggered procurement and pricing strategy that accounts for the threshold level in cost of storage (Sendhil *et al*., 2020a). It can also be useful to tackle other crises in the future such as natural disasters, financial recession, global pandemic, etc., thereby, optimizing food security for national growth and economic prosperity.

Conclusion

The Covid-19 pandemic crisis has started a new era in the agriculture and food industry. It has created several challenges in the agriculture and food ecosystem worldwide. It has affected major areas of production, processing, food supply chain, dietary changes, logistics, etc. along with national economy and food security. In order to retain its rise and spread, stringent measures were adopted such as restrictions in movements, social distancing, quarantine measures that posed huge barriers in transportation, disruptions in value supply chains, economic growth and sustainable development in agriculture and food sector. The pandemic has shattered economic prosperity, food securities, government policies, world commerce and financial markets. However, the disruption of the food systems opens up to opportunities to connect local production and consumption (Blay-Palmer *et al*., 2021). It has created new interventions in the food business, food handling, agriculture and food supply chain network which we have never seen previously (Galanakis, 2020). Furthermore, the Covid-19 pandemic complex vagaries adversely affected economically vulnerable communities across the world in the most impulsive ways requiring an effective understanding along with mitigation and coping strategies to overcome the consequences. The Covid-19 pandemic has created wide havoc in agriculture and food sector by disrupting supply and demand value chain, low inputs, loss of job, reduced household incomes, higher retail prices, etc. In order to tackle the situation, a diverse set of agriculture and food related measures were adopted by governments in response to the agrarian crisis with major concern on agricultural production, functioning of the food chain and consumer demand. The impact of COVID19 on the Indian agricultural system enabled us to arrive at a 10-point strategy for strengthening the sector against the crisis and sustainability issues (Workie *et al*., 2020). During the peak period local governments were highly vigilant and responded promptly by providing quarantine facilities to the returnees along with distribution of health and ration kits for vulnerable families (Thapa, 2022). The post-2020 context has revealed some transformations which paved the way for agri-food systems to operate (Snow *et al*.,

2021). Along with input subsidies and farm loans, measures such as empowering farmer's access to latest technological interventions can also be taken into account (Demont, Fiamohe and Kinkpé, 2017). Considering farms as micro-systems nested within the larger agricultural systems which can support farmers to deal with uncertainty, being essential in becoming resilient (Slijper *et al*., 2022). Thus, one of the vital lessons that can be learnt due to the outbreak of the virus would be building a resilient supply chain management and food system. Resilience is about the capacity of a system to live with complexity, uncertainty, and (abrupt or incremental) change, and to ensure continuity in ever-changing environments through adaptation and transformation (Folke *et al*., 2021). Major reforms in the agricultural marketing and distribution systems along with e-commerce will boost farmers' income. Government efforts are needed to identify gaps and bring desired changes in order to avoid further economic and nutritional disparities. Special, government funds and emergency food rations such as PDS (public distribution system), work guarantee schemes (e.g., MGNREGS[1]) and supply of agricultural inputs can play a prominent role if mobility and supply chains are severely disrupted. Additionally, accessibility and functioning of e-National Agricultural Markets, quick and hassle-free direct payment through banks, enabling contract farming, farmer producer companies (FPCs) and logistics like scientific storages at grassroots level along with food, income and job safety net for the poor and needy during lockdown are helpful. On the policy front, facilitating agricultural reforms by promoting transfer of technology directly to the farmers and addressing their grievances supported by the researchers, scientists and farmers together along with new initiatives such as Aatma Nirbhar Krishi (self-reliant agriculture) will enable the economy to transform into a powerhouse of food production and distribution providing sufficient insulation and shock absorption to the vulnerable groups. Innovations such as development and introduction of new products and services, introducing new financial schemes, family farming, community farming, roof top farming, hydroponics, digitalization, etc. will address the modern challenges in agricultural sectors moving a step ahead towards resilience and sustainability.

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Authors' Declarations and Essential Ethical Compliances

Authors' Contributions (in accordance with ICMJE criteria for authorship)

Contribution	*Author 1*	*Author 2*	*Author 3*	*Author 4*
Conceived and designed the research or analysis	Yes	Yes	No	No
Collected the data	Yes	No	Yes	Yes
Contributed to data analysis & interpretation	Yes	Yes	Yes	Yes
Wrote the article/paper	Yes	Yes	No	No
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Research involving human bodies or organs or tissues (Helsinki Declaration)
The author(s) solemnly declare(s) that this research has not involved any human subject (body or organs) for experimentation. It was not a clinical research. The contexts of human population/participation were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or ethical obligation of Helsinki Declaration does not apply in cases of this study or written work.

Research involving animals (ARRIVE Checklist)
The author(s) solemnly declare(s) that this research has not involved any animal subject (body or organs) for experimentation. The research was not based on laboratory experiment involving any kind animal. The contexts of animals were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or ethical obligation of ARRIVE does not apply in cases of this study or written work.

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The author(s) solemnly declare(s) that this research has not directly involved any local community participants or respondents belonging to non-Indigenous peoples. Neither this study involved any child in any form directly. The contexts of different humans, people, populations, men/women/children and ethnic people were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or prior informed consent (PIC) of the respondents or Self-Declaration in this regard does not apply in cases of this study or written work.

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Influence of Plant Density and Application of Different NPK Doses on Growth and Yield Performances of Cucumber (*Cucumis Sativus* L.) under the Open Field Conditions in Kabul, Afghanistan

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Abstract

The present study was conducted for one growing season from 12th March 2022 to 15th July 2022 in Horticulture Research Farm at Agriculture Faculty of Kabul University in open field, with the specific objective of finding out the interaction influence of three plant density and four NPK doses as a treatment on the growth and yield parameters of Nahid-F1 variety of cucumber. The experiment was laid out following the Factorial Randomized Block Design (FRBD), with three replications consisting of combined three level of plant geometry viz. 75×35 cm (S1), 75×45 cm (S2) and 75×55 cm and four doses of NPK viz., control (F0), 60:30:30 (F1), 80:40:40 (F2) and 120:60:60 (F3) as a treatment. The data on growth attributes and yield contributing characteristics of cucumber crop were recorded and analyzed trough SPSS (22) software (2011) using Analysis of Variance (ANOVA) for Factorial Randomized Black Design (FRBD). The results obtained from the current study reveal that all growth and yield characteristics under the study were remarkably influenced by plant density and dose of NPK and cucumber variety of Nahid-F1 performed better with T12 (75×55 cm + NPK 120:60:60), T8 (75×35 cm + NPK 120:60:60) and T3 (75×35 cm + NPK 80:40:40) in respect to the various growth and yield characteristics, such as number of branches, number of leaves per plant, plant height, stem girth, days to first flower bud initiation, days of first fruits picking, fruit length, fruit girth, average fresh fruit weight, number of fruits per plant, number of fruit per vine, yield per square meter and yield per hectare. While T1 (75×35 cm + control), T5 (75×45 cm + control) and T9 (75×55 cm + control) did not show any superiority in any growth and yield attributes as evaluated in Kabul agro-climatic region. Thus, T8 and T12 could be recommended to the farmers of Kabul province for better cucumber production in Kabul agro-climatic condition in Central Afghanistan.

Keywords

Cucumber; Growth; Kabul; Plant geometry; Variety; Yield

Introduction

Cucumber (*Cucumis sativus* L.) is day neutral monoecious annual crop belonging to the Cucurbitaceae family, and it produces both male and female flowers on the same plant on separate nodes (Bist *et al.,* 2020), which comprised of approximately 125 germplasms and 960 species, mainly in tropical and subtropical region (Bist *et al*., 2020; Sadiq *et al*., 2019). However, some of the genotypes may yield bisexual flowers (Elsheikh and Ahmed, 2005). This indicates that sex appearance in the cucumber plant is influenced by a numbers of environmental factors, such as photoperiod, temperature, plant hormones and genetic make-up (Renner, Achaefer and Kocyan, 2007). Cucumber is believed to have been domesticated in India for 3,000 years and in Eastern Iran and China probably for 2,000 years. It was much appreciated by earliest Greeks and Romans (Sadiq *et al.*, 2019), and it is one of the oldest vegetables cultivated by mankind with historical records dating back 3,000 years (Singh *et al.*, 2019; Eifediyi and Remison, 2010). Cucumber is fourth most vital vegetable after tomato followed by cabbage and onion in Asia and second most important vegetable crop after tomato in Western Europe (Bist *et al.*, 2020; Eifediyi and Remison, 2010). The immature fruits of cucumber are used as salad and for making pickles, *rayata* and brined on commercial scale, consumed either raw as salad, cooked as vegetable, or kept in its unripe stage (Bairagi, Singh and Ram, 2013; Khan *et al.*, 2017). The global production of cucumber is 71.36 million tons (FAOSTAT, 2014; Singh *et al.*, 2019) and commercially it is cultivated in the countries like China, India, Turkey, Iran, Japan, Europe, United States and Afghanistan (Sadiq *et al.*, 2019; Singh *et al.*, 2019). Immature and tender fruits of cucumber are rich in two of the most basic elements required for healthy digestion: fiber and water (Sadiq *et al.*, 2019), but it is very low in energy containing 0.6 g protein, 2.6 g carbohydrate, 12 calories energy, 18 mg Ca, 0.2 mg Fe, 0.02 mg thiamine, 0.02 mg riboflavin, 0.01 mg niacin and 10 mg vitamin C per 100 g of edible portion (Sruthi and Prasad, 2020). The high water content makes cucumber a diuretic and it promotes cleaning action within the body by removing gathered pockets of old waste material and chemical poisons (Sadiq *et al.*, 2019). The high level of potassium and magnesium helps regulate blood pressure, and relaxes nerves and muscles. Ascorbic acid (vitamin C) and coffee acid existing in cucumber lessen skin frustration and swelling. It is said to have cooling effect and avoids constipation (Singh and Kumar, 2012; Sruthi and Prasad, 2020).

Cucumber is a warm season vegetable crop, grown and harvested best in almost all climatic regions around the world (Adinde. *et al.,* 2016; Hochmuth, 2001), ranging from tropical to semi-temperate regions in more than 150 countries with mean temperature of between 25°C to 29°C and plenty of sunlight, over dry and rainy season (Adinde *et al.*, 2016; Hector *et al.*, 2005; Hochmuth, 2001). Cucumber is a frost susceptible horticultural crop, usually cultivated in open fields during spring-summer period or in greenhouse all the year round. While high light intensity causes more male flowers initiation per plant but lower light intensity brings more female flowers per plant (Sadiq *et al.*., 2019). Cucumber grows on a wide range of soil and does best on fertile soil enriched with organic matter having a deep and well-drained sandy loam textures of soil with a pH ranging 5.5 to 6.7 (Ranjian *et al*., 2015), though infertile soil results bitter and misshapen fruits that have little marketability value and are rejected by consumers in the market (Sadiq *et al.*, 2019). However, the nutrient demand of the cucumber crop varies depending on soil types, previous cropping

pattern, native fertility and cultural practices, but it responds positively to organic and inorganic or combined nutrient applications for optimum growth and yield productivity.

The climate of Kabul is deliberated to be continental, cold semi-arid weather with precipitation concentrated in the winter (almost exclusively falling as snow) and spring months, with annual mean temperature of 12.1°C and spring is the wettest season of the year (Belda *et al.*, 2014). From total arable land area in this province is only 6% of rain-fed land, which is available for wheat crops. The fruit crops and vegetables like potato, cucumber, tomato, onion and other seasonal vegetables are grown on the remaining 94% of irrigated farmlands, which are considered as being some of the best quality in Afghanistan. The average farm size in this province is about two *jeribs* (4,000 meter square) and small landowners make up the majority of farming households (FAO, 2007; FAO, 2018). Cucumber cultivation under the open field condition is common in Kabul and its demand is increasing. At present, there are numbers of local and hybrid varieties of cucumber imported by both public and private sectors, but no formal information exists related to their growth, yield and organoleptic performance (FAO, 2016; USAID, 2010). The agro-ecological situation of Kabul province is must suitable for vegetables production particularly for cucumber. Whereas, the low cultivated areas of this crop in Kabul agro-climatic region is due to the various environmental and agronomical factors (Opara *et al.*, 2012; USAID, 2010), and non-availability of proper varieties with high growth and yield performance, climatic situations, edaphic properties, lack of technological knowledge about plant spacing and improper application of fertilizer doses, water shortage for irrigation, plant management and cultural practices in this region (Behzad, Omerkhil and Faqiryar, 2021; Sadiq *et al.*, 2019).

The favorable air temperature, optimum relative humidity, light intensity and auspicious growing season, optimal plant spacing, on time planting and timely irrigation and nutrient supply have a crucial role on the high cucumber yield production (Adinde *et al.*, 2016) and fruit quality. Optimum sowing time brings about proper growth and development of plants resulting in maximum yield of the crop and economic uses of farmland (Sadiq *et al.*, 2019). The plant density and application of different doses of NPK fertilizer influences the vegetative growth and the final yield of cucumber crop (Adinde *et al.*, 2016; Sadiq *et al.*, 2019); plant vegetative growth increased as crop density decreased within rows and column, and cucumber plant disease and pest susceptibility frequently happened in crops with a closest plant spacing among the rows and column (Arif *et al.*, 2019). Dense plants affect the basal internode of cucumber plant, and longer dense plants result in more susceptibility to pest and diseases and low yield compared to the sparse density plants (Opara *et al.*, 2012). Optimal plant density and application of suitable NPK doses are deliberated as a key management element for an effective yield of cucumber, because it is under the farmer's control in most cropping systems and is important in cucumber production (Sadiq *et al.*, 2019; Singh *et al*., 2019). Soil properties, topography, nature of varieties, climatic conditions, and sowing time greatly affect the ideal plant density (Singh *et al.*, 2019). If optimum plant spacing exceeds, final yield decreases often. Earlier, many studies showed that plant spacing significantly influence plant internodes and biological yield (Sadiq *et al.*, 2019; Singh *et al.*, 2019; Sruthi and Prasad, 2020). High amounts of fertilizer compensate for reduced plant vegetative growth improvement

and stimulate more central stem and more fertile flowers, which can be satisfactory, particularly for variety inclined to produce fewer fertile flowers per plant (Singh *et al.*, 2019).

However, no plant density and application of optimal doses of NPK have been identified as best adapted or most suitable for Kabul agro-climatic region, Center Zone, Afghanistan. Hence, the current study focuses on the effect of plant density and dose of NPK on vegetative growth and yield performance of cucumber variety of Nahid-F1 under open field of Kabul region to identifying the best adapted or the most suitable plant density and doses of NPK with the most effective performance for increased yield in Kabul agro-climatic region. This is to be recommended to the farmers for enhanced best quality cucumber production in Kabul agro-climatic region, Center, Zone of Afghanistan, to meet the local and national population's cucumber demands.

Methodology

To evaluate the influence of plant density and different doses of NPK on vegetative growth and yield performance of cucumber (*Cucumis sativus* L.), the experiment was conducted for one growing season from 12th March 2022 to the 15th July 2022 in research farm of Agriculture Faculty of Kabul University in open field at Kabul, Afghanistan. The site is located in center part of the country at 34° 30' 58" N 69° 08' 13" E with a mean altitude of 1,800 m (Figure 1). The climate of Kabul is considered to be continental, cold semi-arid climate with precipitation concentration in the winter (almost exclusively falling as snow) and spring months with annual mean temperatures of 12.1°C, and spring is the wettest season of the year. The experiment was laid out following Factorial Randomize Block Design (FRBD) with three replications and combination of three levels of plant density viz. 75×35 cm (S1), 75×45 cm (S2) and 75×55 cm and four doses of NPK fertilizer viz., control (F0), 60:30:30 (F1), 80:40:40 (F2) and 120:60:60 (F3) was used as treatments. The experimental field size of 221.4 m^2 was marked using measuring tape, rope and peg. Soil samples of experimental field were randomly collected from the site between 0 and 30 cm depth by using soil auger, bulked to make a composite soil samples. The soil samples were analyzed for physio-chemical properties (Table 1). Land clearance was done with the help of cutlass, and the debris was packed using rake. The soil was ploughed to fine tilts using machine plug and harrowing tolls. The experiment field area was marked into three blocks, each block containing three plots of 8.5 m × 3 m and was prepared using a hoe. 0.8 m wide irrigation canals were separated from adjacent blocks and 0.60 m alleys plots, respectively.

Table 1: Physio-chemical analysis of the experimental field soil (2022)

Mechanical analysis		*Chemical analysis*	
Parameters	Value	Parameters	value
Fine Sand %	53.4	Organic matter %	0.47
Course Sand %	28.4	EC mmhos/cm^3	02
Silt %	7.20	pH	8.04
Clay %	6.13	Soluble N %	0.022
Soil texture class	Loam	Available P ppm	15.85
Bulk density g/cm^3	1.3	Exchange K ppm	6.04

Seeds of cucumber variety were collected from seed market and socked in normal water (18°C) for 20 hours for pre-germination and raising healthy cucumber seedling for open field cultivation. One seed of selected cucumber variety of Nahid-F1 was sown in black polythene bags of 12 cm length and 12 cm girth, filled with mixture of sand: soil: vermicompost (1:2:1) on 20 March. Twenty days old seedlings at 2-3 true leaf stage were transplanted, according to the different treatment combination from polythene bags on 15 April to open field from greenhouse. A steady mechanical weed control of broad and narrow leaf weeds was done at every 10 days' interval with the help of hoe. The agronomical practices including irrigation and hoeing were carried out as per the standard procedure.

Data were collected for 15 different growth attributes and yield contributing characteristics of cucumber crop, such as number of branches per vine, number of leaves per plant, vine length, leaf area, days to first flower bud initiation, days to first fruits picking, and yield characteristics like, fruit length, fruit girth, average fresh fruit weight, number of fruits per vine, fruit yield per plant, yield per square meter and yield per hectare, from six randomly selected middle tagged plants per plot of each treatment. The standard statistical techniques as developed by Steel and Torrie (1980) for factorial experiment in Randomized Block Design (RBD) was adopted for statistical analysis of data recorded, and comparison was made at (P<0.05%) probability level using SPSS (22) software (2011) to compare treatment means.

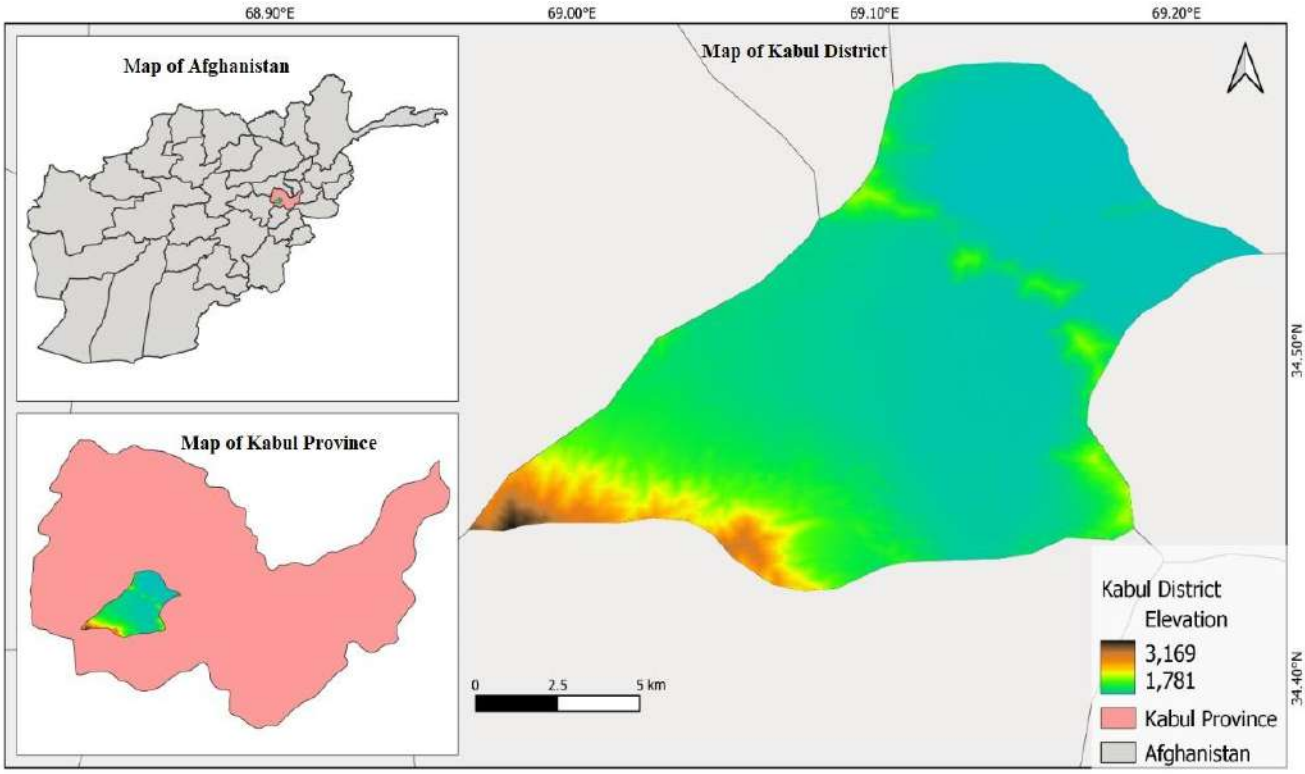

Figure 1: Map of study area (Kabul district, Kabul, Afghanistan)

Results and Discussion

Plant Branches

Number of branches is one of the key characteristics representing cucumber plant's vegetative growth reflecting the effect of agro-chemical and genetic variation. Analysis of variance of the cucumber growth traits under the effects of three plant densities and different doses of NPK are presented in (Table 2). The results revealed significant differences ($p<0.05\%$) due to combination of different doses of NPK and plant densities. T6 (75×35 cm + NPK 60:30:30) produced the highest number of branches per plant (3.45), followed by T3 (75×35 cm + NPK, 120:60:60) i.e. (3.00), T7 (75×45 cm + NPK 80:40:40) i.e. (3.12) and T2 (75×35 cm + NPK, 80:40:40) i.e. (2.93), and the lower with T1 (75×35 cm + control) i.e. (1.14) and T5 (S2, 75×45 + Control) i.e. (2.01), respectively. This may be due to closest plant spacing that may cause high plant population in the current study and low level of NPK since the cucumber variety was the same, which led to competition among plant branches resulting in few branches or flowering buds per plant. Branching stage is mainly controlled by agro-ecological factors and genetic make-up of the variety. The same result of the number of branches per plant was reported by Sruthi and Prasad (2020), Shukla *et al.* (2020) and Singh *et al.* (2019). Better availability of space and higher rates of nitrogen, phosphors and potassium for plant growth seem to have increased the number of branches per plant and it tends to raise the femaleness of cucumber and, thereby, results increased the final yield.

Number of Leaves per Plant

The data recorded for the number of leaves per plant showed significant difference ($p<0.05\%$) among all treatments evaluated under this investigation. Among the different treatments, 82.41 leaves per plant was recorded with T7 (75×45 cm + NPK 80:40:40), and T3 (75×35 cm + NPK, 80:40:40) showed the second highest number of leaves per plant, i.e. (73.00). The minimum number of leaves per plant (55.76) was noted in case of T9 (75×55 cm + Control) and T10 (75×55 cm + KPK, 60:30:30), which were statistically in line with other treatments (Table 2). This study observed that a greater number of leaves per plant were generated at the plant density of 75×45 cm with the combination of NPK at the rates of 80:40:40 and the lowest in case of the plant geometry of 75×55 cm combined with control. The greatest number of leaves per plant in plant density of 75×55 cm combined with NPK doses of 80:40:40, i.e. (82.41) was because of the less competition and appropriate plant placement in line. This might be due to the optimum availability of macro-nutrients to boost the number of leaves per plant. Whereas, the plant competition causes fewer number of leaves per plant, a high density of plants per capita provides the situations more prone to disease occurrence and stumpy osmotic pressure among the cucumber plant population. Generally, more number of leaves per plant gives more yields in cucumber. The results of this study are in line with the findings concluding that appropriate placement of plants in line reduces the competition among the plant population having more number of leaves, and enhances the nutrient absorption, vegetative growth, and number of branches per plant and flowering buds, as reported earlier by Sruthi and Prasad (2020), Umamaheswarappa *et al.* (2005) and Singh and Kumar (2012).

Plant Height

Plant height is one of the key characteristics representing cucumber plants' vegetative growth reflecting the genetic make-up and agro-eco-technical effect. The results showed that there were significant differences ($p<0.05\%$) among all the treatments combined the plant height, the mean value for this vegetative trait ranges from 173.12 cm to 204.15 cm (Table 2). The plant height in T10 (75×55 cm + NPK, 60:30:30), i.e. (173.12 cm), was significantly shorter than rest of the treatments studied. The plant height was observed maximum (204.15 cm) in T3 (75×35 cm + NPK, 80:40:40) followed by T5 (75×45 cm + NPK, control), i.e. (200.38 cm), T7 (75×45 cm + NPK, 80:40:40), i.e. (198.34 cm), T4 (75×35 cm + NPK, 120:60:60), i.e. (198.33 cm), and T12 (75×55 cm + NPK, 120:60:60). i.e. (199.54 cm), it is significantly higher. The height is lower in plants with T1 (75×35 cm + control) and T10 (75×55 cm + NPK, 60:30:30). Increasing plant spacing significantly influenced plant height, stimulated stem length, and caused higher number of female flower initiation. The plant height of cucumber plant is mainly controlled by genetic make-up of a variety and agro-ecological factors. However, these results are in harmony with the findings of Sruthi and Prasad (2020) who reported that combination of closest plant geometry with different level of NPK increased plant height due to high competition among the plant population. It resulted because of the low level of photosynthesis, more synergistic effect, or their genetic make-up. These results were quite in line with the findings of Singh, Singh and Prasad (2019) and Opara *et al.* (2012), who revealed that cucumber sown at high plant spacing with optimal NPK level produced greater plant height when the shortest plant height was recorded with the closest placement of plant in rows and column.

Stem Girth

The present study indicates that there were non-significant differences ($P>0.05\%$) in stem girth of the cucumber sown in combinations of three plant spacing and four doses of NPK fertilizer. The mean value for stem girth laid from 0.72 cm to 0.82 cm, the highest stem girth with a mean value of (0.82 cm) was recorded with the combination of plant density of 75×35 cm and NPK doses of 120:60:60, which was statistically different from the stem girths recorded with treatment combinations of plant geometry and different NPK doses that made T1, T2, T4, T5, T6, T7, T8, T9, T10, T11 and T12. The plant density of 75×55 cm and NPK doses of 80:40:40 had the lowest stem girth with the mean value of (0.72 cm), which was statistically in line with plant spacing of 75×35 cm + control and plant density of 75×55 cm + control. On the other hand, plant spacing of 75×35 cm with combination of NPK doses of 120:60:60 and 75×45 cm with NPK doses of 120:60:60 had second highest mean value (0.78 cm), but was statistically in harmony with the treatments of T2, T4, T5, T7, T8, T10 and T12 (Table 2). This may be due to the availability of more macro-nutrient and suitable spacing for the plants. Generally, the vigorous is the stem the higher is the final yield in cucumber crop. Earlier, similar results were reported by Natsheh and Mausa (2014), Opara *et al.* (2012) and Singh, Singh and Prasad (2019) who reported significant linear increases of stem girth with increased plant spacing, and they indicated that this character was mostly affected by raised level of NPK in cucumber crop.

Leaf Area

When assessing vegetative cucumber leaf area, significant statistical differences ($p<0.05\%$) were detected among the combination of three plant spacing and four different doses of NPK. The average values for the leaf area, ranged from 405.12 cm^2 to 412.34 cm^2. Plant density of 75×35 cm combined with NPK doses of 60:30:30 produce the maximum leaf area of 412.34 cm^2 and, respectively, followed by T11 (75×55 cm + NPK 80:40:40) i.e. (412.23 cm^2), T10 (75×55 cm + NPK 60:30:30) i.e. (411.56 cm^2), T6 (75×45 cm + NPK 60:30:30) i.e. (406.76 cm^2), and T5 (75×45 cm + control) i.e. (408.76 cm^2), and minimum was recorded from combined plant density of 75×35 cm with control (405.12 cm^2), (Table. 2). Nwofi, Amajouyi and Mhab (2015), Kuranga (2014) and Kumar *et al*. (2017) obtained a lower leaf area with lower doses of NPK and minimum plant spacing due to high density of plant population per capita and plant competition. Supplementary decreases in doses of NPK and plant density would not increase leaf area because the dense plant population will create intense competition between plants for moisture, light and nutrients uptake. In the case of higher NPK level and proper placement of plant in rows, the growth and vegetative improvement of plants were increased due to low competition and equal uptake of essential nutrients and sunlight, which caused high performance of cucumber crop leaf area and finally increased the cucumber final yield (Opara *et al.*, 2012; Singh, Singh and Prasad 2019).

Days to First Flower Bud Initiation

The observation recorded for days to first flower bud initiation showed significant statistical differences ($p<0.05\%$) among the combined plant density and NPK doses studied. The minimum days to first flower bud initiation (40.92 DAS) was recorded with T7 (75×45 cm + NPK 80:60:60) followed by T6 (75×45 cm + NPK 60:30:30), i.e. (41.31 DAS), T11 (75×55cm + NPK 80:40:40), i.e. (41.87 DAS), and T9 (75×55 cm + control) i.e. (41.87 DAS). The maximum days required for first flower bud initiation was reported in T5 (75×45 cm + control), (43.16 DAS) followed by T3 (75×35 cm + NPK 80:40:40), i.e. (42.95 DAS), T12 (75×55 cm + NPK 120:60:60), i.e. (42.12 DAS) and T1 (75×35 cm + control). The greater number of days for first flower bud initiation in maximum plant geometry and highest amount of NPK was because of the increased vegetative growth and more production of vine and leaves per plant. While the plant competition causes less flower bud initiation per plant, a high population of plants per capita makes condition prone to osmotic pressure among the plant population and disease outbreak. This study is in harmony with the findings of Eifediyi and Remison (2010), Umamaheswarappa *et al.* (2005), Kumar *et al.* (2017) and Natsheh and Mausa (2014), who concluded that nutrient absorption is more due to reduced competition among the plant population enhancing vegetative growth and increased number of days to first flower bud initiation.

Days of First Fruit Picking

The present study shows that the days of first fruits picking was also significantly affected by the plant density and NPK doses ($p<0.05\%$). Minimum number of days required to first fruit harvest (52.13 DAS) was recorded with T8 (75×45 cm + NPK 120:60:60) followed by T4 (75×35 cm + NPK120:60:60), i.e. (52.65 DAS), T3

(75×35 cm + NPK 80:40:40), i.e. (53.13 DAS), T6 (75×45cm + control), i.e. (53.22 DAS), and T11(75×55 cm + NPK 80:40:40), i.e. (53.11 DAS), which was statistically at par with each other. While the maximum days to first fruit picking was recorded with T9 (75×55 cm + control), i.e. (57.43 DAS), T1 (75×35 cm + control), i.e. (56.43 DAS), T10 (75×55 cm + NPK 60:30:30), i.e. (55.23 DAS), T2 (75×35 cm + NPK 80:40:40), i.e. (55.24 DAS), T5 (75×45 cm + control), i.e. (54.13 DAS), and T7 (75×45 cm + NPK 80:40:40), i.e. (54.23 DAS). The result reveals that the highest number of days to first fruit picking in minimum plant spacing and unavailability of macronutrient is due to decreases in plant vegetative and reproductive growth. Availability of macronutrients (NPK) and proper plant density promote the first fruit picking of cucumber crop, whereas low level of plant density combined with reduced NPK rate has major reverse effect on the vegetative and reproductive growth of the cucumber plant. The findings of this study contradict the results of several other researches done by Singh, Singh and Prasad (2019), Eifediyi and Remison (2010) and Khan *et al.* (2017). Application of optimal NPK level and plant density decreased the deterioration chance in plant vine and late improvement of cucumber fruits in plant; otherwise, in the situation of plant branches worsening, final fruit yield is also reduced.

Table 2: Effect of plant density and NPK rates on the growth components of cucumber crop (*Cucumis sativus* L.) under the open field

Treatment combinations	*No. of branches/ plant*	*No. of leaves/ plant*	*Plant height (cm)*	*Stem girth (cm)*	*Leaf area (cm^2)*	*Day to first flower bud initiate (DAS)*	*Days of first fruits picking (DAS)*
S1+F0 (T1)	1.14	58.17	178.67	0.73	405.12	42.23	56.43
S1+F1 (T2)	2.93	58.33	191.76	0.75	412.34	42.13	55.24
S1+F2 (T3)	3.00	73.00	204.15	0.82	408.05	42.95	53.13
S1+F3 (T4)	1.38	61.17	198.33	0.78	406.18	42.67	52.65
S2+F0 (T5)	2.01	66.67	200.38	0.76	408.76	43.16	54.13
S2+F1 (T6)	3.45	61.50	187.10	0.74	406.76	41.31	53.22
S2+F2 (T7)	3.12	82.41	198.34	0.75	411.65	40.97	54.23
S2+F3 (T8)	2.16	61.43	191.45	0.77	405.91	42.17	52.13
S3+F0 (T9)	1.98	55.76	185.38	0.73	406.17	41.87	57.43
S3+F1 (T10)	1.78	57.41	173.12	0.76	411.56	42.13	55.23
S3+F2 (T11)	2.01	58.12	197.32	0.72	412.23	41.13	53.11
S3+F3 (T12)	1.99	67.01	199.54	0.74	407.13	42.14	54.98
F- test	*	*	*	NS	*	*	*
S.Ed. (±)	0.26	0.058	0.005	0.002	0.04	0.103	0.071
CD at 5%	0.89	0.118	0.010	0.004	0.09	0.209	0.144

Note: *= (Critical variation); S.Ed = Standard Error division; NS; Non-significant and CD; critical different at (P<0.05%).

Fruit Length

The data recorded for the fruit length showed significant variability (p>0.05%) among the all treatments combined. The highest fruit length (19.42 cm) was recorded with

T12 (75×55 cm + NPK 120:60:60), and it was statistically superior than the rest of the combinations of planting geometry and NPK doses, followed by T8 (75×45 cm + NPK 120:60:60) i.e. (19.30 cm), T7 (75×45 cm + NPK 80:40:40) i.e. (18.10 cm), T6 (75×45 cm + NPK 60:30:30) i.e. (17.00 cm) and T3 (75×35 cm + NPK 80:40:40) i.e. (17.20 cm). However, the lowest fruit length was observed in T9 (75×55 cm + control), i.e. (15.14 cm), and were statistically at par with T2 (75×35 cm + NPK 60:30:30) i.e. (15.78 cm) and T1 (75×35 cm + control) i.e. (15.30 cm). The high plant distances combined with raised doses of NPK gradually improved the fruit length in cucumber. The results showed that the cumulative consequence of yield influencing characteristics, such as effective fresh fruit yield, fruit weight and final yield per hectare had a positive impact on increased fruit length that achieved from 75×55 cm plant spacing and 120:50:60 NPK doses. Application of optimal NPK dosages is very important for the vegetative growth and high yield of cucumber. In the case of higher plant spacing and increased NPK doses, the growth and vegetative improvement of cucumber plants were increased due to low competition and equal uptake of essential nutrients among the plant population, which caused high performance of cucumber crop yield traits and finally increased the fruit yield. The results of this study are in harmony with the findings of Sruithi and Prasad (2020), Singh *et al.* (2019), Singh and Kumar (2012) and Garawany and Albaloushi (2015), as they concluded that plant spacing and optimal nutrients application for the vegetable are two important factors to increase the productivity and final yield. Optimum amount of fertilizers causes improved growth and yield, if the fertilizer doses increase from its recommended rate and the leaching of nutrient, soil degradation, etc. may take place.

Fruit Girth

The interaction of plant density and NPK doses on fruit girth of the evaluated Nahid-F1 cucumber variety showed significant statistical differences at $p<0.05\%$ probability level. The mean value for this yield attribute laid from 16.97 cm to 13.32 cm (Table 3). The highest girth with a mean value of 16.97 cm was recorded in T8 (75×45 cm + NPK dosed of 120:60:60), which was statistically different from the fruit girth recorded with rest of the combined treatments for this yield characteristic. The plant density of 75×35 cm combined with control had minimum fruit girth with the mean value of 13.32 cm, which was statistically in consonance with T2 (75×35cm + NPK 60:30:30) i.e. (14.33 cm), T5 (75×45cm + control) i.e. (14.38 cm) and T9 (75×55 cm + control) i.e. (14.32 cm). On the other hand, T12 (75×55 cm + NPK 120:60:60) had second highest mean value of 16.87 cm, but was statistically different with T8 (75×45 cm + NPK 120:60:60) i.e. (16.79 cm). To determine yield and yield component and physical properties of cucumber fruits, plant density and nutrient supply from soil are considered two important agriculture practices. Generally, the more vigorous is the fruit the higher is the yield in cucumber crop. Earlier, similar finding was reported by Kuranga (2014), Singh and Kumar (2012), Garawany and Albaloushi (2015) and Bist *et al.* (2020). Nutrients from mineral fertilizers enhance the establishment of crops, while optimal plant spacing promoted fruit girth and yield when both fertilizers and plant spacing were combined.

Average Fresh Fruit Weight

Due to variation in plant density and NPK doses, the average fresh fruit weight was significantly different ($p<0.05\%$) in the current investigation. The maximum fresh fruit weight was found in T8 (75×45 cm + NPK 120:60:60) i.e. (313.17 g), statistically identical to T3 (75×35 cm + NPK 80:40:40) i.e. (305.08 g), T12 (75×55 cm + NPK 120:60:60:60) i.e. (313.12 g) and T4 (75×35 cm + NPK 120:60:60) i.e. (291.63 g). The minimum fresh fruit weight of 213.92 g was recorded from T1 (75×35 cm + control) (Table 3). Likewise, T12 (75×55 cm + NPK 120:60:60) had the second highest average fresh fruit weight valuing 313.12 g, but was statistically at par with T4 (75×35 cm + NPK 120:60:60) i.e. (291.63 g) and T3 (75×35 cm + NPK 80:40:40) i.e. (305.08 g). However, there was statistically non-significant difference ($p>0.05\%$) between T11 (75×55 cm + NPK 80:60:60) and T5 (75×45 cm + control) applied in this study. The mean values for interaction of different plant densities and NPK doses revealed that treatments T8 (75×45 cm + NPK 120:60:60) and T12 (75×55 cm + NPK 120:60:60) were optimal for agro-ecological situation in Kabul. The present study showed that the plant spacing and NPK optimal rate has a key role in the yield and improvement of fruit fresh weight and its final weight. A similar findings of plant geometry and NPK rate on the average fresh fruit weight of cucumber were also been reported by Adinde *et al.* (2016), Bist *et al.* (2020), Khan *et al.* (2017), Ahmed *et al.* (2007) and Garawany and Albaloushi (2015), as their findings indicate that NPK doses and plant spacing play an important role in determination of quality and quantity of cucumber fruit. NPK fertilizer reaches directly to the root zone of plant and increases the vegetative growth and fruit yield, but application of proper NPK doses and plant spacing management will be necessary with many of agricultural practices, especially irrigation method and its time interval.

Number of Fruits per Plant

The data recorded for the number of fruits per plant shows significant statistical differences ($p<0.05\%$) resulting from some plant geometry and NPK combinations. The maximum number of fruits per plant (21.80) was observed with T12 (75×55 cm + NPK 120:60:60) followed by T8 (75×45 cm + NPK 120:60:60) i.e. (21.58) and T3 (75×35 cm + NPK 80:40:40) i.e. (21.12), which were statistically at par with each other. While the lowest number of fruits per plant (16.78) was recorded in plants sown at the plant density of 75×35 cm + control), it was the same with the plant density of (75×45 cm + NPK 60:30:30), (75×45 cm + control) and (75×55 cm + control) (Table 3). The result reveals the lowest number of fruits per plant in T5 (75×45 cm + control) i.e. (17.65), T6 (75×45 cm + NPK 60:30:30) i.e. (17.01) and T9 (75×55 cm + control) i.e. (17.43) showing more competition due to improper NPK placement. The cucumber plant requires fertile soil and enough space. Infertile soil and close space result low initiation of female flowering bud that cause low number of fruits per plant. Optimal plant spacing and NPK rate have a significant influence on the vegetative improvement of the plant at the same time at reproductive stage. Its role is more considerable, which is why different levels of NPK and plant density affect the number of fruits per plant significantly. Total number of fruits per plant showed positive significant relationship with vine length and number of flowers per plant. Bist *et al.* (2020), Khan *et al.* (2017), Ahmed *et al.* (2007), Eifediyi and Remison (2010) and Khan *et al.* (2017) also reported the number of fruits per plant varied significantly

with variation in plant geometry and NPK rates, and biotic and abiotic stresses are the main factors responsible for low yield and poor quality under open field cultivation. This variability may be due to the unsuitable placement of plant in rows and columns and minimum availability of NPK nutrients.

Number of Fruits per Vine

The results related to number of fruits per vine as influenced by various NPK levels and plant densities are given in table 3. Both plant spacing and their interaction with NPK levels demonstrated highly significant difference ($p<0.05\%$). The highest mean value (14.23) of fruits per vine was recorded in T11 (75×55 cm + NPK 80:40:40), followed by T3 (75×35 cm + NPK 80:40:40) i.e. (14.20) and T8 (75×45 cm + NPK 120:60:60) i.e. (14.00), which was statistically at concordance with each other. The lowest number (11.23) of fruits per vine was noted in T9 (75×55 cm + control), which was in line with T5 (75×45 cm + control) i.e. (11.75) and T1 (75×35 cm + control) i.e. (11.66). Over all, plant density of 75×55 cm + NPK doses of 80:40:40 had greater number of fruits per vine (1,423) as compared to the rest of the two plant densities and three NPK doses. However, the nutrient and spacing requirements of the crop vary depending on the native fertility, soil type, previous cropping and cultural practices. It is concluded that number of fruits per vine significantly increased, as the plant spacing between rows was increased and optimal level of NPK applied. Proper plant density and application of NPK rates promotes the initiation of flowering bud that resulted in increased number of fruits per vine; but decreased NPK rates and plant geometry reduced the number of fruits due to improper vegetative development of cucumber crop as witnessed in case of plant elevation. The results of this study are in the close conformity with the findings of Nwofia, Amajouyi and Mbah (2015), Khan *et al.* (2017), Bist *et al.* (2020) and Khan *et al.* (2017) who reported that cucumber rarely grows luxuriantly in close plant spacing and reduced level of NPK. Hence, its level of susceptibility to poor soil fertility and improper placement of plants between rows and columns manifests in the form of low vegetative growth, decreases in initiation of flowering bud that resulted in low number of fruits set per vine. On the other hand, raised level of NPK and plant density increases the number of fruits due to proper vegetative development of cucumber crop as witnessed in case of plant elevation in cucumber crop.

Fruit Yield per Plant

The present study reveals that the fruit yield per plant was also significantly affected by the combination of plant spacing and NPK doses at $p<0.05\%$. The average value for this characteristic of cucumber crop laid between 1.67 kg to 2.84 kg (Table 3). Treatment three, (75×45 cm + NPK 120:60:60) produced maximum fruit yield per plant (2.84 kg), and it was statistically superior to the rest of the treatments. Minimum fruit yield per plant (1.67 kg) was registered in T1 (75×35 cm + control). The second-high mean value of fruits yield per plant was observed in T4 (75×35 cm + NPK 120:60:60) i.e. (2.73 kg) and T7 (75×45 cm + NPK 80:40:40) i.e. (2.73 kg). Statistically, it was at par with T8 (75×45 cm + NPK 120:60:60) i.e. (2.84 kg). The mean value of fruit yield per plant gradually improved with increased plant density and NPK doses. The findings of this trail showed that the cumulative consequence of yield influencing attributes, such as effective vine length, number of branches per

plant, number of fruits per plan, fruit diameter, fruit length and fresh fruit weight having a positive influence on increased fruit yield per plant achieved from the interaction of plant density of 75×45 cm with NPK rates of 120:60:60. In the case of application of lower NPK rates and closest plant spacing, the growth and vegetative enhancement of plants were reduced due to high competition and unequal uptake of macro-nutrients, which caused poor performance of cucumber crop yield attributes and ultimately decreased the fruit yield per plant (kg). The results of this study corroborate the findings reported by Khan *et al.* (2017), Nwofia, Amojouyi and Mbah (2015) and Singh and Singh Prasad (2019). Combination of nitrogen, phosphate, potash and plant spacing are important and play a key role on vegetative growth and fruit yield than other nutrients and cultural practices, as it promotes the rapid growth of roots, vegetative parts, setting of flowers, blooming setting and cucumber crop yield attributes, ultimately increasing the fruit yield per plant in cucumber crop.

Yield per Square Meter

Documented results of the data recoded for yield per square meter of combined three plant density and four NPK doses studied are presented in table 3 and vary significantly ($p<0.05\%$) amongst in all treatments. The average value related to this character ranged from 11.01 kg to 13.77 kg. 13.77 kg is the higher yield per square meter of cucumber variety Nahid-F1 sown in T8 (75×45 cm + NPK 120:60:60) was statistically identical to T3 (75×35 cm + NPK 80:40:40) i.e. (13.46 kg), T11 (75×55 cm + NPK 80:40:40) i.e. (13.43 kg) and T12 (75×55 cm + NPK 120:60:60) i.e. (13.37 kg). It was minimum (11.01 kg) in T9 (75×55 cm + control) compared to the other treatments studied in this study. It was statistically similar to T5 (75×45 cm + control), T6 (75×45 cm + NPK 60:30:30) and T1 (75×35 cm + control). These results showed the optimal plant spacing and NPK doses for this trait in Kabul agro-climatic situation for two combinations (75×45 cm + NPK 80:40:40 and 75×55 cm + 120:60:60). The proper plant density and NPK doses have a crucial role and are responsible for cucumber crop yield attributes increase ultimately the quality, quantity and weight per meter square. The findings of this study are pretty in line with the results of Natsheh and Mausa (2014), Opara *et al.* (2012), Kumar *et al.* (2017) and Sing and Kumar (2012) who concluded that optimal planting space and NPK doses increased significantly the yield attributes, like plant elevation, number of branches, number of female flower per plant, fruit diameter, fresh fruit weight, and fruit weight per plant. This ultimately increased the quantity and yield (kg) per square meter of cucumber crop.

Yield per Hectare

The mean value recorded for yield per hectare showed a vital difference ($p<0.05\%$) among the combined treatments under the study. The data for yield per hectare depicted a linear upward rise with the increases in plant spacing and NPK doses (Table 3). Different plant spaces and NPK doses in cucumber crop showed variability in yield per hectare significantly. Maximum yield per hectare (69.65 t/ha) was observed from the T8, which was made from the combination of plant density of 75×45 cm + NPK doses of 120:60:60. In comparison, minimum yield (47.40 t/ha) was recorded from the treatment with combination of plant spacing of 75×35 cm + control, which was statistically identical to the T6 (75×45 cm + NPK 60:30:30) i.e. (57.21

t/ha), T5 (75×45 cm + control) i.e. (59.20 t/ha) and T9 (75×55 cm + control) i.e. (58.56 t/ha). The results of this study reveal that the yield per hectare progressively improved with the increased level of plant density and NPK rates. The average value for this parameter indicated that the cumulative influence of yield contributing traits, such as adequate number of branches per vine, vine length, number of fruits per plant and yield per square meter, had effective influence on higher yield per hectare obtained from T8 (75×45 cm + NPK 120:60:60). In the case of closest plant spacing and reduced NPK rates, the growth and enlargement of cucumber plant were exposed due to high competition of uptake of vital nutrients and sunlight. It has caused depleted yield attributes and finally culminated in the most minor yield per hectare. Earlier, similar results for final yield per hectare were also reported by Tiwari and Mishra (2013), Adinde *et al.* (2016), Bist *et al.* (2020), Khan *et al.* (2017), Ahmed *et al.* (2007) and Garawany and Albaloushi (2015). Optimal NPK rates and proper plant density had an influential role on different biochemical and physiological processes resulting in more yield production per capita in cucumber crop. But, reduced NPK rates and closest plant density cause high competition for the uptake of vital nutrients and sunlight for physiological process and caused depleted yield attributes and finally culminating in the most minor yield per hectare.

Table 3: Interaction effect of plant densities and NPK doses on some yield characteristic of cucumber crop (*Cucumis sativus* L.) under open field situation

Treatment combinations	*Fruit length (cm)*	*Fruit girth (cm)*	*Average fresh fruit weight (g)*	*No. fruit/ plant*	*No. fruits/ vine*	*Fruit yield per plant (kg)*	*Yield per square meter (kg)*	*Yield per hectare (t/ha)*
S1+F0 (T1)	15.30	13.32	213.92	16.78	11.66	1.67	11.13	47.40
S1+F1 (T2)	15.78	14.33	272.13	19.65	13.68	2.58	12.86	62.50
S1+F2 (T3)	17.20	15.30	305.08	21.12	14.20	2.56	13.46	69.21
S1+F3 (T4)	16.60	16.21	291.63	20.62	13.23	2.73	12.93	68.86
S2+F0 (T5)	16.10	14.38	218.21	17.65	11.75	1.98	11.56	59.20
S2+F1 (T6)	17.00	15.57	247.56	17.01	12.84	2.00	11.78	57.21
S2+F2 (T7)	18.10	16.79	287.01	18.35	13.67	2.73	12.01	61.34
S2+F3 (T8)	19.30	16.97	313.17	21.58	14.00	2.84	13.77	69.65
S3+F0 (T9)	15.14	14.32	267.32	17.43	11.23	1.87	11.01	58.56
S3+F1 (T10)	16.01	14.78	254.37	19.07	12.32	1.98	12.98	57.43
S3+F2 (T11)	16.42	15.65	231.76	18.21	14.23	1.87	13.43	63.13
S3+F3 (T12)	19.42	16.87	313.12	21.89	13.35	2.67	13.37	69.32
F- test	*	*	*	*	*	*	*	*
S.Ed. (±)	0.102	0.180	0.212	0.058	0.175	0.041	0.101	0.034
CD at 5%	0.228	0.014	0.432	0.118	0.355	0.083	0.204	0.068

Note: *= (Critical variation); S.Ed = Standard Error division; NS; Non-significant and CD; critical different at (P<0.05%).

Conclusions`and Recommendations

Cucumber (*Cucumis sativus* L.) is one of the oldest vegetable crops belonging to the Cucurbitaceae family, which comprised of approximately 125 genera and 960 species (Bist *et al.*, 2020; Sadiq *et al.*, 2019). This crop is the fourth most important vegetable

after tomato, cabbage and onion in Asia (Eifediyi and Remison, 2010). This experiment was designed to identify the best adapted combination of plant density and doses of NPK with the most effective performance for increased yield of cucumber variety of Nahid-F1 under the open field of Kabul region. The results acquired from the current study reveal that the application of various plant density, namely, 75×35 cm (S1), 75×45 cm (S2) and 75×55 cm and different doses of NPK fertilizer viz. control (F0), 60:30:30 (F1), 80:40:40 (F2) and 120:60:60 (F3), remarkably influenced all growth attributes and yield characteristics of cucumber variety of Nahid-F1. The result indicated that T12 (75×55 cm + NPK 120:60:60) and T8 (75×35 cm + NPK 120:60:60) performed better in respect to the various growth and yield characteristics, such as number of branches per plant, number of leaves per plant, plant height, stem girth, days to first flower bud initiation, days of first fruits picking, fruit length, fruit girth, average fresh fruit weight, number of fruits per plant, number of fruits per vine, yield per square meter and yield per hectare. While T3 (75×35 cm + NPK 80:40:40) were the second best treatment after the T12 and T8. However, T1 (75×35 cm + control), T5 (75×45 cm + control) and T9 (75×55 cm + control) did not show any superiority in any growth and yield attributes of cucumber crop as evaluated in Kabul agro-climatic region. Therefore, T8 (75×35 cm + NPK 120:60:60) and T12 (75×55cm + NPK 120:60:60) can be recommended to the farmers of Kabul province for better and more profitable cucumber production in Kabul agro-climatic condition in central Afghanistan.

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Authors' Declarations and Essential Ethical Compliances

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Contribution	*Author 1*	*Author 2*	*Author 3*
Conceived and designed the research or analysis	Yes	Yes	No
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Contributed to data analysis & interpretation	Yes	Yes	Yes
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Research involving human bodies or organs or tissues (Helsinki Declaration)
The author(s) solemnly declare(s) that this research has not involved any human subject (body or organs) for experimentation. It was not a clinical research. The contexts of human population/participation were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or ethical obligation of Helsinki Declaration does not apply in cases of this study or written work.

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The author(s) solemnly declare(s) that this research has not involved any animal subject (body or organs) for experimentation. The research was not based on laboratory experiment involving any kind animal. The contexts of animals were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or ethical obligation of ARRIVE does not apply in cases of this study or written work.

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M – 00326 | Review Article

Environmental and Psychological Effects of Russian War in Ukraine

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Abstract

Russia invasion on Ukraine has extensive and unprecedented negative impacts on natural environment and human life. Since saving human lives and protecting nuclear establishments are a priority, the environmental destruction has even not been assessed fully. Russian war imposed on Ukraine has, no doubt, caused serious negative consequences on Ukrainian people and rest of the planet Earth. A massive damage to industrial and civil infrastructure has contaminated soil, water and food sources, which are hazardous not only for human but also for the ecosystem health. In addition to the devastating environmental effects, Ukrainian citizens are facing triple psychological problems: as human, as environmental repercussions, and as their national identity. Based on limited literature, this paper has compiled and reviewed the environmental consequences and psychological effects of Russian war in Ukraine in two interdependent parts: (a) Environmental Damages from Russian War in Ukraine, and (b) Psychological Injuries from Environmental Damage. The environmental damages covered include industries and chemical pollution, shelling-generated fires, pollution and waste from military vehicles, pollution by weapons and missiles, refugees-caused emissions, nuclear pollution, loss of water bodies, and damages to wildlife, biodiversity, ecosystems, to fuel and associated infrastructure, to mining operations, to ambient air quality, and to urban infrastructure. Based on narrative review of literature, this paper addresses the psychological effects of environmental pollution or damages caused by Russian war. Foremost psychological symptom of the war appears in the form of fear and uncertainty followed by direct threats to peoples' lives. Various stressors contribute to anxiety, panic, mild or severe depression, insomnia, post-traumatic stress disorder (PTSD) and other stress-related disorders that severely affect public health.

Keywords

Russian war in Ukraine; Environmental destruction; Psychological effects

Introduction

Proxy war in Donetsk and Luhansk regions of Ukraine between 2014 and 2022 has affected environment and human psychology in all possible ways, as were documented in known cases of war in Afghanistan, Syria and Iraq. From 24 February 2022, the Russians led by Putin launched an unprovoked large-scale invasion of Ukraine rendering a humanitarian crisis of millions of people dying, getting injured or having to flee their homes (de Klerk *et al*., 2022). Massive military concentration using munitions and ammunitions has damaged or destroyed civilian infrastructure, energy installations, residential buildings, factories, and roads, while affecting adversely the humans' mental health. Ongoing full-scale invasion by Russia has extensive and unprecedented negative impacts on natural environment and human life. Since the recent war erupted on 24 February 2022 till January 2023 (almost 10 months), death toll of civilians has reached nearly 7,000, while more than 11,000 are injured (Early, 2023). Moreover, nearly 10,000 soldiers have been killed and 30,000 injured, while more than 5,000 are missing, as a result of Russian war in Ukraine (Early, 2023).

Gardashuk (2022) classifies environmental impacts of war and hostilities in different ways: direct and indirect, short-term and long-term. She included:

- Destruction of landscapes, ecosystems, habitats, and species populations;
- Risks of technogenic catastrophes;
- Destruction, pollution, and withdrawal from the use of farmlands, violation of natural life support systems and natural services, which threatens the food safety of many people;
- Threats to human life and health due to degradation of ecosystems and technogenic catastrophes; restriction of access to natural resources, soil, water, and clean air, and risks of epidemics outbreaks.

The Ukrainian citizens have been facing triple psychological problems: as human, as environmental repercussions, and as their national identity. During this unprecedented war, Ukraine's people are experiencing agonies of injustice and terror as their hard-earned democracy and freedom are being mercilessly threatened (Javanbakht**,** 2022**)**. International Organization of Migration has assessed that over 15 million Ukrainians reported deterioration of their mental health since onset of the war on 24 February 2022 (IOM, 2022).

During one year of intensive war in Ukraine has not given chance to assess the environmental damages completely. Only a scarce little assessment is done by various organizations and scientists. An estimation of the total environmental damage inflicted by the war would be possible only after war is stopped. Preliminary assessments indicate that Ukraine's nature will take at least 15 years to recover. With the above introductory remarks, this paper is aimed at compiling and reviewing the environmental consequences and psychological effects of Russian war in Ukraine in two interdependent parts:

a) Environmental Damages from Russian War in Ukraine
b) Psychological Injuries from Environmental Damage

This paper is based on the review of the literature along with analysis of facts.

Methodology

The existing literature in contexts of environmental effects and psychological effects of environmental damages was the primary method to compose this paper. As explained by Templier and Paré (2015), six generic steps were undertaken in conducting the review process: 1) formulating the research questions and objectives, 2) searching the extant literature (chiefly from web sources), 3) screening and selecting for inclusion, 4) assessing the match or mismatch of findings, 5) extracting data, and 6) analysing and writing data and facts. The following main research questions that were formulated before the review was started:

a) What are different environmental damages caused by Russian war in Ukraine?
b) What are the extents of the environmental damages?
c) What are the secondary effects of direct environmental damages?
d) How are the human psychologies affected by environmental pollution and damages?
e) What may be the scenario of psychological impacts in the long-term?

It is a well-known fact that clearly articulated research questions are key ingredients that guide the entire review process; they underscore the type of information that is needed, inform the search for and selection of relevant literature, and guide or orient the subsequent analysis (Jesson, Matheson and Lacey, 2011). It has been tries to include majority of relevant published studies and news items to make the coverage of literature all-inclusive knowledge base. However, in psychological contexts, only selected studies published in reputed journals and available on PubMed platform were given priority. The literature was downloaded from web sources and was kept segregated. It was then screened and included or excluded keeping in view the research questions. Depending on the variables and headings set under the structure of this paper, the information and data was extracted from the screened articles by following the guidance of Cooper and Hedges (2009) and Okoli and Schabram (2010).

Narrative Review

Basically, composition of this paper, method of *narrative review* was applied. It is the "traditional" way of reviewing the extant literature and is the sources of interpreting qualitatively the prior knowledge (Sylvester, Tate and Johnstone, 2013). In fact, a narrative review is an attempt to summarize or synthesize what is written on a particular topic (Davies, 2000; Green, Johnson and Adams, 2006). As such, it selectively picks up certain studies and ignores others in order to make a point. It is the limitation of such a review. The review is presented in logical sequence with lucid presentation of the text.

Part-A: Environmental Impacts of Russian War in Ukraine

According to Rawtani *et al.* (2022), Russian war imposed on Ukraine has caused serious negative consequences on local people and rest of the planet Earth. It is observed that massive damage to industrial and civil infrastructure has contaminated soil, water and food sources, which are hazardous not only for human but also for the ecosystem health. The bombing and missile explosion create toxic substances, such

as lead, mercury, depleted uranium, and many more. They are released into air, water, and soils. When entered human bodies, the explosives like TNT (Trinitrotoluene), DNT (Dermonecrotic toxin), and RDX (cyclonite or cyclotrimethylenetrinitramine) cause malfunction of all organs and systems. Apparently, attacks in heavily industrialised areas are causing technological disaster, such as spills of tailings and fuel, poisoning a vast area in Ukraine. Destruction of buildings releases carcinogenic dust, impacting human health and plant life. Resulting spread of heavy metals and chemicals reaches ultimately to underground waters, poisoning water sources, killing all life in rivers and water bodies. Likewise, military emissions of CO_2 are recorded to be millions tonnes undermining the goals of Paris Agreement. Along with the electricity interruptions, there is a rampant water shortage and deterioration of sanitary conditions. Different reports indicate that destruction of civil infrastructure has already left more than 4 million people without access to pure drinking water (English, 2022). Russian war in Ukraine posed enormous threats of nuclear accidents. The war has adversely affected the air quality due to unprecedented bombarding, missile attacks and ground ammunitions. The Russian occupation of Ukrainian nuclear sites caused leakage of radiation in north and southern Ukraine. Rawtani *et al.* (2022) have reiterated that physical, chemical and biological characteristics of soil have changed negatively as a result of excessive shelling and explosions; consequently, agriculture is severely affected. This war has caused large-scale deforestation and wildfires, couples with biodiversity loss (Rawtani *et al.*, 2022). Gardashuk (2022) articulated that the war causes suffrage to all living beings and their habitats. The ecosystems are "silent victims" of the war. According to her, military actions heavily disrupt the normal functioning of ecosystem services, like climate support systems, soil fertility, purification of water and air, pollination, etc. (Gardashuk, 2022), since the military actions cause high level of emission of harmful substances from the military machines and other weapons, triggering technogenic pollution by targeting the industrial objects. She reiterates, "war violates basic principles of environmental justice and exacerbates injustice in all its forms and manifestations".

Bombing of Industries and Chemical Pollution

Data of State Register of Potentially Dangerous Objects of Ukraine declares that Ukraine has over 23,000 facilities, including 2,987 warehouses that store highly toxic pesticides (Bazhenova, 2022), with majority of them in Donetsk, Dnipropetrovsk, Zaporizhzhia, Kharkiv and Lviv regions. Some of such facilities are located in the combat zone. Within initial 3 months of war, damages to the infrastructure of Ukraine reached USD 97.4 billion. At least 216 plants, factories, and enterprises suffered in 3 months of war (Bazhenova, 2022). More than 10 m tonnes of toxic waste and tailings are said to be stored in this region (CEOBS, 2018). Rockets and explosions result in leakages from various facilities of hazardous materials that poison air, water, and soils (Morber, 2022). It was reported that on 25 February, chemical reagents were disposed (BBC, 2022; Suspilne, 2022) followed by an attack on Lysychansk refinery that ignited 50,000 tonnes of oil sludge, on two reservoirs with 20,000 tonnes of petroleum, and on a sulphur store (Interfax, 2022). Ever since the war broke, there is large number of attacks on Ukrainian infrastructure and industries. For example, on 21 March, ammonia reservoirs at Sumykhimprom were hit (Kizilov, 2022), followed by a leakage covering an area of 2.5 km in radius. On 5 and 9 April

2022, nitric acid tanks were blown in Rubizhne (Izvestiya, 2022). There is an endless series of attacks and accidents; some are also mentioned in table 1.

According to UNEP (2022), between 2014 and 2017, potentially hazardous coke and chemical plants, power plants and other chemical industries were affected due to armed conflict between Ukraine and Russia. Damage was reported in Avdiivka Coke and Chemicals Plant, Toretsk Phenol Plant, the Donetsk State-Owned Chemicals Plant and the Stakhanov Ferroalloy Plant in 2016-2017 (UNEP, 2022). Fire at the Avdiivka Coke and Chemicals Plant in 2015 resulted in the emission of coke gas with high concentrations of benzene, toluene, naphthalene, hydrogen sulphide, mercaptan, hydrocyanic acid and ammonia (OSCE, 2017). Today, it is hard to assess the toxic effects of the gaseous air pollutants emitted from burning industries. The hazardous toxic chemicals in the atmosphere last from several hours to several days, and subsequent fallout onto soil and into water can last longer than several years (OPCW, 2022).

Table 1: State Environmental Inspectorate of Ukraine (2022a) documented in June 2022 seven confirmed incidents of release of toxic industrial chemicals caused by military activities (UNEP, 2022)

Industrial Site	*Location*	*Date*	*Description of the Incident*
Coke Plant	Avdiivka	13 March 2022	Large fire caused by shelling.
Sumy Khimprom	Sumy	21 March 2022	Release of ammonia; the gas cloud covered an area of 2.5 km^2.
SOE Khimprom	Chernihiv	23 March 2022	Depressurizing of a tank with liquid ammonia (12 tons), followed by a fire in the working premises.
Scientific–Industrial Enterprise Zorya	Rubezhne, Luhansk oblast	5 April 2022	Release of the 80 tons of nitric acid caused by the hit of storing tank. The radius of the affected area reached 3.5 km.
Severodonetsk Azot	Severodonetsk	5 May 2022	Heavy shelling in the one of the largest ammonia producers in Ukraine.
Azovstal	Mariupol	29 May 2022	Release of liquid ammonia due to the damage of pumping station. The radius of the affected area reached 2.5 km.
Ammonium pipeline Tolyatti – Odessa	Nearby town of Bakhmut in Donetsk oblast	30 May 2022	Release of technical (low pressure) ammonium from a non-operational by-pass pipe. At least six communities were under threat of chemical pollution.

Source: Adapted from UNEP (2022)

Scientists have explained that the explosions, destructed armour and vehicles, burning and spilled fuel actually pollute air, water and soils indiscriminately. It is evident that explosion of every bomb releases pollutants, such as heavy metals (McCarthy, 2022), formaldehydes, nitrous oxide, hydrogen cyanide, and toxic organic compounds (Omelchuk and Sadohurska, 2022). These pollutants are spread by winds and underground waters, that's why the hazardous ecological impact of war will affect not only Ukraine but also Russia and Europe (Kotarska and Young, 2022). According to Omelchuk and Sadohurska (2022), explosives release chemical compounds that are

oxidized on air and may cause acidic rains causing burn of vegetation and respiratory organs of mammals, including humans.

As highlighted by Zalakeviciute *et al.* (2022), the resulting pollution has short-lived impact as well as persisting impacts. They articulate, "the toxic emissions, originating from military actions and destruction, will go on contaminating not only the atmosphere, but also water and soil, through wet and dry deposition. The pollution-related health problems will affect not only the local population, but also the combating armies and the surrounding territories." Massive attacks of Russian rockets cause large-scale fires at targeted critical infrastructure, especially oil depots, storage terminals, and chemical plants. This destruction causes serious damage to ecosystems and leads to significant environmental pollution that poison the air, land, rivers, groundwater and surface water. Assessment of the loss and damage has been continuing preliminarily, although the final assessment can be possible years after the ceasefire.

Damage to Fuel and Associated Infrastructure

Fuel storage facilities are often targeted by Russian missile and drone attacks to undermine the ability to sustain military operations by Ukraine (de Klerk *et al.*, 2022). In April 2022, missiles demolished (Ukrainskaya Pravda, 2022) the Kremenchug refinery, which has a capacity of 3 million tons of oil per annum, in Poltava oblast. Similarly, Shebelinka gas processing plant in Kharkiv oblast was forced to stop its operations (Reuters, 2022) in February 2022. Andriy Herus, a parliamentarian and the Head of the Parliamentary (Verkhovna Rada) Committee on Fuel and Energy, stated during a briefing (Interfax Ukraine, 2022a) in the Crisis Media Centre on 5 May 2022 that "about 15 different oil depots in Ukraine were destroyed or damaged as a result of missile strikes, which means that significant fuel reserves were destroyed, the storage of oil products was also complicated". Simultaneously, the State Environmental Inspectorate of Ukraine (2022b) reported more than 20 cases of attacks on reservoirs with petrol, diesel, liquefied petroleum gas and mazut (fuel oil).

Effect on Mining Operations

Ukraine is known for heavy industry associated with mining in eastern regions. There are nearly 150 coal mines in Ukraine. Between 2014 and 2017, armed conflicts negatively impacted mining operations (OSCE, 2017) with destruction of equipment and interruptions of electrical supply. Failure of electric supply in mining resulted in flooding; and some coal mines were completely submerged, causing risks of groundwater and surface water pollution (Ministry of Environmental Protection and Natural Resources of Ukraine, 2017). UNEP (2022) highlighted that old mines used for waste storage were also affected in Donetsk and Luhansk regions. The Ministry further warmed that major mine flooding reaching surrounding areas endangered nearby buildings and other critical infrastructure through contaminated groundwater. As a result of excessive shelling, the tailing pond of the Phenol Plant Coke and Chemicals Enterprise (Donetsk oblast) containing 400,000 cubic meters of waste, had failed and caused water pollution of drinking water sources coming from Kryvyi Torets and Siverskyi Donets rivers (OSCE, 2017).

According to Marx *et al*. (2022), coal mines in eastern Ukraine have deteriorated since active and intensive hostilities have made it difficult to continue. Groundwater pollution across Donbas region is reported prominently. Evidently, when a mine is flooded, radionuclides and toxic substances contaminate underground waters, poisoning water sources of local residential areas (Renáta, 2022). European Commission specialists registered at least 35 abandoned coal mines in Donbass region (European Commission, 2022), and waters of Komyshuvakha river turned orange in 2021 due to a leakage from the abandoned 'Zolotoe' mine.

Worsening of Ambient Air Quality

Zalakeviciute *et al.* (2022) analysed satellite images of nitrogen dioxide (NO_2), carbon monoxide (CO), ozone (O_3), sulphur dioxide (SO_2) and [1]$PM_{2.5}$ over Ukrainian territory and $PM_{2.5}$ land monitoring data for Kyiv. They found that NO_2 and $PM_{2.5}$ are released the most during war activities. According to the authors, drastic increases in pollution (especially $PM_{2.5}$) from bombing and structural fires raise additional health concerns. Zalakeviciute *et al.* (2022) reported O_3 (2.45% for Ukraine and 3.38% for Kyiv) and SO_2 (38.06% for Ukraine and 10% for Kyiv) levels higher during the first two weeks of the war compared to pre-war conditions (before 24 February 2022). The $PM_{2.5}$ data presented by these scientists demonstrated the most drastic increase in its concentrations nationally. The same authors have highlighted Kyiv and Donetsk recording a prolonged exposure to smoke particles pollution arising from the bomb/missile explosions and destruction of military/civil objects.

In the COP27 meeting of UN Climate Summit held in Egypt, Ukrainian official delegation reported that “Russia's invasion of Ukraine has caused a large amount of warming gases released into the atmosphere, equivalent of adding nearly 16 million cars to the UK's roads for two years”. According to BBC, war has pumped directly into atmosphere the emission of 33 million tons of greenhouse gases that would warm the Earth's atmosphere (Rannard, 2022). Ruslan Strilets, Ukraine's Environmental Protection Minister is quoted claiming in UN Climate Summit 2022 that “Russia has turned our natural reserves into a military base. Russia is doing everything to shorten our and your horizons. Because of the war, we will have to do even more to overcome the climate crisis” (Rannard, 2022). Minister also claimed that rebuilding Ukraine will cause significantly more emissions, up to 49 million tons of carbon dioxide. Since the start of the war, Ukraine claims to have gathered evidence of 2,000 environmental crimes costing 37 million Euros, including destruction of forests, release of toxic gases, and damage to water facilities (Rannard, 2022).

Damage from Shelling-Generated Fires

Ukraine Nature Conservation Group (UNCG), a non-profit coalition of the country’s scientists and activists, claimed that 37,000 fires occurred in the first 4 months of the invasion affecting severely a quarter-million acres of forests and other natural ecosystems (Pearce, 2022). These fires have been caused by shelling, bombing and mine-laying operations. No accurate data is available about the small and medium sized fires. The assessments are available of the fires that had more than 1 hectare

[1] $PM_{2.5}$ refers to tiny particles or droplets in the air that are two and one half microns or less in width.

size. Such assessments are conducted by US-based Fire Information for Resource Management System (FIRMS)[2] and the European Forest Fire Information System (EFFIS)[3] by dividing the territory of Ukraine into 3 zones (see Figure 1), namely:

Zone 1: It covers 66.5% of the territory of Ukraine, where no ground warfare is operational;
Zone 2: This is zone of active warfare (ground warfare were/are conducted for more than 24 hours[4]), covering 19.5% of the territory of Ukraine; and
Zone 3: It is temporarily occupied territory (14.0% of the territory of Ukraine), where ground warfare was/is conducted for not more than 24 hours or did not take place at all.

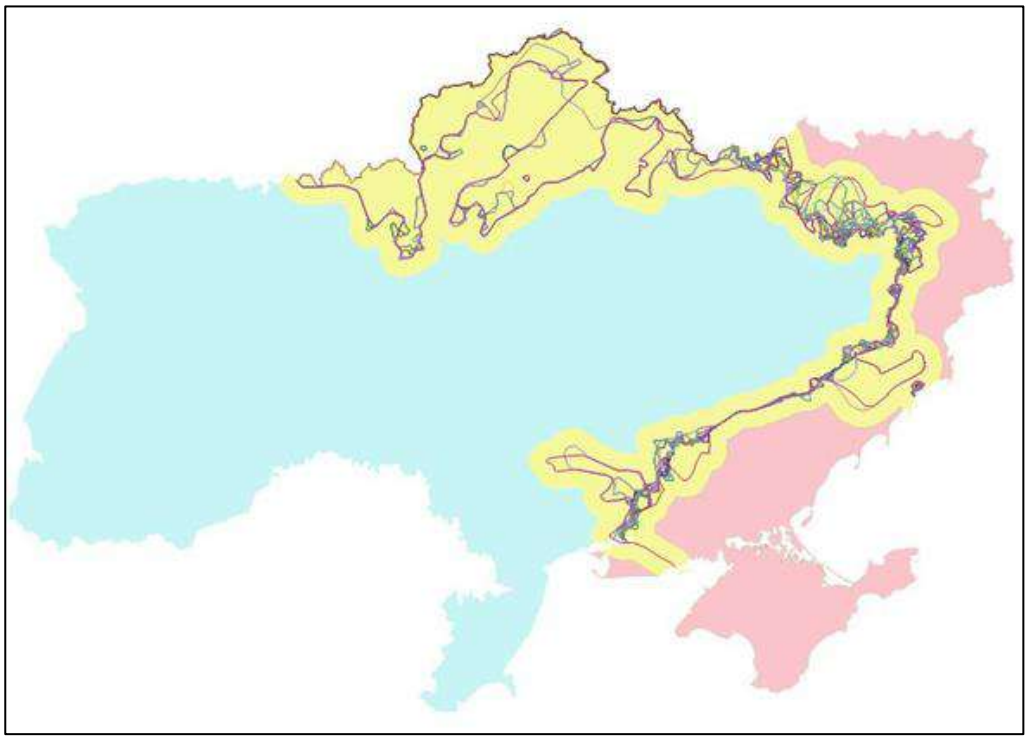

Figure 1: Frontlines and Zone 1 (blue), Zone 2 (yellow) and Zone 3 (red) (adapted from de Klerk *et al.* (2022)

Between 24 February 2022 to 24 September 2022 (214 days), the fires were assessed by EFFIS and are illustrated in table 2. EFFIS created data from satellite imageries and compared it with the data for the period 24 February 2021 to 24 September 2021.

Based on the assessment of fires, the CO_2 emissions are calculated by de Klerk *et al.* (2022), which are illustrated in table 3.

[2] https://firms.modaps.eosdis.nasa.gov
[3] https://effis.jrc.ec.europa.eu
[4] https://liveuamap.com/uk

Table 2: Fires in Ukraine for 214 days of the war (with an area of more than 1 ha)

Distribution of fires	*Number of fires*	*Total fire area, ha*	*Area of forest fires, ha*	*Area of farm fires, ha*	*Area of other natural component fires, ha*	*Area of fires in built-up areas, ha*	*Area of other fires, ha*
Zone 1	2,066	122,693	7,618	94,656	19,342	471	604
Zone 2	3,724	315,046	47,443	234,002	29,302	2,747	1,546
Zone 3	425	48,423	2,164	43,057	2,965	146	92
Total	6,215	486,162	57,225	371,715	51,609	3,364	2,242

Source: Adapted from de Klerk *et al.* (2022)

Table 3: Greenhouse gas emissions for 214 days of the war (in thousand tons CO_2e)

Distribution of fires	*Emissions from forest fires*	*Emissions from farm fires*	*Emissions from natural component fires*	*Emissions from fires in built-up areas*	*Total emissions*
Zone 1	2,202	1,068	137	373	3,780
Zone 2	13,711	2,640	208	2,177	18,736
Zone 3	625	486	21	116	1,248
Total	16,538	4,194	366	2,666	23,764

Source: Adapted from e Klerk *et al.* (2022)

Above analysis by de Klerk *et al.* (2022) for 7 months of Russian war imposed on Ukraine reveals that total number of fires having an area of >1 ha increased 122 times compared to the same period in 2021, while its total area has increased 38 times. It means, 79% of greenhouse gas emissions from the war-related fires accounted for 20% of the territory (Zone 2), and the density of greenhouse gas emissions from fires in Zone 2 was found 17 times higher than in Zone 1 (de Klerk *et al.*, 2022).

Pollution and Waste from Military Vehicles

According to Solomon *et al.* (2018), "heavy military vehicles consume a lot of fuel and produce many hundreds of thousands of tons of carbon monoxide, nitrogen oxides, hydrocarbons and sulphur dioxide. de Klerk *et al.* (2022) have analysed that large volume of fuel is required during the mobilisation of forces, relocations, and operational movements. Usually, old tanks and armoured fighting vehicle (AFV's) lack auxiliary power units to run for recharging its batteries, so engines need to run periodically to recharge the batteries. In addition, fuel is also used by civilian vehicles involved in war-related activities e.g., emergency services, medical vehicles, movements related to evacuation, rebuilding supply chains, the use of tractors to recover abandoned and damaged vehicles, etc. (de Klerk *et al.*, 2022). Extended consumption of fossil fuels leads to significant emissions of greenhouse gases (GHGs) and climate change impacts. From 24 February 2022, the consumption of fuel for military purposes in Ukraine has increased significantly, approximately threefold.

Important to note here is that Russia's significantly higher consumption of fuel (1.5 million tonnes compared to 0.5 million tonnes) is used for war against Ukraine. Gross fuel consumption by Russian war in Ukraine is estimated at 2 million tonnes with total GHG emissions of 6.37 million tonnes CO_2e (de Klerk *et al.*, 2022).

In context of Ukraine, as of now, exact data is unavailable on debris generated by the destruction or abandonment and subsequent degradation of military vehicles. The debris inevitably causes environmental pollution and associated health risks. Specific components of vehicles (e.g. vehicle batteries) contain lead or other toxic compounds that are harmful to biota and humans (Lawrence *et al.*, 2015). Massive debris of fuel deposits, grease, paint, batteries, tyres and cables result in harm to flora and fauna (Clark and Jorgenson, 2012). In addition to the vehicles, military aircrafts result in massive air pollution with high concentration of ammonium perchlorate, polyvinyl chloride, lead stearate, polybutadiene and polyethylene (Edeko, 2011). The warships are big source of contamination of sea water. Along with the emissions and pollution, waste from ships can also contain the pollutants and metals ending up in the brackish water. Destroyed naval ships result in oil contamination and, thus, pose a heavy risk to marine ecosystems (Lawrence *et al*., 2015).

Pollution by Weapons and Missiles

According to an estimate by de Klerk *et al.* (2022), artillery use is 0.9 million rounds per month (30,000 rounds per day) or 5.4 million per 6 months of the war for Russia and additionally 0.2 million rounds per month (7,500 rounds per day) or 1.35 million per 6 months of the war for Ukraine. de Klerk *et al.* (2022) further quoted the Royal United Services Institute for Defence and Security Studies report[5] claiming that Russia was firing approximately 20,000 of 152-mm artillery shells per day compared to Ukraine's 6,000. Another analyst claimed on social media[6] that the firing rate was 1-1.5 million rounds per month (30,000 – 50,000 per day) from May 2022 onwards. Representatives of the Ministry of Defence of Ukraine reported the use of 40,000-60,000 rounds per day by Russia (de Klerk *et al.*, 2022) during the period of intense fighting.[7] Other estimates claim that during 6 months of the war, Russia alone could have fired 7 million of artillery rounds, excluding the losses occurred due to the destruction of warehouses.[8] These above estimates are again illustrative, as there is no accurate data available. To understand the quantum of artilleries used, it is essential to assume weight of an artillery round together with its container, which is 80 kg. The total weight of artillery rounds that need to be transported to the battle field is 432,000 tonnes for Russia and 108,000 tonnes for Ukraine (540,000 tonnes in total) (de Klerk *et al.*, 2022).

How much is the emission load from the artillery fires and smokes? It is expected to be approximately 1 million tonnes CO_2e. In their report, de Klerk *et al.* (2022) reported the emissions from the use of artillery munitions as follows:

[5] Ukraine at War Paving the Road from Survival to Victory, https://static.rusi.org/special-report-202207-ukraine-final-web_0.pdf
[6] https://twitter.com/Volodymyr_D_/status/1560350883929620481
[7] https://telegraf.com.ua/ukr/ukraina/2022-09-06/5715744-godovoeproizvodstvo-snaryadov-raskhoduetsya-za-mesyats-okkupanty-istoshchayut-svoi-arsenaly-pomozhetli-kndr
[8] https://theins.ru/politika/254514

- 918,000 tonnes CO_2e from the manufacture of munitions (steel casing and explosives);
- 19,778 tonnes CO_2e due to emissions at the point of firing and at the point of impact;
- 1,283 tonnes CO_2e from detonation at the point of impact; and
- 18,131 tonnes CO_2e from the transportation of munitions.

The following estimate reveals that overall emissions from the use of munitions and explosives would reach 1.2 million tonnes CO_2e. It is because an additional 30% of the emissions should be added to above figures attributing to the use of other explosives and munitions, e.g. small calibre rounds, medium and heavy mortar projectiles, land mines, hand and drone grenades, munitions for tank guns, artillery rockets and air missiles, etc. (including various munitions exploded during the destruction of armour and vehicles). Break of the emissions from different sources is given in the table 4.

Table 4: Total GHG emissions from the warfare (adapted from de Klerk *et al.*, 2022)

Emission types and sources	*thousand ton CO_2e*	*%*
Emissions from fuel consumption by the Russian Army	4,779	
Emissions from fuel consumption by the Ukrainian Army	1,593	
Emissions from Air Force	1,036	
Pre-invasion force accumulation	136	
Invasion and Russian troops' operational movement	74	
Delivery of artillery munitions from temporary warehouses to the battlefield	18	
Subtotal fuel consumption	*7,636*	*86.2*
Emissions from the use of artillery munitions	20	
Emissions from the manufacture of artillery munitions	918,000	
Emissions from the use of other munitions	5,933	
Emissions from the manufacture of other munitions	275	
Subtotal ammunitions	*1,219*	*13.8*
TOTAL	8,855	100

The ammunition used in war is made 95-97% of lead, zinc, nickel, barium, manganese, copper, antimony, depleted uranium, etc. Undoubtedly, lead is toxic and highly penetrable as it enters human body not only with air or water, but also through skin and hair. Prolonged exposure to lead leads to kidney failure with effects on nervous system. Serious illnesses include encephalopathy, anaemia, loss of coordination and memory. Numerous neurotoxic effects are observed in animals too. In the Russian war in Ukraine, TNT, DNT, and RDX have been used recklessly, causing acute intoxication with long-term mutagenic effects in populations. Because TNT is easily absorbed through skin and mucous membranes, its carcinogenic effects can induce alopecia, anaemia, liver failure, cataract, etc. (Zaborona, 2022). Hexogen poisoning causes nausea and anaemia, and prolonged exposure leads to kidney and liver failure. Likewise, DNT is equally toxic, and, in high doses, it can disrupt

cardiovascular system apart from oncological provocation. Various sources indicate that toxic clouds rose after the massive explosions and fires covered residential towns and villages, resulting to a severe damage to health of the locals seen already and may be seen in near future (Darbyshire, 2022; Weir, 2022; Wesolowsky, 2017). In Ukraine, the toxic damages caused by hostilities are even more hazardous (Dathan, 2020).

Refugees and GHG Emissions

According to UNHCR website[9], as on 31 January 2023, there were 8,046,560 refugees from Ukraine recorded across Europe, and 4,823,326 refugees from Ukraine registered for Temporary Protection or similar national protection schemes in Europe. Likewise, since 24 February 2022 till 31 January 2023, 18,159,214 Ukrainians crossed the borders into neighbouring countries (Bulgaria, Czech Republic, Romania, Slovakia, Moldova, Hungary and Poland). As many as 5,352,000 people were estimated to be internally displaced in Ukraine as on 23 January 2023, according to Internal Displacement Monitoring Centre (IDMC)[10] quoting IOM (2023).

Forced migration of affected people leaves serious footprints. Thus, forced mass relocation of people overloads infrastructure of host regions. It is observed that refugee camps accumulate[11] waste (Cottrell and Dupuy, 2021) and have almost no recycling facilities[12]. One other report by de Klerk *et al.* (2022) projected the emission of GHGs by Ukrainian refugees (as on 22 October 2022) in various European countries and the internally displaced people (IDPs)[13]. The projections are illustration in table 5.

Table 5: GHG Emissions by Refugees and IDPs (Calculations of emissions by de Klerk *et al.*, 2022, p.28)

Category of People	*Thousand ton CO2 Emitted*	*%*
Internal displacements	50	3.6
International refugees	539	38.6
Transports returning empty	539	38.6
Refugees returning	215	15.4
Refugees visiting	54	3.7
Total	1,397	100.0

Source: Adapted from de Klerk *et al*, (2022)

Nuclear Pollution from Russians War in Ukraine

Noticeably, Ukraine is Europe's second largest producer of nuclear power. In Ukraine, almost 50% of electricity comes from nuclear power plants. Commonly, the nuclear plants are vulnerable to missile, rocket or mortar hits (Brown and Solomon, 2022; Castelvecchi, 2022; Cavanagh, 2022). Reports revealed that, in February 2022, the Russia took control of the Chernobyl nuclear power plant and other nuclear facilities

[9] https://data.unhcr.org/en/situations/ukraine, assessed 08 February 2022
[10] https://www.internal-displacement.org/countries/ukraine#internal-displacement
[11] https://article36.org/wp-content/uploads/2013/09/DAMAGE.pdf
[12] https://www.trtworld.com/magazine/an-ecocide-how-the-conflict-in-ukraine-is-bombarding-the-environment-56730
[13] https://data.unhcr.org/en/situations/ukraine, accessed 22 October 2022

in the Chernobyl Exclusion Zone (CEZ) (UNEP, 2022). It was massive dispersion of dust by the military vehicles, leading to sharp increase in background radiation. On 1 April 2022, the following radiation-hazardous facilities located in the Chernobyl Exclusion Zone went into Russian control (Ministry of Environmental Protection and Natural Resources of Ukraine, 2022; State Nuclear Regulatory Inspectorate of Ukraine, 2022): i) New Safe Confinement and Shelter, ii) Spent Fuel Storage Facility (SNF-1), iii) SNF storage-2, iv) Liquid Radioactive Waste Processing Plant, v) Chernobyl Solid Radioactive Waste Processing Plant, vi) Buryakivka Radioactive Waste Landfill, vii) Radioactive Waste Landfill '3rd Stage of the Chernobyl NPP', viii) Pidlisny Radioactive Waste Landfill, and ix) 'Vector' Industrial complex.

Another explosion was reported on 27 February 2022 by a rocket attack in the Kyiv suburb of Pirogovo. That explosion hit the location of the Central Production Site of the Radon Association doing a disposal of radioactive waste (Ministry of Environmental Protection and Natural Resources of Ukraine, 2022; State Nuclear Regulatory Inspectorate of Ukraine, 2022). Kharkiv Institute of Physics and Technology located with the Neutron Source nuclear reactor with 37 nuclear fuel assemblies was attacked on 6 March 2022 (State Nuclear Regulatory Inspectorate of Ukraine, 2022). As Gardashuk (2022) states, "invaders brutally violate all rules of war, international conventions and treaties, resorting to terror, thus threatening ecology and human lives apart from global safety. Russian forces deliberately occupy and target nuclear power and research facilities (including Chernobyl and Zaporizhzhya nuclear plants, and Kharkiv Institute of Physics and Technology), thus resorting to nuclear blackmailing and putting human lives and environmental safety at stake."[14] According to de Klerk *et al*. (2022), outage of the Zaporizhzhia Nuclear Power Plant supplying 25% of electricity demand will lead to more coal-fired power production. It would add to already exorbitant levels of pollution. In the operation of power plants, more attention is given to nuclear reactors, any damage to the spent nuclear fuel or storages of spent nuclear rods can be extremely devastating (Jacobo, 2022; SMC, 2022). According to the International Atomic Energy Agency (IAEA), two Russian missiles already hit nuclear waste ponds in Ukraine (Conover, 2022; Mathiesen, Guillot and Zimmermann, 2022). Mega accident was escaped by Ukrainian army. According to experts, the spent nuclear fuel may release 20 times the fatal dose of radiation in an hour (Stapczynski and Oda, 2022).

Radioactive pollution from nuclear reactors has been world known from Chernobyl of Ukraine. It is known fact that particles of depleted uranium are 100 times smaller than leukocytes and easily pass the blood-brain barriers. These radioactive high energy particles directly reach the olfactory nerves and disrupt cognitive and thinking processes. Moreover, radioactive antimony causes inflammation of cardiovascular, respiratory and digestive systems. Similarly, radioactive nickel damages the immune system (Omelchuk and Sadohurska, 2022).

Damage of Wildlife, Biodiversity, Ecosystems

Russian invasions on Ukraine have severely destroyed the steppe grasslands existing only 3% in southern and eastern Ukraine. Out of many rare and endangered plant

[14] https://suspilne.media/214505-okupacia-rujnuvanna-i-riziki-golova-energoatomarozpoviv-pro-stan-zaporizkoi-aes/

species in steppes, about 20 steppe species are believed to have disappeared due to the war (Pearce, 2022). Largely, these species are endemic to the Black Sea peninsula of Crimea, believed to be "the largest centre of endemism on the territory of Ukraine," having 44 plant species that are found nowhere else on Earth (Pearce, 2022). Moreover, Ukraine's protected areas are claimed to have been heavily suffered from Russian war waged in Ukraine. The Ukrainian Parliament Commissioner for Human Rights, Lyudmila Denisova, emphasized that there are about a third of the nature reserve fund of Ukraine under threat of destruction. Luhansk Nature Reserve, Black Sea Biosphere Reserve, Askania-Nova Biosphere Reserve, National Nature Parks "Azov-Sivasky" and "Dzharilgatsky", arboretum "Trostyanets", and others have seriously damaged. The Kherson Hydrobiological Station has been severely damaged (Gardashuk, 2022). The Ministry of Environmental Protection and Natural Resources of Ukraine (2017) reported 60 protected sites being affected in eastern Ukraine. The war affected heavily the biological diversity and declining rare animal and bird species.

Early (2023) has reported that more than 600,000 hectares of wetland are under threat from this war. Of such watershed, 16 ecosystems are designated as Ramsar sites for the international importance of its unique biodiversity and birdlife. War has affected all natural corridors of national importance except the Crimean and Carpathian ones, causing significant damage to landscapes and nature (UNEP, 2022). According to official estimates, 20% of all nature conservation areas of Ukraine are severely affected by the Russian attacks. About 1 million hectares area of protected areas has been affected and 812 specific sites in different protected areas are damaged. As the Nature Reserve Fund of Ukraine (2022) reported, nearly 160 territories of the Emerald Network[15] having an area of 2.9 million hectares, 14 Ramsar sites[16] expanding over an area of 400,000 hectares, and 4 biosphere reserves[17] are under threat. Reports spell that Russians had occupied 8 nature reserves and 10 national parks. Ukrainian army liberated the Kamianska Sich National Park in the Kherson region in November 2022 after 8 months of occupation by Russian forces. More than 90 species of rare animals in grassland ecosystem have suffered. A satellite data shows that 635 hectares area containing rare plant species, such as hairy feather grass and Ukrainian feather grass, is destroyed by fire as a consequence of shelling by Russians (Early, 2023).

Some examples of impact of war on nature are illustrated hereunder:

- Images from the European Space Agency's Sentinel 2 showed on 18 March 2022 an active fire in primeval forest of nature reserve in Svyate (44 hectare protected area in the southern part of Chernihiv city) (NASA, 2022).
- In the Luhansk region, fire was caused 9 May 2022 by heavy shelling resulting into forest burning in Kudryashivka, Kreminnaya, Chervona Dibrova and between Purdivka and Metelkin. This fire advanced in the direction of Yampol and approximately 15,000 hectares were reported burnt (State Environmental Inspectorate of Ukraine, 2022b).
- On 10 May 2022, Heroyske, Chulakivske, Ivanovske, Kardashinske forests, Holoprystansky forestry enterprise and the Black Sea Biosphere Reserve in the Kherson oblast were reported burning (State Environmental Inspectorate

[15] https://uncg.org.ua/en/
[16] https://www.ramsar.org/news/ukraine-designates-eleven-ramsar-sites
[17] https://en.wikipedia.org/wiki/Biosphere_reserves_of_Ukraine

of Ukraine, 2022b). Despite the attempts of extinguishing fire and sweeping the areas to prevent fire spread, nearly 6,000 hectares were destroyed (Interfax Ukraine, 2022b).

- According to the Ukrainian Ombudsman, Liudmila Denisova, fires (Ukrinform, 2022a) in the forests of Kinburn Spit Reserve were observed. It was reported that the entire vegetation in that forest was under threat of destruction. It is the largest field of wild red orchids in Europe (more than 60 hectares), perennial trees, pink lakes and animals.

Another classical case of destruction of natural ecosystems by war is the case of Snake Island in the Black Sea, known locally as Zmiinyi Island. Ukraine retook the island in June 2022 after 4 months of Russian occupation. The reoccupation of the island by Ukraine left the island burned and littered with toxic munitions. Recently, the island was recorded having about 200 species of flowering plants and inhabited by more than 200 species of birds. According to Pearce (2022), everything is reported to have been burned in the island. "Most of the exclusion zone was damaged by the invasion and may be contaminated with unexploded ordnance and mines," director of the Chernomorskiy Biosphere Reserve, Oleksandr Galushchenko, lamented. He emphasized that wolves, deer, brown bears, lynx, elk, and bison are at particular at risk (Pearce, 2022). According to the World Wildlife Fund (WWF), more than 280,000 hectares of forests are destroyed or felled by army operations (VoA, 2022). It amounts to a damage of more than $37 billion, according to the Audit Chamber, a non-governmental group (VoA, 2022).

Not only the wild animals, but farm animals, especially cows, were also targeted by Russian forces. Large number of dead cows was seen in trenches (Dairy Global, 2022). Deaths of animals from cold, hunger and injury were confirmed in the contact zoo (TSN, 2022) and the Mykolaiv Zoo (Novoye Vremya, 2022a). Similarly, 300 dogs were reported to have died in the Borodianka Kyiv oblast (The Village, 2022). According to the Ukraine's Minister of Environmental Protection, "since February, 120 deaths of dolphins in the Black Sea are documented having links to the war" (Rannard, 2022). Other report by Early (2023) quoted Ukraine's Environment Minister claiming death of at least 700 Black Sea dolphins, which became victims of acoustic trauma caused by sonar equipment of Russian submarines.

Loss of Water Bodies

Omelchuk and Sadohurska (2022) termed the Black Sea a place for theatre of Russian war. The abandoned vehicles pollute sea water with leaking fuel and lubricants, and fuel spills induce fires on water surface (Seibt, 2022). The spilled out oil itself is very toxic to marine life and microorganisms (Seibt, 2022); oil also contains hydrocarbons that dissolve with pesticides or heavy metals leading to its high concentration on the surface of water (Omelchuk and Sadohurska, 2022). Due to the massive movement of naval vessels in the Black Sea, marine ecosystems are affected badly. Tuzlovski Limany Reserve was reported to have the deaths of several thousand dolphins in the Black Sea over 3 months (New York Times, 2022; Odessa News, 2022). Scientists estimated the deaths of about 3,000 dolphins in the Black Sea (UNEP, 2022). Ukrainian Armed Forces claimed 15 ships carrying hundreds of tons of fuel sunk in the open sea and in the port of Berdiansk (Ukrinform, 2022b).

On 26 February 2022, a dam on Irpen river near Kozarovichi village was destroyed by Russian troops. It resulted in a flood inundating more than 10 km up to Horenka (NV Kyiv, 2022). According to TMRF (2022), the loss of biodiversity in the Gulf of Odesa, Danube Delta, and Azov Sea is yet to be estimated. Severe pollution was recorded in Seversky Donets river in 2018. Levels of heavy metals and alkylphenols in the river were found 7 times higher than acceptable (Dathan, 2020; UNEP, 2018). During current war, bombs have destroyed Popasnyansky and Uzhnodonbassky waterways, 'Seversky Donets - Donbass' channel, and Donetskaya filtration plant. It was reported that untreated sewage runoff was spilled into the river after pipeline ruptured (PAX, 2022; Roscini, 2022; RYB.RU, 2022).

Damage to Urban Infrastructure

Seriously hit is the urban infrastructure. Shelling of missiles has resulted in large quantities of debris in cities and towns in entire country. The Office of the President of Ukraine (2022) and Pereira *et al.* (2022) claimed that all buildings are either damaged or demolished completely in some settlements. According to Nielsen and Hodgkin (2022), asbestos level from the debris of buildings has gone high in the cities/towns, as the asbestos is used 60 per cent in roofing materials of buildings. Some cases of damages to the urban infrastructure are illustrated as follows:

- Volnovakha (Donetsk oblast) has been destroyed 90 per cent (State Border Guard Service of Ukraine, 2022).
- According to a statement by Kharkiv's Mayor released on 31 March 2022, at least 1,292 of multi-storey residential buildings were damaged or demolished (Novoye Vremya, 2022b). Mayor's report quoted 239 administrative buildings, 70 schools, 54 kindergartens and 15 hospitals were partly or fully destroyed as on 31 March 2022.
- UNITAR (2022) published a satellite image of Chernihiv city illustrating the damage to 21% of the city. Simultaneously, the Governor of the Chernihiv oblast reported that 3,500 buildings were damaged in the oblast, from which 80% were residential buildings (Governor of Chernihiv oblast, 2022).
- Territorial communities of Kyiv region informed that 1,875 buildings were either significantly damaged (1,329) or destroyed (546) (Novoye Vremya, 2022b).
- Until 16 April 2022, in the town of Makariv, 28 multi-storeyed buildings, 441 private estates, 8 educational institutions, 4 health care institutions, 8 cultural institutions and 2 sports institutions were destroyed. Likewise, in the town of Borodyanka, 8 out of 29 multi-storeyed residential buildings were completely destroyed and 21 partially destroyed (Kyiv Regional Military Administration**,** 2022).
- The case of Mariupol is world known. Hardly any building is left undamaged or unburnt, with more than 20,000 residents killed.

Kyiv School of Economics produced a report "*Assessment of damages in Ukraine due to Russia's military aggression as of 1 September 2022*", which presented the data of destroyed and damaged residential infrastructure, as depicted in table 6.

Table 6: Destroyed and damaged units in the residential sector

Infrastructure	*Unit Stock Units*	*Damaged Units*
Destroyed		
Apartment buildings	178,921	6,153
Private houses	8,984,976	65,847
Dormitories	7,114	85
Damaged		
Apartment buildings	178 921	9,490
Private houses	8,984,976	54,069
Dormitories	7,114	155

Source: de Klerk *et al.* (2022)

Assuming the reconstruction of destroyed or damaged infrastructure will cause GHG emissions, de Klerk *et al.* (2022) estimated the emissions. They assumed 100% of the embodied carbon factor for renovation of infrastructure, and 33% factor was assumed for damaged facilities. The projected emissions from destruction and damage of the civil infrastructure are illustrated in table 7.

Table 7: Overview of reconstruction emissions in the civilian sector for various categories

Item	*Emission, thousand tons CO_2e*	*Emissions, %*
Residential buildings	28,432	58.4
Social sector	1,055	2.2
Health care	96	0.2
Educational and science	2,232	4.6
Culture, religion, sports, and tourism	1,818	3.7
Infrastructure	6,006	12.3
Retail	814	1.7
Vehicles	2,448	5.0
Energy	1,314	2.7
Industry and business services	3,615	7.4
Utilities	840	1.7
Total	48,670	100

Source: Adapted from de Klerk *et al.* (2022)

Environmental effects of the destruction of cities appear in the form of huge ecological threats, as the undetonated bombs are buried in debris (Dathan, 2020). The ruined houses release carcinogenic dust for decades (de la Garza, 2022) and millions of tonnes of rubble are of generated having no possibility to recycle (Dathan, 2020).

Implications for European and Ukrainian Energy Sector

Zetterberg, Johnsson and Elkerbout (2022) have simulated policy implications of Russian war in Ukraine in context of rest of the Europe. European security order has ramifications for its entire European economy apart from the transformation of European economies to climate neutrality (Zetterberg, Johnsson and Elkerbout, 2022). Far more than the COVID-19 crisis, some of the immediate challenges to climate

action policies are raised by Russia's aggression. Several EU countries have increased defence spending already. This war actually challenged the order and geopolitical landscape impacting climate and energy policies in numerous ways. The issues such as energy security and supply security have reappeared. Energy prices continue to remain high on the political agenda for as long as energy prices are souring, in particular for heating and electricity ((Zetterberg, Johnsson and Elkerbout, 2022). Authors like O'Riordan and Sandford (2022) emphasize that the war in Ukraine adds complexity to the global climate change. It manifests more money to be pumped by the west and emerging economies into Russian coffers through purchase of gas, oil, coal and minerals. In fact, 70% of the Russian economy is buttressed by increasing contributions, further flattering cruel Russian war machine. The authors further articulate that grim and unrelenting climate change politics of corporate dominance confront the world, especially by the fossil fuels-based military complexes (O'Riordan and Sandford, 2022). Associated impact is the inflation and insufferable rises in the living costs.

In particular, some nuclear power plants in Belgium and Germany have prolonged its operations due to energy crisis. Further, dormant coal-fired power plants have been reactivated that bound to increase GHG emissions in the coming years. In August 2022, as de Klerk *et al.* (2022) documented, "Russia was flaring substantial amounts of natural gas close to the border with Finland as it was not able or willing to supply it to Europe". Gas flaring is high grade contributor to the global warming (Nwaogu and Akpoghome, 2022).

According to Lloyd's Futureset (2022), Russian war in Ukraine has disturbed the European businesses and economy greatly while damaging global agriculture and manufacturing, creating further risks to food and energy security worldwide. Some realize that the disruption to critical exports from Ukraine, especially grain exports, threatened significantly global food security. Another important problem has arisen from the refugee flow into Europe from Ukraine. It is the largest since World War II, surpassing the flow of asylum seekers at the height of the Syrian refugee crisis. About 3 million people fled Ukraine during the first 3 weeks of the war broke on 24 February 2022 and this continued to grow as the conflict continues (Lloyd's Futureset, 2022), and by 31 January 2023, the figure of Ukrainian people fled was above 18 million.

Pecheniuk *et al*. (2022) highlighted that the Russian Federation's military aggression against Ukraine dealt a significant blow to the development of Ukrainian renewable energy. With the full-scale invasion of Russia, the stable operation of the Ukrainian energy system was threatened; the energy infrastructure of renewable energy facilities was significantly damaged due to the actions of the Russian army. The main capacities of renewable energy (solar, wind generation) are located in the southern and southeastern regions of Ukraine, where active military operations are currently taking place: the invaders primarily attack transformer substations, and power lines, and personnel. Up to 40% of these facilities have already been destroyed or damaged (Pecheniuk *et al*., 2022). Other estimates indicate that about 90% of power generation is located in the territory where active hostilities are taking place, and the generation of solar power has decreased by 40% (Omelchenko, 2022). Pecheniuk *et al*. (2022) reiterate that producers of "green" energy operating in Ukrainian market are in a rather difficult situation. It is not only the threats of shelling of stations, but also a significant

limitation of the state-guaranteed support available for renewable energy. According to the experts, assets valuing USD 5.5 billion are currently in the war zone causing significant losses of renewable energy (Demchenkov, 2022). Pecheniuk *et al*. (2022) further disclose that the renewable energy sector is on the verge of bankruptcy; for example, the National Energy Company "Ukrenergo" owed about USD 0.4 billion by the end of August 2022 to the producers of the industry under the "green" tariff. Usenko (2022) recommends that the State should preserve the industry and develop plans for its development after the war. There is another problem for the industry: the solvent demand for electricity has significantly decreased (Pecheniuk *et al*., 2022). Ukrainian population consumed 30-40% less energy causing the fall of payments significantly - by 40-45% (Omelchenko, 2022). Thus, the war-generated pathetic situation in energy sector has significantly worsened the energy production. In fact, the Ukraine government does not have the financial means to support the power generation in the current conditions. Funds that enter the state treasury are directed, first of all, to military, humanitarian, and social purposes (Pecheniuk *et al*., 2022), and they are still not enough.

Breach of International Law and Human Rights of Peace and Dignity

International legal regimes are as old as the history of wars. The foundation of the League of Nations (changed to United Nations) in 1945 took place after the World War II. To protect the environment from negative impacts of war, the Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques[18] was adopted in 1976. This Convention prohibits using the methods of the modification of the environment as a tool of war (Gardashuk, 2022). Both Ukraine and the Russian Federation are signatories to this Convention. Under Article 35 of the Protocol (I) to the Geneva Conventions[19], which was adopted in 1977, it is prohibited "to employ methods or means of warfare which are intended, or maybe expected, to cause widespread, long-term and severe damage to the natural environment". This document[20] further states "to protect the natural environment against widespread, long-term and severe damage. This protection includes a prohibition of the use of methods or means of warfare which are intended or may be expected to cause such damage to the natural environment and, thereby, to prejudice the health or survival of the population" (Art. 55). The General Assembly of the United Nations in 2001 proclaimed November 6 as the International Day for Preventing the Exploitation of the Environment in War and Armed Conflict in order to curb the environmental harms of the war caused to ecosystems and natural resources (Gardashuk, 2022).

Chowdhury and Rosencranz (2022) informed that 5th Session of the United Nations Environment Assembly (UNEA 5.2) convened in Nairobi, Kenya discussed on global environmental concerns including the reason why the biodiversity and wildlife of Ukraine must bear the brunt of Russian war in Ukraine. Russia remained oblivious to these concerns, and environmental protection was not a major issue for Russia. Meanwhile, the Ukraine's president, Volodymyr Zelensky, urged all EU States repeatedly to stop energy trading with Russia terming it 'blood money' fuelling the

[18] https://www.un.org/disarmament/enmod/
[19] https://www.ohchr.org/en/instruments-mechanisms/instruments/protocol-additional-geneva-conventions-12-august-1949-and
[20] https://ihl-databases.icrc.org/en/ihl-treaties/api-1977

Russian war machine. Estimates indicate that sale of Russian oil and gas accounts for $1 billion per day (Chowdhury and Rosencranz, 2022). Lloyd's Futureset (2022) has assessed the emerging scenarios globally as a result of war. Their report (Lloyd's Futureset, 2022) exclaims that the geopolitics has undergone a crisis exhibiting the vulnerabilities coupled with globalisation in an international system wherein a powerful State asserts self-interest and breaches international laws. Resultantly, emerging world order pushes many organisations to adopt hedging strategies protecting global self-interests and assets since increasingly protectionist trade policies are introduced (Lloyd's Futureset, 2022). It implies that various countries and businesses are gearing to grab supply chains in order to achieve self-sufficiency and extended control on access to priority goods and services. This trend of trade and specialisation will inevitably add to the inflation in the long term (Lloyd's Futureset, 2022).

In Daily Maverick, Ngcuka (2022) wrote explicitly, "*United Nations member states attending the UN Environment Assembly's opening session have raised concerns over the environmental impact of the Russia-Ukraine crisis. Russia says they are hypocrites. The resumed fifth session of the United Nations Environment Assembly (Unea 5.2) got underway in the Kenyan capital, Nairobi, with some world leaders condemning the Russian invasion of Ukraine and raising concerns over the environmental impact of the conflict. Russia called the concern "hypocrisy". The meeting coincides with the release of the sixth report of the International Panel on Climate Change. It details the grim effects of the climate crisis on humanity, biodiversity and marine life. While environmental concerns over the conflict cast a shadow over the world's highest-level decision-making body on the environment, urgent concerns were raised over the triple threat of the climate crisis, loss of biodiversity and pollution*" (Dhingra, 2022).

Bazhenova (2022) elaborated that the Protocol Additional to the Geneva Conventions of August 12, 1949 for the Protection of Victims of International Armed Conflicts (Protocol I), adopted on June 8, 1977 enforces warring States (e.g. Russia) are obliged to protect the natural environment against "widespread, long-term and severe damage". The warring States cannot employ warfare intended to cause or causing such environmental damage threatening the health or survival of the population. Similarly, Principle 24 of UNCED 1992 instructs that warfare inevitably has a destructive impact hampering the process of sustainable development. It implies that the States must respect international law obliging to protect the environment in times of armed conflicts (Bazhenova, 2022). From all the angles, it is observed that Russia does not adhere to the obligations of international conventions defining the rules of warfare, and, thereby, destroying the environment. Within 3 months of war since 24 February 2022, Russian military committed 245 crimes against the environment recorded only in Black Sea (Bazhenova, 2022). It was a loss of approximately USD 6.8 billion. Within these 3 months, the largest number of cases of ecocide was reported in Kyiv (34), Donetsk (28), and Dnipropetrovsk (22) and Luhansk (22), apart from over 1,500 cases of environment damages that were recorded as a result of Russian missile explosions (Bazhenova, 2022).

All-Ukrainian Ecological League campaigned[21] through national videoconference "Environmental Threats and Risks to the Environment, Life and Health from Russian Military Aggression" to discuss the environmental challenges of the war and to work out and document environmental crimes of Russian Federation, and the notes were submitted to the International Criminal Court.

According to the International Association of Applied Psychology (IAAP), Russia's aggression against Ukraine also violates the *Universal Declaration of Human Rights* 1948, which proclaims that freedom, justice, and peace in the world rest on honouring the inherent dignity and fundamental rights of all members of the human family including but not limited to "the right to life, liberty and the security of person" (IAAP, 2022).

Part-B: Psychology Effects of Russian War in Ukraine

Anjum, Aziz and Hamid (2023) have rightly highlighted that recent Russian invasion in 2022 and 2023 has led to the world's largest war-led humanitarian and mental health crises among Ukrainians. Foremost psychological symptom of the war appears in the form of fear and uncertainty followed by direct threats to peoples' lives. The same was observed when the full Russian invasion began on 24 February 2022. IOM (2022) observed common sufferings in the following forms: 1) fleeing homes in search of safety and living through repeated displacement, 2) being a refugee in a foreign country without knowing the language, 3) hiding in the basements from shelling, 4) trying to earn for families after losing a job, 5) being separated from loved ones, 6) facing outages of power and electricity. Among these sufferings, number 3 and 6 are common for all, people migrated and people living in Ukraine during the war. IOM (2022) emphasizes that all these stressors contribute to anxiety, panic, mild or severe depression, insomnia and other stress-related disorders that severely affect public health.

Long-Term Stress and Trauma

War causes long-term environmental stress, which is harmful to human's health. Various authors have described 'environmental stress' referring to factors in a person's surroundings or environment that can cause emotional or mental strain in their lives (Washmuth, 2022). Causing the environmental stress, the environmental stressors are external and they can often lead to increased levels of discomfort, anxiety, and aggression. War, pollution, noise and fire are the causes of environmental stress (Washmuth, 2022). However, appropriate responses of the victims of pollution from war munitions rely upon both the temporal and spatial attributes of the environmental shocks and the characteristics of the person encountering them (Angilletta Jr. and Sears, 2011). Nevertheless, ecological stress may occur as an intense, short-lived event of destruction (from war) called a disturbance. Inevitably, damage in terms of psychological responses happens when one or more stressors elicit reactions known as 'degradation of environmental quality'.

[21] https://www.ecoleague.net/pro-vel/tematychni-napriamy-diialnosti/vplyv-voiennykh-dii-na-dovkillia

Psychological direct impacts of war and the direct/indirect impacts of environmental damages are inseparable. Opaas (2022) emphasize that the war victims struggle for survival when their life is under risks. Occupational health of the people is affected severely by sirens, aeroplane sounds and bombing by missiles or rockets. Mental distress and trauma are major constituents of occupational health and well-being. Severely threatening situations, including those generated from excessive air pollution, nuclear risks, sound pollution (as a result of planes, rockets and bombing), and fires create fear, sleeplessness, sleep disturbance, irritation, anxiety, nightmares, somatization restlessness, jumpiness, physical arousal, high bodily activation, being alarmed and on guard, helplessness, and physical experience of numbness (Almoshmosh, 2016; Balaban *et al*., 2005; WHO, 2015). Hodes (2022) suggested additional emotional reactions that include shock, disbelief, grief, anger, irritability, anxiety, fear, detachment, and insecurity.

At the human personal level, such difficult experiences lead to severe consequences in the form of post-traumatic stress disorder (PTSD), depression, and anxiety (Javanbakht**,** 2022**)**. In the words of Javanbakht (2020), "the PTSD symptoms include terrifying and realistic flashbacks of war scenes, intrusive memories of the trauma, panic, inability to sleep and nightmares, as well as avoidance of anything that resembles the trauma". According to him, a lot of research is focused on environmental factors, such as war, lead to development of PTSD in a person having visible anxiety, feelings of danger, nightmares disrupting the sleep, flashbacks or sensory experiences, intrusive traumatic memories, irritability, emotional numbness, social withdrawal, and avoidance of any reminder of trauma (Javanbakht, 2020). Studies by Fel, Jurek and Lenart-Kłoś (2022) show that women are at a higher risk of PTSD. Ukrainian women who are living in limbo of the war reflect higher PTSD which is outcome of violence and damage caused by war but also of other stressful circumstances, such as social and financial conditions (Fel, Jurek and Lenart-Kłoś, 2022).

Impacts on Children

Onset of war pushes children to suffer both acute and chronic traumatic stress. Children's suffering can be understood within an ecological framework underlying 5 elements: the child's psychobiological makeup, the disruption of the family unit, the breakdown of community, and the ameliorating effects of culture (Elbedour, ten Bensel and Bastien, 1993). Javanbakht (2022) articulates that children are specifically vulnerable to the effects of war. They imagine the terror in a dark basement, often watching the faces of their parents praying that the next missile will not hit their building. Of course, the parents can shield their children against trauma only to some extent (Javanbakht, 2022). Basner, Clark and Hansell (2017) have suggested that children exposed to regular aircraft noise have poor performance on standardised achievement tests conducted in schools.

Psychological Effects Noise Pollution Caused by War

During the war, noise is intensely created by aeroplanes, rockets, missiles, bombings, tanks, and ammunition. Noise pollution from the war creates anxiety, depression, high blood pressure, heart disease, and stroke. The health disorders connected to noise

uneasiness, wretchedness, hypertension, heart sicknesses and strokes, restlessness, depression, anxiety, insomnia, and psychosomatic disorders (Watkins, Tarnopolsky and Jenkins, 1981). Noise has diverse negative impacts on the performance of human being. According to Basner *et al*. (2015), non-auditory impacts of noise include perceived disturbance, irritation, cognitive impairment, cardiovascular issues and sleep disturbance (Muzet, 2007). Studies show that noise causes psychological debilitation and oxidative stress in the brain. It has been seen that exposure to noise impacts the central nervous system (CNS) leading to extreme stress, anxiety, intellectual and memory problems. Some of the physiological signs are also recorded: (a) Signals related to the peripheral nervous system, including heartbeat and Electromyogram; (b) Signals related to the central nervous system including electroencephalography (EEG). Hegewald *et al*. (2020) found recent evidence showing a depression risk increased significantly from aircraft noise. Stansfeld *et al.* (1996) found that individuals with high noise sensitivity suffer from hypertension and emphysema, whereas cardiovascular mortality levels are increased in noise-sensitive women. Stansfeld *et al.* (1996), Shepherd *et al.* (2010) and Iwata (1984) have reported an association between noise sensitivity and various mental health-related factors, such as anxiety, depression, higher benzodiazepine usage, and future psychiatric disorder.

Noise and social behaviour are very well connected. The noise created by war machinery has detrimental effects on cognitive processes along with social behaviour. Due to the increasing degrees of noise, lower levels of social interaction (Appleyard and Lintell, 1972), increased aggressiveness (Adelson, Geen and O'Neil, 1969) and lower levels of altruistic behaviour (Mathews and Canon, 1975) were recorded. More aggressive behaviour of common Ukrainians during the war is a general negative effect of the noise. Noise has also been shown to be a factor attributed to violent reactions (Elizondo-Garza, 1999).

Psychological Effects of Air & Chemical Pollution Created by War

In the part-A of this article, a lot is written about the environmental impacts of Russian war in Ukraine. Massive air pollution is dangerously causing toxic effects on humans, animals and ecosystem. The psychological effects of air pollution are leading to psychiatric symptoms, including anxiety and changes in mood, cognition, and behaviour (Lundberg, 1996). It is reported by Lundberg (1996) that numerous toxic pollutants interfere with the development and proper functioning of the nervous system, with prominent symptoms of asthma, psychosocial stress, and neurotoxic effects. Dzhambov *et al*. (2018), Manisalidis *et al*., (2020) and Ventriglio *et al*. (2021) illustrated that inhalation of air pollutants can have major consequences on the human central nervous system and neuro-behavioural mechanisms of human population.

Because different types of pollutants have different toxic effects in human body when inhaled, Thomson (2019) articulated that air pollution, especially smog or PAN (per acetyl nitrate) create risks for cardiovascular and respiratory morbidity and mortality. Russian war in Ukraine has built up highest doses of toxic substances (e.g., nanoparticles, particulate matter, NOx, sulphur oxides, etc.) that cause neurological and psychiatric disorders, such as cognitive decline, dementia (including Alzheimer's disease), anxiety, depression, etc. Thomson (2019) has rightly highlighted the adverse

impacts of air pollutants on human's central nervous system causing early initiating events triggered by gases inhalation, contributing to the disease progression. In a study conducted recently, Abed Al Ahad *et al.* (2022) reported poor mental well-being observed with every 10μg/m^3 increase in NO_2, SO_2, PM_{10} and $_{PM2.5}$ pollutants in UK. If we compare this with reported levels of similar pollutants in Ukraine (Zalakeviciute *et al.,* 2022) during initial months of war, O_3 was found 2.45% higher in overall Ukraine and 3.38% higher in Kyiv; and SO_2 was 38.06% higher in overall Ukraine with 10% higher in Kyiv. There are an increasing number of studies confirming the adverse effects of air pollutants on the psychiatric disorders among citizens. For example, exposure to NO_2 and particulate matter (PM_{10} and $PM_{2.5}$) in the Netherlands was found causing poor mental health and anxiety (Klompmaker *et al*., 2019). One study in South Korea recorded an increased exposure to NO_2, SO_2, and PM_{10} pollutants resulted in higher frequency of suicide deaths (Jin-Young, Hye-Jin and Kyoung-Bok, 2018). A recent systematic review and meta-analysis by Braithwaite *et al*. (2019) revealed that exposure to $PM_{2.5}$ pollution increases the risk for depression and anxiety with a pooled odd ratio estimate of 1.10 for every 10 μg/m^3 increase in $PM_{2.5}$ concentration.

The science of air pollutants is quite complex. Calderón-Garcidueñas *et al.* (2015) narrated that war created particulate matter of small diameters, such as $PM_{2.5}$, has potential of initiating oxidative stress and forming inflammatory cytokines that infiltrate the blood-brain barrier producing neuro-degeneration and neuro-inflammation. Abed Al Ahad *et al.* (2022) indicates that the aesthetic and odorous nuisance caused by air pollution clouds results in avoidance behaviour and inhibition of psychological-supporting outdoor activities, thereby, leading to low happiness, high stress, anxiety, loneliness, and poor mental well-being (Claeson *et al.*, 2013; Lu, 2020). Various negative impact are seen of air pollutants on human's physical health along with higher risk for acute and chronic diseases, such as cardiovascular, respiratory, cancer and immune system diseases. Moreover, people residing in excessively polluted areas experience stress and anxiety, and poor mental well-being (Abed Al Ahad *et al*., 2020; Manisalidis *et al*., 2020). Petrowski *et al*. (2021) established a linkage between air pollution of particulate matter having aerodynamic diameter smaller than 10 μm (PM_{10}) and the effects on determinants of mental health and well-being (life satisfaction, stress resilience, anxiety, depression, and self-esteem). The correlation was positive.

Ukraine is the hub for chemical producing industries, including the storage depots. As a result of bombing and missile attacks, chemical factories, fuel stations, chemical storages, and toxic substances depots have been destroyed causing tremendous spillage of organic and inorganic substances. Among the organic substances are persistent organic pollutants (POPs), especially dioxin, polychlorinated biphenyls (PCBs), and chlordane. Many chemical contaminants are classified as known neurotoxic substances. There are thousands of potential neurotoxic substances that are associated with mental health developmental disorders of the brain (Lyssikatou and Oikonomou, 2020). Such toxic chemicals are known to cause depression and anxiety following chronic exposures (Brown Jr., 2013). However, non-persistent organic chemicals (mostly inorganic chemicals) cause more severe psychiatric symptoms (depression, anxiety, mania, psychosis, and aggression) following the acute and chronic exposures, particularly to organophosphates (OPs), organo-metals, and

solvents (Brown Jr., 2013). War has caused mass chemical disasters in industrial settings, individual chemical accidents, targeted destruction of production centres. The consequences of the chemical pollution caused by the war will be known in coming years.

Psychological Effects of Radioactive Pollution Caused by War

Radioactive pollution was caused heavily from Russian war in Ukraine in Chernobyl and Zaporizhzhia. Russians took no lesson from world's most dangerous nuclear disaster occurred in Chernobyl of Ukraine. The same Chernobyl was occupied by Russians during initial days of their invasion in Ukraine, although it backfired themselves. Despite past dangerous incidences, not only the threats for nuclear explosions are continuing but sporadic damages of nuclear power stations are done by Russian forces. This scary warfare is causing tremendous psychological stress, anxieties, fear and concerns among the common people and the Ukrainian government. In the subsequent paragraphs, the impacts of radioactive pollution documented in Chernobyl of Ukraine and sporadically in others parts of the world are highlighted to understand the unseen and envisaged scenario of mental health in the event of nuclear disaster caused by Russian war in Ukrainian territory.

Mental health of people exposed to the radiation is a subject of classical neurobiology. The first and foremost psychological effect generates from the panic created from the information of the nuclear disaster or radioactive fallout. The moment news spreads about land, water, air and food polluted by deadly and invisible radioactive contaminants, there is a panic among the people to protect their life, particularly their children and unborn babies. Chernobyl nuclear disaster of 1986 in Ukraine forced the humans to evacuate from a radiological or nuclear accident area led to social isolation, anxiety, depression, psychosomatic medical problems, reckless behaviour, and suicide. As a consequence of nuclear disaster, not only the psychological danger put people at risk but serious health concerns also worry them. Occurrence of cancer and other deadly illnesses is commonplace. In cases of emergencies, it is observed that many thousands of radiation emergency survivors subsequently undergo to develop PTSD, depression and anxiety disorders (Martin, 2015). The consequences of low-level radiation are far-reaching and often more psychological than radiological. It is because the damage from very low-level radiation cannot be detected; and hence people remain in uncertainty about what would happen to them. Fears continue to penetrate among the human brains that they have been contaminated for life and may have birth defects.

Study by Bromet (2014) on the emotional consequences of nuclear disasters is a classical work to warn all of us. The author found that populations affected by Chernobyl accident show enduring impacts on emotional well-being, manifested in terms of depression, anxiety, PTSD, poor self-rated health, and medically unexplained symptoms (Bromet, 2014). According to her, "overall, the rates of psychological impairment range from 25–75%, depending on the population under study, the timing of the assessments, the perceived or actual magnitude of the exposure, and the degree of direct involvement with the accident". Similar findings were recorded by Bromet *et al*. (2005) indicating that the lifetime prevalence of depression in women in Ukraine was 20.8%, while the lifetime prevalence of depression in women 11 years after

Chernobyl was 46.7%. In 1986, Chernobyl accident resulted in a meltdown and extensive contamination of regions of Ukraine, Belarus, and Russia. Apart from 31 deaths amid emergency clean-up, permanent evacuation of nearly 200,000 residents was followed by a marked increase of thyroid cancer among young children occurred from contaminated milk (Bard, Verger and Hubert, 1997).

Ionizing radiation is identified as a potential risk factor for cognitive dysfunction. The impact on mental health, for example, is the largest public health consequence following the Chernobyl disaster (Bennett, Repacholi and Carr, 2006; IAEA, 2006) with reported increased levels of anxiety and depression among the citizens (Danzer and Danzer, 2016; Ginzburg, 1993; Pastel, 2002). The term *radiophobia* was coined to denote the fear of radiation exposure from the Chernobyl disaster (Pastel, 2002). 'Phobia' is an excessive or unreasonable persistent fear regarding an object or situation (American Psychiatric Association, 2013). Another nuclear disaster, Fukushima, has caused the psycho-societal impact (Kamiya *et al*., 2015) not to a significant level. Despite no deaths directly caused by acute radiation exposure in Fukushima disaster (Steinhauser, Brandl and Johnson, 2014), a new term "*Radiation-anxiety"* was introduced, which pertains to the negative cognition regarding the potential adverse health effects following the radiation exposure (Fukasawa *et al*., 2017). Both the *radiophobia* and *radiation-anxiety* have been observed during the current Russian war in Ukraine.

Wirtz and von Känel (2017) established a clear link between psychological stress and the cardiovascular risk-factors induced by vascular inflammation. Anxiety is believed to cause high blood pressure (Tully, Cosh and Baune, 2013), which is manifestation of stress-induced increased secretion of pro-inflammatory cytokines, such interleukins (IL-6), interferons, and tumour necrosis factors (Hänsel *et al*., 2010). Caused by nuclear pollution incidents, increased psychological stress and systolic blood pressure are recorded in both exposed and 'potentially-exposed' individuals (Collins and de Carvalho, 1993) following the Goiânia (Brazil) accident[22]. The Fukushima nuclear accident was also found increasing systolic blood pressure in both evacuated male residents and non-evacuated male and female residents (Ohira *et al*., 2016). Similarly, among the Three Mile Island[23] residents, a higher systolic blood pressure and an increase in anxiety symptoms were also observed (Davison *et al*., 1991). In terms of neurobiology, the psychological stress affects vascular inflammation, endocrine factors, and subsequently cognitive functioning contributed by potential low/moderate-dose radiation exposure. In fact, the neuro-inflammation (Solleiro-Villavicencio and Rivas-Arancibia, 2018) and vascular inflammation (Baselet *et al*., 2016) are caused by reactive oxygen species (ROS) and reactive nitrogen species (RNS) produced as a result of direct ionised radiation exposure.

Psychological Effects of Fire Caused by War

Russian war in Ukraine has set on fire all types of complexes: industrial, offices, residential, government, civilians, military, agriculture fields, storages, fuel stations, hotels, and so on. From all the fires the Ukrainian people are severely affected: in terms of surviving and escaping from fire, loss of property, fire hazard, and heat

[22] https://en.wikipedia.org/wiki/Goi%C3%A2nia_accident
[23] https://en.wikipedia.org/wiki/Three_Mile_Island_accident

manifestation. Among the Ukrainians, residential fires lead to significant emotional distress apart from possible physical injuries or efforts to save lives. So, the fires do cause emotional distress as well as physical damage. The fires threaten life and property and are unpredictable, uncontrollable, and terrifying (Penney, 2016). The children are affected often by what they see during and after a fire, whether or not they are physically injured. Most important is that the fire causes traumatic events, characterized by emotions of horror, helplessness, serious injury, or the threat of serious injury or death. According to Penney (2016), a traumatic event is perceived and experienced as a threat to one's life safety or stability. It may also involve burns, physical injury or illness, and separation from parents (abandonment), family member, or pet. The fire also leads to hospitalization, anxiety, fear or pain (Penney, 2016). A website[24] has rightly pointed out the common emotional reactions after a residential fire. Such reactions include shock, disbelief, anger, fear, loss, despair and hopelessness. Jones *et al.* (2002) confirmed the consequences of fire that include threat to life or bodily integrity (Green, Grace and Gleser, 1985; Maida *et al*., 1989; McFarlane, Policansky and Irwin, 1987), severe physical harm or injury (Green *et al*., 1983), and sudden loss of a loved one (Green *et al*., 1983; Green *et al*., 1989).

Existing literature explores the psychological effects of different types of fires – house, residential, industrial, fuel stations, property, office complexes, hotels, wildfires, marine surface fires, and others. As is quoted above, the Russian war in Ukraine has caused literally all types of fires with complex psychological effects on the citizens, including the children.

Psychological Effects of Urban Infrastructure Destruction under War

In the war imposed by Russia, large scale destruction and damage of urban infrastructure and properties has occurred. There is massive destruction of properties: office complexes, government buildings, residential buildings, factories, industrial and other buildings. Each of the destructions of urban infrastructure is associated with the psychological distress among the residents and owners of properties. Nakamura *et al.* (2015) estimated that psychological distress prevalence reported was significantly higher (adjusted OR[25] = 1.47 and 1.44, respectively) in the 'more' and 'most' damaged sub-districts than that in the 'least' damaged sub-districts (reference). They further concluded that prevalence of psychological distress in communities with substantial property damage was 1.4–1.5-fold higher than that in community with minimal damage. Chen *et al*. (2001), Kuwabara *et al*. (2008) and Cerdá *et al.* (2013) highlight that property damage is considered a major factor contributing to psychologically unfavourable effects on victims. Başoğlu *et al.* (2004) reported a significant correlation between levels of property damage and post-traumatic stress disorder. Neither study provided sufficient evidence of a possible association between property damage and long-term psychological distress. Başoğlu *et al*. (2004), Kuwabara *et al*. (2008) and Oyama *et al.* (2012) indicated that the mechanism by which property damage increases the risk of psychological distress is complex. They further argue that property damage can lead to several factors or events causing psychological distress, including financial problems, living at a relative's home or

[24] https://www.alldryus.com/fire/common-emotions-after-house-fire/
[25] Odd Ratio

temporary housing, loss of social contact, and injury to self or family members (Başoğlu *et al.*, 2004; Kuwabara *et al*., 2008; Oyama *et al.*, 2012).

There is lot of gap in understanding the psychological perspectives of the war-caused infrastructural damages. In context of Russian war in Ukraine, data on psychological consequences will arrive immensely once the war ends or the ceasefire is in place.

Other Psychological Effects

There are many other environmental damages occurred as a result of war, and, obviously, various studies do exist establishing psychological impacts of water/marine pollution, pesticides pollution, soil pollution, wildlife killing, nature destruction and ecosystem degradation and so on. However, linking the war, there is a vacuum of literature on different environmental damages and degradation. There are plenty of studies undertaken to assess environmental damages from World War II, but not in psychological contexts.

Climate change and warming temperatures will accrue not only in Ukraine but in entire Europe primarily. Human psychology and rising temperatures and erratic rainfalls, and resulting floods and droughts, do have an intimate connection. American Psychological Association (APA) created a Task Force to study the 'Interface between Psychology and Global Climate Change' in 2008 and 2009, and the Task Force produced a report titling, "Psychology and Global Climate Change: Addressing a Multifaceted Phenomenon and Set of Challenges"[26]. Doherty and Clayton (2011) noted the psychological consequences of climate change and described 3 classes of psychological impacts: 1) direct (such as traumatic effects of extreme weather and a changed environment), 2) indirect (such as threats to emotional well-being based on observation of impacts and concern); and 3) psycho-social (e.g., chronic social and community effects of heat, drought, migrations, and climate-related conflicts).

Riad *et al*. (2022) have recently studied anxiety and depressive symptoms among university students in the Czech Republic following the Russian war in Ukrainian. They reviewed the situations of individuals affected by war who suffered high risk of mental health, including post traumatic disorder (PTSD), anxiety, and depression (Morina *et al*., 2018). Under the war imposed by Russians, damage to properties or other valuable assets, death of a close one, displacement of the family, lack of mental preparedness for man-made disaster, lack of social support, and negative coping skills, are the factors contributing to affect the mental health of Ukrainian people (Bryant, Schnurr and Pedlar, 2022). Bogic, Njoku and Priebe (2015) reviewed systematically the mental health issues and found that psychological disorders, such as PTSD, depression, and unspecified anxiety disorders, tended to be highly prevalent among war refugees even after long period of resettlement.

A report by WHO (2022) also indicated the exacerbation of chronic mental health problems and high levels of PTSD, depression, and anxiety among war affected population of all ages in Ukraine. Jawaid, Gomolka and Timmer (2022) wrote an

[26] https://www.apa.org/science/about/publications/climate-change

important letter to Nature stressing upon the trauma accruing from Russian invasion. Their words are worth mentioning in following quote:

> "Ukrainian residents have been facing 'complex trauma' which combines multiple exposures to trauma, often in a sequential fashion. These individuals are constantly exposed to several forms of traima: fear of losing life and/or freedom, grief, separation from families, social isolation, social disruption and forced migration, to name a few. Even when these exposures occur in an isolated form, they have long-term sequelae for human psychological and physical health. These sequelae include an increased risk of post-traumatic stress disorder, depression, and anxiety disorders, as well as physical ailments."

General psychology of Ukrainians has and will have a profound effect as a result of war. How the decline of green forests from Carpathian Mountains will affect the mindset of people is explained by Khrushch (2021). Further, Khrushch and Karpiuk (2021) strongly argued that a person's level of psychological state depends on overall surrounding (e.g., good or evil, improvement or destruction, augmentation or wastage) and environmental situations (see also Khrushch, 2013, p.5). In their article, "Psychological Peculiarities of the Ukrainian People in Context of Globalization and Transformations", Pecheniuk, Pecheniuk and Arjjumend (2022) acknowledged that Ukrainians are adaptable, flexible, hospitable, and sociable, since they are pragmatic, inherently intuitive, hardworking, versatile, and creative. However, their all the productive features are suppressed and crushed under the war and its long-term impacts.

Conclusion

For almost 8 years, Russian Federation waged war against Ukraine after occupation of Crimea in 2014. This war was continuing in eastern parts of Ukraine where environment has been the casualty apart from human beings and animals. Then, from 24 February 2022, Russia invaded Ukraine with full-scale war having massive negative impacts on natural environment and human life. No doubt, the Government of Ukraine, security forces and territorial armies in Ukraine have first priority of saving human lives. The environment is the biggest casualty as a consequence of Russian war imposed on Ukraine. Mass destruction of the industrial and civil infrastructure, chemical and air pollution, radioactive pollution, ammunition and missiles caused fires, forest and agriculture damages, wildlife and biodiversity loss, and contamination of waters and soil will make Ukrainian lands inhabitable during and after the war. Examples of World War II are in front of humanity. Plenty of areas in Europe are unusable and inhabitable after almost hundred years. This massive destruction of environment in Ukrainian territories by Russians will deform the whole Ukrainian society not only in economic and infrastructural terms but also in terms of survival, health, psychology, social fabric, and man-nature relations. Diseases like cancer, tumours, mental sicknesses, depression, anxiety, trauma, fear, irritation, stress, high blood pressure, cardiovascular disorders, post-traumatic stress disorder, have already increased among Ukrainian population. Nearly 18 million people have left their homes and fled to neighbouring European countries where they mostly live as refugees. Over 8 million people are internally displaced. It is not unreal to say this war is the largest human tragedy ever seen by the world both in terms of environmental destruction and human psychological disaster.

Although no systematic and enough data and information do exist as yet (as the war deprives the research and information collection) both on environmental aspects and human psychology, this paper has tried to build the analysis on the basis of scarcely available literature. The reviewed composition under this paper on the environmental consequences and psychological effects of environmental damages will galvanize and catalyse the academic and research community to investigate and document further on this subject. This will also motivate active global citizens to raise voices against the Russian invasion so that the environment, human lives, wild and domestic animals, natural ecosystems can be saved. Last, but not least, entire world must come forward to stop Russian invasion and war against humanity to save entire Europe from the phenomenon of rising temperatures and climate change. Obviously, this war is adding enormously to the warming of not only the Northern Hemisphere but also the globe. The horrors created by madness of Russian war machinery must be stopped to save Ukrainian broken human psychologies, now spilled over across Europe and North America.

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Authors' Declarations and Essential Ethical Compliances

Authors' Contributions (in accordance with ICMJE criteria for authorship)

Contribution	*Author 1*	*Author 2*	*Author 3*	*Author 4*	*Author 5*	*Author 6*	*Author 7*	*Author 8*
Conceived and designed the research or analysis	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Collected the data	Yes	No	Yes	Yes	Yes	Yes	Yes	No
Contributed to data analysis & interpretation	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Wrote the article/paper	Yes	No	Yes	Yes	No	No	No	Yes
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Research involving human bodies or organs or tissues (Helsinki Declaration)
The author(s) solemnly declare(s) that this research has not involved any human subject (body or organs) for experimentation. It was not a clinical research. The contexts of human population/participation were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or ethical obligation of Helsinki Declaration does not apply in cases of this study or written work.

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Mountain Biodiversity in Romania

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Abstract

There exists a strong link between mountain regions and biodiversity. These regions represent the most important source of regional and global ecosystems forming the core elements of environmental and sustainable development policies. Mountains operate as true refuge for endemic species but are affected by uncontrolled human actions, while alpine meadows are exposed to losses of traditional pasture practices. Mountains can be analyzed from the economic, ecological, environmental, social, cultural viewpoints and their multidisciplinary nature is acknowledged both in the academic milieu and by decision makers involved in territorial development policy. The negative impact of economic activities in mountain regions is becoming more visible, therefore, necessitating a sustainable approach to preserve the biodiversity and habitat in order to salvage the fragile ecological balance. The present paper gives an overview of the relationship between biodiversity and sustainability within mountain regions and its implications on the economic and social development process. By interpreting the finding of previous research and studies, the article presents the current knowledge of mountain biodiversity in Europe and Romania and its relationship with sustainable development process.

Keywords

Biodiversity; Mountain region; Sustainable development

Introduction

The mountain areas covering about 22% of the Earth's surface (32 million km^2), sustain directly about 13% of the world's population (915 million inhabitants), of them 70% is the rural population. Mountains provide approximately 60-80% of the water resources

of the Earth[1]. Due to the unique natural exquisiteness, mountains host most of the protected areas. Thus, approximately 25% of the total land surface covered by mountains represent the permanent dwelling place of some rare species of fauna and flora, either relict or in peril (Blyth *et al*., 2002, p. 494) or shaping unique habitats and ecological shelter corridors for forest species (Körner and Ohsawa, 2005).

The mountain regions hold 60% of the biosphere's reserves that contribute by 15-20% to the tourism activities at global level (Romeo *et al.*, 2021). They are covered by 23% by forests. They shape a living supporting life-environment of populations continuously and aggressively subjected to severe economic pressures (unemployment, migration, change of land use models, habitat fragmentations, deforestation, industrialization, mining pressure, pollution and uncontrolled exploitation of natural resources, and environmental degradation, water deficit, etc.) contributing to decreasing intrinsic values. Mountain regions are found in all continents, at all latitudes and within all types of ecosystems (from the arid desert and tropical rainforests to the polar zones).

Mountain regions are relevant and play an important role in the economic, social, environmental development, as well as in the culture and traditions of local communities. They provide ecosystem services, such as water provisioning and cycling to both mountain and lowland communities. They also host a high diversity of habitats and species highly adapted to extreme climatic conditions. Mountain ecosystems are fragile and vulnerable, and are severely threatened by land abandonment or intensified agriculture, infrastructure development and rapid climate change (Korner, 1985). The use and exploitation of natural resources within the mountains affect biodiversity, sometimes, causing inestimable damage to it (Zemp, Hoelzle and Haeberli, 2009), which are as follows:

1. *Impact of the agricultural sector on mountain biodiversity*: There are mutual and complex interactions between agriculture and mountain biodiversity. Agriculture affects biodiversity. The mountain biodiversity is one of the main element of the ecological production in agriculture field. On the one hand, sustains the crops and domestic livestock and the variety within them. On the other hand, components of wild biodiversity in agricultural provide and maintain ecosystem services that are essential to agricultural production. The heterogeneous mountain environment contributes to the evolution of a variety of agricultural cultures adapted to the environmental conditions and human needs. The cultivation of food crops (corn, potatoes, barley, sorghum, tomatoes, apples, etc.) and rearing of domestic animals (sheep, goats, etc.) originated from the mountainous regions. Over time, the genetic diversity of the plants and animals from the mountain region are on the increase due to the cultural diversity and extreme variations of the environmental conditions. Currently, the mountainous biodiversity is threatened by the continuing modernization processes of agricultural production, an aspect that leads to the pauperization of the ecosystem by using few sorts and lacking genetic variation[2]. The expansion of

[1] https://gridarendal-website-live.s3.amazonaws.com/production/documents/:s_document/412/original/SynthesisReport_screen.pdf?1544437610

[2] According to a recent FAO estimate, 78% of the world's mountain area is unsuitable or only marginally suitable for growing crops.

agricultural production on untilled land triggers the destruction of habitats for some species and the deterioration of ecosystems, especially where the lands are not adequately exploited for agriculture. The mountainous agricultural ecosystems may bear invasions of some alien habitats thereby affecting local species and, implicitly, the local biodiversity as they are separated by valleys and mountain peaks (Romanian Parliament, 2003).

2. *Impact of the forestry sector on mountain biodiversity*: Mountain forests deliver ecosystem goods and service to millions of individual in mountain communities and adjacent lowland areas. Globally, 23% of the world's forests are located in mountain regions, covering 9 million square kilometers. Mountain forests and biodiversity provide many benefits, such as erosion control, improved water quality and quantity, carbon fixation, recreation and aesthetic appeal, timber, fuel wood and non-timber forest products (Mountain Partnership, 2020). The vast majority of the mountainous area is made out of the forest ecosystems of low and medium altitude. Under certain conditions, the mountain forests provide basic goods and services to local communities. The forest ecosystems within the mountain areas are threatened by the unsustainable methods of wood exploitation (uncontrolled, abusive wood-cutting, setting-up forest monocultures, etc.). The situation of forests in Europe appears to be relatively promising with respect to their biodiversity in the future. Approximately 10% of the forest area in Europe is in conservation areas. Nevertheless, an increase in area of conservation appears not to be the only remedy to protect forest biodiversity. While some authors concluded that conserved forests have higher biological diversity than managed plantations, others have found that some taxa or species profit from human-managed forests (Horák *et al*., 2019).

3. *Impact of the tourism sector on mountain biodiversity*: During the past some years, tourist activities in the mountain region had important dynamics (winter sports, outdoor activities, etc.), a fact which led to extending the tourism infrastructure and tourism services. This affected rapidly the fragile ecosystems and the mountain biodiversity in an uncontrollable manner. For instance, the remodeling of mountain slopes for skiing and other winter sports has a strong impact on the integrity of the mountain ecosystems. The building of tourist infrastructure has resulted in the urbanization of some mountain areas with (total or partial) biodiversity loss.

4. *Impact of mining on mountain biodiversity*: Exploitation of ore, metal and other resources has a negative impact within mountain regions leading to severe water pollution and disturbance of the downstream areas. Moreover, the cutting of trees/plants and digging of the soil in areas where mining is practiced result into the destruction of landscapes, habitats, soil and agricultural lands. At the same time, rains wash away the land of open strip mining and the sediments pollute groundwater, poisoned fish, disfigure the rivers and rivulets, and generate flooding and landslides.

5. *Impact of the hydropower plants on mountain biodiversity*: The mountains and mountain lakes are frequently used in building power plants for generating electricity. Even if they represent an important source of renewable (green) energy, their design has negative impact on rivers and ecosystems in the vicinity. The creation of artificial lakes and the alteration of watersheds also affect negatively the habitats, ecosystems and valleys in the immediate proximity (Romanian Parliament, 2003).

6. *Impact of climate change on biodiversity*: Another process that has an important impact on mountain biodiversity is climate change. Mountain environments are very sensitive to climate change (Beniston, 2003). They appear among the most severely and rapidly impacted ecosystems, and can be affected by any change in temperature and precipitation patterns at all scales (Zemp, Hoelzle and Haeberli, 2009). Thus, global warming affects negatively mountain ecosystems by the retraction and sometimes extinction of some life forms from the alpine area. Endemic mountainous species pulled back at high elevations and some destroyed due to habitat loss. Changes in the precipitation periods and increase in temperatures have triggered the melting of glaciers and decline of snow-covered mountain areas, thus, reducing the capacity of rejuvenating waters. By a process of non-compliant water management process in the mountain areas, both low altitude and vicinity areas were subjected to water scarcities.

Moreover, air pollution influences negatively the mountain biodiversity. In the mountain areas, the high rates of precipitation results to the depositing polluters from the atmosphere in soils and/or its accumulation in the snow layers affecting ecosystems and vulnerable species. Acid rain triggers the destruction of trees, although it involves intensive research and careful monitoring activities of polluters and main sources (Rey and Gruia, 2016).

This paper addresses a number of problems relating to mountain biodiversity in Romania. Following an introduction outlining the overarching issues, a short summary is given on important factors that affected the biodiversity of mountain regions. The biodiversity of mountain is subjected to a phenomena correlated directly to the activities of the local communities (and not only): abandoning the area, tourism and winter sports development, infrastructure development, urbanization, soil compaction, etc.

Biodiversity of the Mountain European Area

In Europe, the mountain area covers 40% of the total surface area hosting 20% of the population[3]. On European continent, seven of the longest and highest mountain chains of the globe do exist, namely: the Alps (localized in the Central Europe), the Apennines (Italy), the Pyrenees (on the border between Spain and France), the Scandinavian Mountains (Sweden, Finland and Norway), the Carpathians (covering 7 countries with the shape of an ark from Slovakia to Romania), the Balkan Mountains (Croatia, Bosnia & Herzegovina, Serbia, Albania, Macedonia) and the Rhodope Mountains (Bulgaria). The main mountain regions from Europe and its countries are presented in table 1.

The extremely complex topography (south-oriented sheltered slopes, snow pockets, wind-blasted crags and rugged land covered by debris) explain the particularly rich biodiversity of the alpine areas (two-thirds of the plants are found in the mountain area) (Korner, 1985, p.93) (Table 2).

[3] http://www.turismulresponsabil.ro/wp-content/uploads/2017/01/2.-Danut-Ungureanu-Zona-montana.pdf

Table 1: Mountain areas and the countries involved

Countries involved	*% of the EU territory*	*Regions*
Belgium, Germany, Denmark, Spain, France, Ireland, Portugal, the Netherlands, the United Kingdom	18.4	Atlantic
Estonia, Finland, Latvia, Lithuania, Sweden	18.8	Boreal
Austria, Belgium, Bulgaria, Czech Republic, Germany, Denmark, France, Italy, Luxemburg, Poland, Romania, Sweden, Slovenia	29.3	Continental
Austria, Bulgaria, Germany, Spain, Finland, France, Italy, Poland, Romania, Sweden, Slovenia, Slovakia	8.6	Alpine
Czech Republic, Hungary, Romania, Slovakia	3.0	Pannonian
Romania	0.9	Steppic
Bulgaria, Romania	0.3	Black Sea
Cyprus, Spain, France, Greece, Italy, Malta, Portugal	20.6	Mediterranean
Spain, Portugal	0.2	Macronesian

Source: European Union[4]

Table 2: Mountain chains in the alpine biogeographic region of Europe

Mountains	*Characteristics of the mountain biodiversity*	*Socio-economic characteristics*
The Pyrenees (430 km^2)	There are 60 types of habitats are present in these mountains (Habitat Directive[5]). The mountains are characterized by numerous torrents, cascades and lakes. At elevations over 1,000 m, there are over 1,500 lakes. The diversity of the flora is exceptionally high: 3,000 species of plants, from among which at least 120 are endemic. There is vast diversity of birds and animals (over 40 species of mammals, including rare endemic species). One of the extinct species is the Pyrenees Ibex[6].	The mountains are relatively low populated, the agricultural sector and sheep breeding being the main activities. In the past, the Pyrenees underwent an intensive deforestation process (and with visible traces mainly on the mountainsides). The beech was intensively used as firewood and in feeding the furnaces for ore extraction. Tourism is another economic activity of high intensity next to winter sports.

[4] http://ec.europa.eu/environment/nature/info/pubs/docs/biogeos/Steppic%20Region/KH7809607ROC_002.pdf
[5] The Habitats Directive ensures the conservation of a wide range of rare, threatened or endemic animal and plant species. Some 200 rare and characteristic habitat types are also targeted for conservation in their own right.
[6] In January 2000, the Pyrenean Ibex was completely extinct. Nevertheless, scientists have attempted to clone this species by using DNA from one of the last females; such a clone died seven minutes after birth. Other sub-species survived: the Spanish western Ibex, or the Ibex Gredos, and the Ibex from the south-eastern part of Spain, while the Portuguese Ibex is extinct. The last Ibex from the Pyrenees disappeared

Mountains	*Characteristics of the mountain biodiversity*	*Socio-economic characteristics*
The Alps (1200 km.)	The forests are in relatively natural state as at high elevations they are true refuge and ecological corridor for many large species (bears, birds of prey). The grasslands and alpine meadows make up 25% of the mountain vegetation (the majority semi-natural, affected over time by moderate agricultural practices) and many of them are threatened by farmstead abandon. 84 types of habitats are listed, from among which 47 species of plants. The Alps have over 40% of the European flora but also 200 species of birds (which lay their eggs here) and other 200 migrant birds. The Alps represent one of the most biodiversity richest mountain chains from European, but also one which is heavily exploited.	In the Alps live over 11 million inhabitants mainly in the urbanized valleys. To them are added 100 million tourists visiting the Alps with tourist or recreational purposes. These phenomena exert an important pressure on the mountainous environment which has a particular fragility.
The Apennines (1350 km)	In the Apennines on the Italian side, during the last Ice Age the ice sheets advanced and after their meltdown the populations began their separate evolution. One of the species running the risk of extinction is the Abruzzo chamois (*Rupicapra pyrenaica* ornate) the reason being excessive hunting (450 individuals that are vulnerable to diseases and consanguinity).	The inhabitants are in small numbers and on a decreasing trend. Consequently, the traditional agricultural systems of cattle breeding are vanishing; however, efforts are made for repopulating the area due to the fact that these mountains are included in a network of interconnected national parks.
The Scandes (1400 km.)	The diversity of the species in the area of the Scandes is relatively low. Nevertheless, they represent an essential component of the European biodiversity due to their considerable size and the unaltered character. They are counted among the few locations in Europe where we might	The low presence of humans in the Scandes is not surprising. Some of the activities, such as river damming for generating hydroelectric power, reindeer herding, or the disappearance of summer grazing had negative impact at local level. However, the majority of the mountainous

before scientists could analyse the species accordingly, the taxonomy of this sub-species being controversial.

Mountains	*Characteristics of the mountain biodiversity*	*Socio-economic characteristics*
	discover authentic wilderness. 44 types of habitats are represented, 29 species of plants and 18 species of animals (Habitats Directive).	lands remain unperturbed by human presence, and therefore this remains one of the largest intact natural areas in Europe.
The Carpathians (1450 km.)	The habitats have a long tradition regarding the exploitation of lands but also sheep and cattle breeding. The Carpathians host many species, with a high level of biodiversity: over 3500 species of plants from among which 481 endemic species. Here we find large carnivores, a varied selection of small mammals, many endemic species from among which the Tatra pine vole and the Carpathian marmot. Over 300 species of birds (the Ural owl, the white-backed woodpecker, the black stork, etc.).	In the Carpathians live about 18 million individuals, who are exerting pressure on maintaining and preserving the biodiversity
The Balkans[7] (550 km.)	These mountains display a typical alpine character and have a strong Mediterranean influence regarding the make-up of the species. Over 60 types of habitat (Habitats Directive) with a considerable forests' component, with many endemic species of trees (the Balkan pine, King Boris fir, and the black (Bosnian) pine. The area contains a huge variety of plant species and numerous large carnivore populations, and species of birds of prey (in Rhodope is found the largest agglomeration of day birds of prey from Europe).	The population density is extremely low. The mountains are in remote areas and still unexplored.

Source: European Commission (2010)[8]

Most of the important-for-community habitats are found in the continental area (7,475), followed by the Mediterranean (2,928) and the Atlantic (2,747) ones. Regarding the special protection areas (SPAs), most of them are designated in the Continental region (1,478) followed by the Boreal (1,165). Nevertheless, the widest surfaces covered by important-for-community habitats are found in the Black Sea

[7] They are constituted from three distinct mountain formations: the Rila Mountains, the Pirin Mountains and the Rhodope Mountains.
[8] https://op.europa.eu/ro/publication-detail/-/publication/9a738f76-c937-478d-b720-1562a53385e4/

region (71.8%) and those of special protection in the Pannonian region (31.3%), according to Habitat Directive[9].

In the mountain areas of Europe, the extensive agricultural practices, the transhumance, forestry, etc. have contributed to creating an important diversity of landscapes and cultures (Huddlestone, Ataman and Fed'Ostiani, 2003). Nowadays, this biodiversity is subjected to a phenomena correlated directly to the activities of the local communities (and not only): abandoning the area, tourism and winter sports development, infrastructure development, urbanization, soil compaction, etc. The development of mountain tourism expanded practically over the entire continent, in parallel with the intensification of traffic and the building of the transport infrastructure (which turns into an important barrier for species migration[10]).

Damming the main rivers in the mountains for the hydropower sector or for irrigation has modified considerably the natural mountain environment. These activities influenced the biodiversity of the mountain areas, a fact mentioned in various reports and analyses at EU level. As might be seen, most mountain areas from Europe are in an unfavorable preservation state (60.68%) from among which 32.57% are in a very bad situation, a fact which should impose the implementation of swift and drastic measures required for rebuilding the state of the affected habitats (EEA Report No. 6/201[11]) (Table 3).

Table 3: Numbers of habitat types in each massif classified by conservation status (no.)

Massif	*Favorable*	*Unfavorable (inadequate)*	*Unfavorable (bad)*	*Unknown*	*Total*
Apennines	47	26	3	8	84
Balkans/South-east Europe	32	27	23	1	83
Atlantic islands	11	12	7	1	31
Nordic mountains	22	13	27	2	64
Central European middle mountains (Belgium and Germany)	16	18	12	2	48
Eastern Mediterranean islands	13	18	6	8	45
Carpathians	10	21	18	2	51
Alps	14	37	35	7	93
French/Swiss middle mountains	11	22	37	7	77

[9] The Habitats Directive ensures the conservation of a wide range of rare, threatened or endemic animal and plant species. Some 200 rare and characteristic habitat types are also targeted for conservation in their own right.

[10] Yearly, about 150 million individuals travel in the Alps, from among which 83% travel on paved roads https://www.eea.europa.eu/themes/regions/the-alpine-region/transport-climate-change-tourism/transport-climate-change-tourism/topics)

[11]http://ec.europa.eu/environment/nature/info/pubs/docs/biogeos/Alpine/KH7809637ROC_002.pdf; http://ec.europa.eu/environment/nature/info/pubs/docs/biogeos/Steppic%20Region/KH7809607ROC_002.pdf

Massif	*Favorable*	*Unfavorable (inadequate)*	*Unfavorable (bad)*	*Unknown*	*Total*
Western Mediterranean islands	7	17	14	15	53
Central European middle mountains (Czech Republic, Austria, Germany)	4	15	32		51
Pyrenees	3	19	30	36	88
British Isles	1	7	52	4	64
Iberian mountains		6	3	77	86
Total mountains (no.)	191	258	299	170	918
Total mountains (%)	20,81	28,10	32,57	18,52	100

Source: European Environment Agency (2010)[12]

The negative effects of climate changes led in time to promote some actions that would counteract them and contribute to reinstating the natural balance. The effects of climate change phenomenon in European mountains (Kohler and Maselli, 2009) are illustrated as follows. Climate change is a reality in present. Some of the best evidence, such as melting glaciers, comes from mountain areas. Many scientists believe that the changes occurring in mountain ecosystems may provide an early glimpse of what could come to pass in lowland environments, and that mountains, thus, act as early warning systems. Because the mountains exist in many regions of the world and they occupy very different positions on the globe and differ in shape, extension, altitude, vegetation cover, and climate regime, they will, therefore, be affected differently by climate change. However, they share following some common features relating to climate change: mountain areas have a marked and complex topography and their climates vary considerably over short distances, temperature changes with altitude and melting of glaciers, the permafrost will trigger the release of loose rock and soil and exacerbate the danger of rockfall, debris and mud flows have a major role in influencing regional and global climates (IPCC, 2007).

Internationally, some legislation has changed the course. Since 1970 various international cooperation agreements regarding the mountain regions of Alps and Carpathians came into existence. In 1975, the European Commission under the *Directive on mountain and hill farming and farming in less-favored areas no. 75/268*[13] acknowledged the necessity of supporting agriculture from mountain areas. In 1978, at the Conference of the EU Council of Ministers responsible with regional planning (CEMAT), launched was the official paper *"Pressures and regional planning problems in mountain regions"*[14], which was the point of reference for all future development and regional planning strategies. After 2000, the mountain areas became important component of the regional development policy of the European Union. This

[12] https://www.eea.europa.eu/publications/europes-ecological-backbone
[13] https://www.sciencedirect.com/science/article/pii/0264837786900621
[14] http://www.bbsr.bund.de/BBSR/EN/Publications/IzR/2003/7DejeantPons.pdf?__blob=publicationFile&v=3

attention consisted of determining some areas where human actions of economic nature cannot take place; such areas were designed as protected areas. Many of the mountain areas were declared as pprotected areas under the influence of international programmes (Huddlestone, Ataman and Fed'Ostiani, 2003). At EU level, these protected areas represent up to 33%[15]. For instance, *Natura 2000*[16] is the European Network of Natural Protected Areas comprising a representative sample of wild species and natural habitats of community interest. It was constituted not only with the purpose of protecting nature, but also for preserving the natural riches on long-term basis and for ensuring the resources required for the socio-economic development[17]. The proportion of protected areas included in Natura 2000 differs from one country to another: Cyprus - 95%, Slovenia - 83%, Greece 82%, Italy - 81%, Slovakia - 79%, Austria - 78%, Spain - 73%, Czech Republic - 71%, Romania - 65%. In total, in the alpine region, there are 1,496 habitats of community importance (Habitats Directive[18]) and 365 areas of special protection (Directive Birds)[19]. These areas with special protection status cover about 40% of the total surface area of the alpine region.

Biodiversity of Mountain Areas in Romania

The status of protected area presupposes a mix of actions regarding the strengthening of conservation, restoration and sustainable valorization of biodiversity and landscape based on efficient management underlying harmonization of the natural capital with its habitats and species, by preserving and promoting natural values (Antonescu, 2017: 71).

The Earth Summit 1992 adopted the Convention for Biologic Diversity (CBD) and Romania ratified the Convention in the year 1994. As compliance, the Government of Romania promulgated the Law No. 58/1994 addressing the biologic diversity by which the following major objectives were set: conservation of biologic diversity, sustainable use of biodiversity's resources, and equitable distribution of benefits resulting from the use of genetic resources. The establishment of some protected natural areas under law was initiated with the purpose of obtaining a more efficient control over maintaining and protecting biodiversity (Popa, 2016). In Romania, the main categories of Protected Areas are established by Law No. 5/2000[20] encompassing the National Plan for Territorial Arrangement (PATN) in Section III (Protected Areas). In accordance with the law, Romania has 845 protected areas classified in IUCN Category-V (Table 4).

[15] Only 5 % from the areas with high natural value are not included also in the category of less-favoured areas.
[16] Natura 2000, the widest world network of natural protected areas. In order to fight against the loss of natural areas, Europe drafted two important laws: the Directive Birds (1979) and Habitats (1992). These laws are the founding milestones for the environmental protection policy and led to setting up Natura 2000 the largest network of protected natural areas in the world covering - 1 million square kilometres of land, (over 18% from the EU land surface) - 250.000 square kilometres of marine habitats (almost 4% of the EU marine habitats), respectively 27.000 habitats and 1.000 species are under special protection.
[17] https://natura2000.ro/ce-este-reteaua-natura-2000/
[18] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:31992L0043
[19]European Topic Centre for Biodiversity (European Environment Agency): http://biodiversity.eionet.europa.euOctober2008.
[20] Law no. 5/2000, Section III, Protected Area [Law no. 5/2000, section III, protected areas] [In Romanian].

Table 4: Romania's Protected Area System

Type	*IUCN Category/ International Designation*	*Number of Protected areas*	*Total area*
Scientific Reserve	I	53	101,288 ha
National Park	II	11	300,819 ha
Natural Monument	III	231	2,177 ha
Natural Reserve	IV	542	117,265 ha
Natural Park	V	6	326,305 ha
Biosphere Reserve Danube Delta	Biosphere Reserve	Retezat (II) Rodnei (II)	576,216 ha. 38,138 ha 47,227 ha
Wetlands of International Importance	Ramsar Site	Danube Delta Small Island of Braila	576,216 ha 20,455 ha
Natural Sites for Universal Natural Heritage	Word Heritage Site	Danube Delta[21]	732,220 ha
Special Areas for Conservation	SAC	None	
Areas for Special Protection of Bird	SPA	None	

Source: Lee and Middleton (2003)

After Romania's accession to EU, the Emergency Ordinance No. 57 of June 20, 2007 was promulgated to regulate the regime of protected natural areas and the conservation of natural habitats (updated in 2016). It determined the areas of major conservation interest, and also included in the National Strategy for Sustainable Development 2013-2030[22]. In order to protect biodiversity of the mountain areas, Romania ratified the Framework Convention on the Protection and Sustainable Development of the Carpathians (Carpathian Convention[23]) in 2006 (Law No. 389/2006). The law stipulates that the Carpathian Mountains represent a unique natural wealth of impressive beauty and ecological value, an important reservoir of biodiversity, the area from which main rivers flow, an essential habitat and refuge for numerous endangered species of plants and animals, and the widest area covered by virgin woods in Europe (Gruia and Gaceu, 2021).

Romanian forests in the mountains area represent 65.25%, followed by forest hills with 26.67% of total (MAP, 2018). In terms of age-class distribution, 71% are maximum 80 years of age and 15% are older than 100 years, most of them are managed using different sylvicultural systems that are typical to high forests with long rotation ages (over 100-120 years) (Nicolescu, 2022). The changes in the ownership structure after 1990 brought important challenges to the management of the forests. Due to forest land restitution, Romanian forestry moved from a heavily centralized sector to a multilayer type of governance, with more actors playing different and even

[21] https://en.unesco.org/biosphere/eu-na/danube-delta
[22] https://faolex.fao.org/docs/pdf/rom195029.pdf
[23]http://www.carpathianconvention.org/tl_files/carpathiancon/Downloads/01%20The%20Convention/1.1.1.1_CarpathianConvention.pdf

conflicting roles (Dragoi and Toza, 2019). The bioeconomy strategy must be considered as a vector to support new governance models needed to ensure the financial viability of forest management (Nichiforel, 2022).

In the National Strategy[24], it is shown that Romania displays a relative variety and proportionality of landscapes: 29.94% mountain massifs (elevations over 1,000 meters), 42% hills and plateaus (elevations between 300 and 1,000 meters) and 30% flatlands/plains (elevation under 300 m) (Antonescu, 2017). The total surface of the mountain area is 71,381.48 square kilometers (29.94% of total surface). The special biodiversity of the mountain area from Romania determined the inclusion of a share of 57% from its surface in the ecologic network Natura 2000. In the mountain area are found 197 Natura 2000 sites (habitats): respectively, 37% from national sites and 67% from the protected area. Romania's lands fall 54% under the Carpathian Mountain chains, mountains of mid-elevation (with an average of 1,136 meters) with only few peaks over 2,500 m[25].

In Romania the mountains represent the least disturbed parts having a low density of the inhabitant population residing in small localities, which are almost depopulated as a result of internal and external migration (Avădănei and Avădănei, 2016). This situation exists in the mountain area of 12 out of the 13 national parks[26] and of 10 out of the 14 natural parks[27]: the forests from the mountain areas display increased biodiversity as there are 150 types of forest ecosystems differentiated depending on the species, the type and quantity of humus in the soil, the water and ionic stress of the soil, etc. Thus, forests shape important wood sources and other non-wood produces (berries, mushrooms, game, etc.). In Romania, surface covered by forests in the mountain area is 4.4 million hectares, from which about 40% ((World Bank, 2014) are private property, the rest being the public ownership of the State or under the territorial administrative units (National Institute of Statistics). In the mountain area of Romania, there are 948 local administrative units (30% of the country's surface), most of them in the counties of Harghita (9.38%), Hunedoara (6.92%), Maramures (6.77%), Alba (6.15%), Suceava (5.85%), Covasna (5.38%), and Brasov (5.1%). In the mountains, there are about 4.892 inhabitants (21.97 % of the total population) (World Bank, 2014).

[24] National Strategic Guidelines for the Sustainable Development of the Carpathians 2014 – 2020, http://ier.gov.ro/wp-content/uploads/2018/12/Daniela-Giurca-Cracovia-2015.pdf
[25] https://biodiversity.europa.eu/countries/romania/green-infrastructure
[26] 12 National Parks: four in the Oriental Carpathians (NP Rodnei Mountains, NP Călimani Mountains, NP in the Ceahlău Massif, NP Cheile Bicazului – Lacul Roşu (Red Lake) –Hăşmaş Mountains), six in the Mid-Carpathians (NP Piatra Craiului, NP in the Coziei Mountains, NP Buila – Vânturariţa, NP in the Jiului Gorge, NP Retezat, NP Domogled – Valea Cernei) and two in the Occidental Carpathians (NP Cheile Nerei – Beuşniţa, NP Semenic Mountains – Cheile Caraşului).
[27] 10 Natural Parks: four in the Oriental Carpathians (NP Maramureşului Mountains, NP Mureşului Superior Gorge, NP Vânători Neamţ which breaks through also in the Neamtului Sub-Carpathians, NP Putna-Vrancea), four in the Mid-Carpathians (NP Bucegi, NP Grădiştea Muncelului-Cioclovina, Geoparcul Dinozaurilor (Dinosaurs' Geo-park) – Haţegului Country, Geo-park Mehedinţi Plateau which overlapps partially also with the areal of the Mehedinti Mountains) and two in the Occidental Carpathians (NP Apuseni Mountains, NP Cazanele Dunării-Porţile de Fier (Danube Cauldrons – Iron Gates). In the period 2007-2016 a series of changes were recorded regarding the surface of the protected mountain areas (increases or diminishments of the included surfaces).

Measures & Actions Supporting the Biodiversity in Mountain Areas of Romania

According to the *Strategy of the Romanian Academy for the next 20 years* (Zaman *et al.*, 2015), the general objective of evolution and development of the protected areas is represented by the protection, valorisation and recovery of the biodiversity, including ecosystem services that it provides (natural capital), by taking into account the intrinsic value it represents and the essential contribution to economic and social development (Zaman *et al.*, 2015). Thus, the general action framework aims at biodiversity conservation practices and at economic and social activities that would provide to local communities with the possibility of achieving their own requirement.

Romania ranks on the first position in Europe from the viewpoint of biodiversity and owns the last 100% natural ecosystems of the continent. Even though the national legislation translating the Natura 2000[28] in Romania does not provide for complete protection, and the implementation issues are identified frequently, a first measure would be the one of continuing with the implementation of these directives and compliance with the statutes of Protected Area in the mountain areas where these are set up.

Due to the important impact of the agricultural sector on the biodiversity from the mountain areas, a first action that might be supported financially is accessing the funds allocated for the mountain biodiversity by the Common Agricultural Policy[29] (CAP). Regarding the mountain area, after 2007, began the implementation of the following measures of CAP: Measure 211 – the less-favoured mountain area; Measure 212 – less favoured areas (others than the mountain area) and Measure 214 – agro-environment. The measures are financed by CAP and support the users of agricultural lands in areas characterised by unfavourable natural conditions, including here the compensation of income losses, and additional expenditures resulting from practicing extensive and ecologic agriculture (by protecting biodiversity, water protection, soil protection, diminishing polluting emissions and adjusting to the effects of climate changes).

In the current programming period, there are supported measures for promoting efficient use of resources and smart/sustainable growth favourable to inclusion in agriculture and in the rural areas, in accordance with the Strategy Europe 2020[30]. The measures package for the current programming period addresses both the objectives of agro-environment and climate (Measure 10), to ecologic agriculture (Measure 11), and to areas faced with natural constraints (Measure 13). Farmers will benefit from funds of about 2.66 billion Euro (Measure 10 – 1.071 billion Euro, Measure 11 – 236.42 million Euro, Measure 13 – 1.355 billion Euro)[31]. These actions might contribute to maintaining the mountain biodiversity, which might be financed from community funds: keeping the youths in these areas, in parallel with encouraging increased birth-rates, professional training and adjusting vocational school curricula in accordance with the demand on the labour market, supporting businesses start-up by youths,

[28] https://ec.europa.eu/environment/nature/natura2000/index_en.htm
[29] https://www.sciencedirect.com/topics/earth-and-planetary-sciences/common-agricultural-policy
[30] https://en.wikipedia.org/wiki/Europe_2020
[31] https://ec.europa.eu/eu2020/pdf/COMPLET%20EN%20BARROSO%20%20%20007%20-%20Europe%202020%20-%20EN%20version.pdf

promoting education-learning centres in the mountain areas for setting up didactic farms (these would provide learning material for the students and would contribute to the integrated valorisation of resources, from the perspective of the concepts of pluri-activity and sustainable development).

For the mountain areas faced with natural or specific constraints have been determined by the National Rural Development Programme 2014-2020, a series of compensation payments that are granted to users of agricultural lands placed in areas defined as eligible after concluding some yearly/multi-annual voluntary commitments. The compensation is aimed at:

- additional costs and income losses resulting from the enforcement of some extensive management measures on agricultural lands targeted on achieving some environmental objectives (biodiversity conservation, water and soil protection);
- additional costs and income losses resulting from the enforcement of practices specific to ecologic agriculture; and
- additional costs and income losses born by farmers because of natural and specific constraints which are present in areas with influence on agricultural production.

Recommendations for the Biodiversity of Mountain Areas

In the context of sustainable development, the following actions aimed at supporting the mountainous areas in Romania can be considered (Popescu *et al*., 2022):

1. the local mountain population should to be involved in the specific activities, which preserve local economy, cultural identity and heritage, maintain biodiversity;
2. the improvement of infrastructure (all types of communications, dwellings, water supply, sewerage collection and use, waste management, electricity, gas, internet access, broadband network, work digitalization, education, medical and sanitary points, agriculture, water drainage systems, investments in isolated chalets etc.);
3. sustain the specific economic activities that have to stimulate young people and firms;
4. to provide some facilities for farmers;
5. to stimulate the creation of associative forms (associations and cooperatives) in order to assure the needed inputs, to increase production, and better promote the mountain products;
6. special measures to encourage the young farmers who grow more than 5 LU (livestock units); and
7. to sustain the tourism to improve their offer (to enlarge the accommodation capacity, facilities, service quality etc.).

The issue of biodiversity loss and the one about ensuring the sustainable development of local communities in areas declared as protected areas is very complex, both from the theoretic and practical viewpoints. At theoretical level, significant debates take place about the methods and techniques for evaluating and interpreting the existing issues of the area. From the practical viewpoint, not enough data and statistic information are supplied in order to support certain specific measures and actions of

political, economic and social nature. The acknowledged complexity of these issues and aspects regarding protected areas imposes currently a multi- and trans-disciplinary approach. At the same time, practitioners in the field of development resort frequently to holistic-type approaches. Their requirements are supported by the modern social sciences that consider that, over time, the localisation of economic activities and the environment are relevant categories for analyses and research (Turner *et al*., 1993).

The interdisciplinary approach appears as necessary when environmental changes are evaluated, while the living conditions for humans are aimed in particular, along with the ones regarding the economic situation. The combination of knowledge from several fields brings its contribution to identifying the best measures leading to improving the living standard for the inhabitants of the mountain areas, being at the same time a challenge for all those involved. Any model should focus the attention on an objective of the study. The definition of the concept bears, in its turn, a multidimensional approach: well-delineated geographic areas, with specific characteristics (economic, social, infrastructural, etc.) of high biodiversity and particular issues for which specific actions/policies are required with the purpose of attaining a certain living standard. From the viewpoint of mountain research, the analysis of the pressure on the environment might be realised by a general and comparative analysis of the mountain regions based on demand, and by disaggregation at household level of some indicators specific to the mountain area.

The global models of analysis for the households' welfare in the mountain area resort, as a rule, to indicators regarding quality of life assuming the idea that development is based on universal values and not on localised experiences and different value systems. These indicators might reflect the basic elements of the subsistence means and the quality of institutions involved in promoting change. Because human activities (economic, social, cultural, etc.) cannot be omitted in this equation, we consider that the basic principle of any model should be: a conservation framework for development in which the conservation practices for the mountain biodiversity maintain both services of economic and social nature and the ones of protection for ecosystems and biodiversity.

Conclusions

In Romania, the mountain areas should play a strategic role in the economic and social development constituting a conducive environment, over time for maintaining the continuity and durability of the Romanian people. It is imperative that the development vision in the field of protected areas. The mountain areas offer a protection, valorization and recovery to the mountains' biodiversity, including ecosystem services they provide (natural capital). Thus, development should meet the protection requirements of the mountain environment because, in a contrary situation, biodiversity might undergo negative, sometimes irreversible, changes caused by the loss of habitats being caused by conversion of agricultural lands to urban areas, by the emergence of some invasive alien species, and by the overexploitation of natural resources. Over exploitation of services/products provided by biodiversity leads to influencing the natural balance with negative impact on human welfare and on the entire process of economic growth.

These mountain areas with high biodiversity should benefit from specific, multidimensional policy that would take into account the principles of sustainable development and would contribute to diminishing ecological and economic imbalances. The mountain policy might be considered as a true link that would ensure the good inter-community and interregional cooperation, as well as partnerships at national and international level.

To combat the negative factors having a direct or indirect influence on the biodiversity of mountain areas, a series of measures and actions are needed. Some important factors increase resilience to the major threats to mountain ecosystems. In addition to designating protected areas, measures to improve connectivity and ecosystem-based management are keys for conserving mountain ecosystems, particularly helping them to adapt to climate change. Another action is needed to minimize the risk of local extinction of several species and to counteract the effects of habitat fragmentation and changes in land use. At the same time, national cooperation across European mountain regions can support improved integrated management practices.

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Research involving human bodies or organs or tissues (Helsinki Declaration)
The author(s) solemnly declare(s) that this research has not involved any human subject (body or organs) for experimentation. It was not a clinical research. The contexts of human population/participation were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or ethical obligation of Helsinki Declaration does not apply in cases of this study or written work.

Research involving animals (ARRIVE Checklist)
The author(s) solemnly declare(s) that this research has not involved any animal subject (body or organs) for experimentation. The research was not based on laboratory experiment involving any kind animal. The contexts of animals were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or ethical obligation of ARRIVE does not apply in cases of this study or written work.

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The author(s) solemnly declare(s) that this research has not involved any Indigenous Peoples as participants or respondents. The contexts of Indigenous Peoples or Indigenous Knowledge were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or prior informed consent (PIC) of the respondents or Self-Declaration in this regard does not apply in cases of this study or written work.

Research involving Plants
The author(s) solemnly declare(s) that this research has not involved the plants for experiment or field studies. The contexts of plants were only indirectly covered through literature review. Thus, during this research the author(s) obeyed the principles of the Convention on Biological Diversity and the Convention on the Trade in Endangered Species of Wild Fauna and Flora.

Research Involving Local Community Participants (Non-Indigenous) or Children
The author(s) solemnly declare(s) that this research has not directly involved any local community participants or respondents belonging to non-Indigenous peoples. Neither this study involved any child in any form directly. The contexts of different humans,

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Mountain Identity and Development Aspirations

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Abstract

This article refers to management issues of mountainous areas, with emphasis on the built environment, highlighting "identity" as a key element for development perspectives and aspirations. Mountain areas are addressed as a system, the identity of which has to be recognized, in terms of protection, promotion, and integrated development. The concept of identity is explored through its reference to the elements that constitute mountain settlements, as well as the conditions of its recognition, protection, and promotion. Further, through the idea of the deliberate "construction" of place-identity and its correlation to the development process, mountain settlements are discussed. References are be made to key concepts related to the issues, such as tradition, tangible and intangible, and the cultural and economic importance of its preservation, considering culture as a key pillar for integrated development. In this context, key issues concerning development aspirations include the component elements of the cultural character and identity of mountainous settlements, its problems, the changes, and the dangers that may threaten them, the relationship between its integrated protection and sustainable development, as well as the problems and strategies of creating and implementing a management plan that ensures its preservation, protection, and invigoration. The article is founded on the research that took place within the framework of the postgraduate program, "Environment and Development of Mountains Regions", annually held at the Metsovion Interdisciplinary Research Center (MIRC) in the Hellenic Mountain Area of Metsovo, Greece.

Keywords

Place identity; Tradition; Mountain settlements; Preservation; Protection; Integrated development

Introduction

This article refers to management issues concerning mountainous areas, with emphasis on the built environment, highlighting

"identity" as a key element for development perspectives and aspirations. Mountain areas are addressed as a system, the identity of which we ought to recognize, in terms of protection, promotion, and integrated development. The concept of identity will be explored through the reference to the elements that constitute mountain settlements, as well as the conditions of its recognition, protection, and promotion. Also, the subject will be understood through the idea of the deliberate "construction" of identity and its relation to development process. Moreover, reference needs be made to key concepts related to the issues, such as the concept of tradition, tangible and intangible, and the cultural and economic importance of its preservation, considering culture as a key pillar of integrated development. In this context, key issues concerning development aspirations include the component elements of the cultural character and identity of mountainous settlements, the problems of mountain settlements, the changes, and the dangers that threaten them, the relationship between integrated protection and sustainable development, problems and strategies of creating and implementing a management plan ensuring the preservation, protection, and development.

The above tenets are founded on an academic course concerning "Identity and development prospects of mountain areas", a course organized within the framework of the postgraduate program, "Environment and Development of Mountains Regions", organized at the School of Architecture, National Technical University of Athens. The program is the only one that focuses on the study of the mountainous regions of Greece, which nevertheless cover almost 70% of the country's total area. The aim of the course is the study of the specific challenges and opportunities being presented by the mountainous areas. It is based on multidisciplinary education, and it, moreover, offers to the students the opportunity not only to study but to live in the mountain regions. The recognition of the mountain settlements proposed through the course, presented in this paper, is a methodological tool for the students, for field research, exercises, dissertations, and often diploma projects in the context of the postgraduate program.

The program is held annually in the Metsovion Interdisciplinary Research Center (MIRC) in the Hellenic Mountain area of Metsovo, an interdepartmental Laboratory organized by NTUA, in a research center for mountainous environments and the local cultures (Figure 1).

Figure 1: Life in Metsovion Interdisciplinary Research Center (MIRC) (Photos by Elena Konstantinidou)

Definitions (Key Concepts)

The basic concepts and definitions are closely correlated to the subject of this paper. Firstly, *Cultural Heritage*, defined by UNESCO in its Draft Medium Term Plan 1990-

1995[1], as *"the entire corpus of material signs - either artistic or symbolic - handed on by the past to each culture and, therefore, to the whole of humankind. As a constituent part of the affirmation and enrichment of cultural identities, as a legacy belonging to all humankind, cultural heritage gives each particular place its recognizable features and is the storehouse of human experience... The idea of heritage has now been broadened to include the human and the natural environment, both architectural complexes and archaeological sites, the rural heritage, and the countryside... Furthermore, the preservation of the cultural heritage now covers the non-physical cultural heritage, which includes the signs and symbols passed on by oral transmission, artistic and literary forms of expression, languages, ways of life, myths, beliefs and rituals, value systems and traditional knowledge and know-how".*

The term *landscape* is defined by the European Landscape Convention[2] of the Council of Europe, Florence 2000, as "*the landscape is part of the land, as perceived by local people or visitors, which evolves through time as a result of being acted upon by natural forces and human beings".* Each landscape forms a blend of components and structures: types of territories, social perceptions and ever-changing natural, social and economic forces. Once this identification work has been completed and the landscape quality objectives are set, the landscape can be protected, managed or developed.

Similarly, the concept of *Architectural Heritage* is defined by the European Charter of Architectural Heritage[3], Amsterdam1975, as "*the European architectural heritage consists not only of the most important monuments: it also includes the groups of lesser buildings in old towns and characteristic villages in their natural or manmade settings. ... The architectural heritage is an expression of history and helps us to understand the relevance of the past to contemporary life".*

Another key concept is the concept of *tradition*. The concept of tradition was firstly formed, in correlation to the concept of the folk culture, during the end of the 18th century and afterwards, as a reaction to the centralized European civilization. It was, firstly, the result of a reaction of the German and northern European ethnicities, against the cultural and political pressure exerted upon them by the southern European countries. In contradiction to the accelerated speed of progress of the southern European countries that destroyed primordial values, European romanticism proposed the respect to the age-long existence of the tradition and the folk culture in many ways associated to the 'sublime' nature (Löwy and Sayre, 2001). The anti-historical quality of the previous three referential domains, as presented by the European romanticism, was presented as existing outside the tormented continuous transformation of history.

However, could such a cultural and political condition be possible, especially in the geopolitical context of the European continent? Contemporary theoretical criticism associates the concept of tradition with the formation of the concept of nations (Hobsbawm and Ranger, 1983) and the creation of the neoteric nation states. Social groups claiming to possess a genuine ethnic identity that survived unaltered for centuries may demand a differentiated nationality and, thus, the formation of a nation

[1] Draft Medium Term Plan 1990-1995 (UNESCO, 25 C/4, 1989, p.57)
[2] https://www.coe.int/en/web/landscape/the-european-landscape-convention
[3] https://www.icomos.org/en/resources/charters-and-texts/179-articles-en-francais/ressources/charters-and-standards/170-european-charter-of-the-architectural-heritage

state. In this way, tradition was many times invented, in order to compensate pressures exerted by other ethnic groups.

Nevertheless, even in the territory of the eastern Mediterranean, where historic changes continuously transformed social and cultural contexts, we could not disregard cultural formations, which seem to survive for centuries. The word 'tradition' itself derives from the Latin 'tradere' literally meaning to transmit, to hand over, and to give for safekeeping (Moraitis, 2013).

To the previous stabilized cultural formations, the *identity* of a social group may be closely correlated; and unaltered habits and beliefs seem to defend and conserve the genuine cultural qualities of the social group. However, the identity is also a matter of the ongoing historical transformation; it could be a continuous association to an active historical process. Thus, identity may be regarded as the sum of all the inherent characteristics of a social group and of all the possible tendencies of its future development that have to be recognized, amplified and promoted. It is in the same way that we analyze the identity of a place, recognizing its inherent characteristics and its possible tendencies as well. We may then continue and discuss the subject of the place identity and its promotion, usually described under the place branding and, thus, correlated to the economic development of the place and the local societies, to its touristic appeal and to the expansion of its consummative character.

However, place identity and its promotion, or place branding, appear also to be of central cultural and political importance, as they may strengthen as well the place pride of the inhabitants of a place. The feeling that they live in a place of local interest has to preserve its important qualities, correct its inadequacies and insist on its future opportunities of development.

Figure 2: Kastanitsa, Kynouria, Peloponnese, Greece (Photo by Elena Konstantinidou)

Mountainous Settlements: Components of Identity

In Greece, the mountainous landscape is formed by small settlements, large in numbers and variety. They are located over a large geographical area, often isolated

from each other due to geomorphological constraints and lack of communication infrastructure. The issue of identity is central in the management of mountainous areas. Mountainous areas are treated as a single system, the identity of which we must recognize, in terms of protection, promotion, and integrated development. The identity of a place may be considered as is a palimpsest of spatial and social phenomena that evolve and transform through time. It consists of tangible and intangible elements, as well as of the wider place formation, physically and culturally considered as the landscape. It is thus established by its *physical, spatial, and human elements*. The physical elements are geographical elements, climate, flora and fauna. They also refer to topography, morphology of the ground, natural relief and orientation.

The creation of settlements has always been correlated to real needs – considered essential and timeless values. We may, for example, refer to sparing, economy, and social data, as well as to a number of additional parameters as to the selection in terms of interconnection with neighbouring settlements, visual communication, views, water sources, quality of topography, safety, climate, sunshine, cultivation or forests for the supply of materials. Settlements are, moreover, located in association with other landmarks or places of importance and significance, a phenomenon rather common in Greece.

The natural landscape, geomorphology, and relief influence the creation and development of the settlements to the maximum extent, and we may comment that traditional ekistics formations are usually located in a way and scale to harmonize with their environment – to become a naturalized, constitutive element of it (e.g., the settlement of Kastanitsa in Peloponnese, see Figure 2). Climate is of great importance for the configuration of the complexes, their general formal outline, as well as for the location of the buildings, and free open spaces. The construction materials are related to natural materials, while constructions take advantage of the environmental characteristics (organized according to bioclimatic principles). The mountain settlements are located in natural environments with abundance and diversity. The free development of nature, the creation of rich ecosystems, the natural environment exhibits large-scale diversity, high steep mountains, ravines, rivers, abundant springs, and rich/varied vegetation.

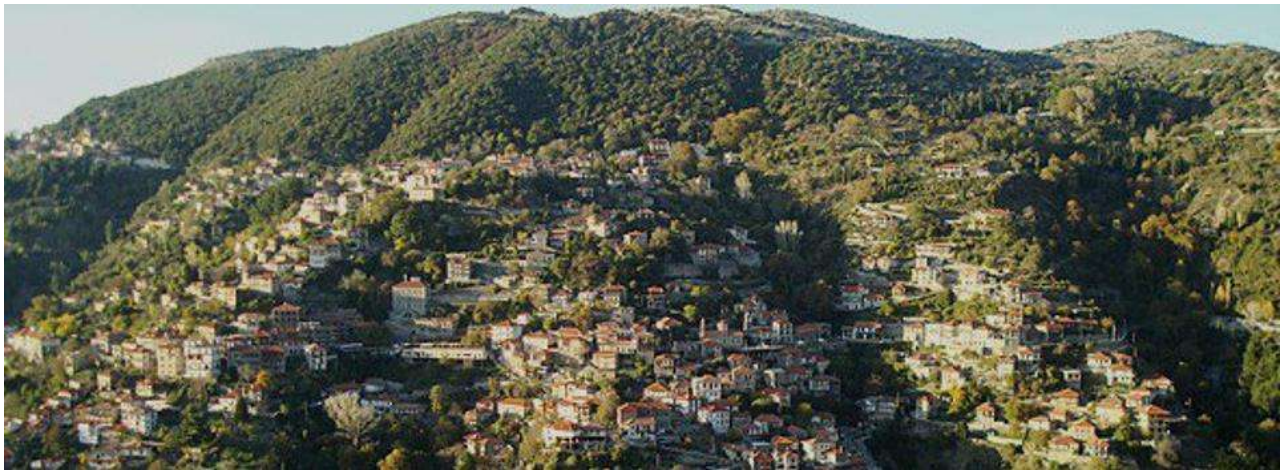
Figure 3: Lagadia, Arcadia, Peloponnese, Greece (Photo by Elena Konstantinidou)

Although, the way we perceive space is not only visual. The identity of a place is associated with aesthetic qualities, visual, acoustic, olfactory, tactile (Stefanou, 2000). Qualities concerning the satisfaction of the human senses contribute significantly to the determination of the character of a place. The colour, scents, tastes, sounds, etc. establish a place and contribute, in a way, to the diachronic link between the present and the past. Human data relates to social activities, historical, economic, demographic characteristics and its traces in the field. Human elements also present dynamics of a site as defined in relation to the population composition, social structures, economic and productive activities, and cultural elements (history, mythology, customs, religious traditions, etc.).

Furthermore, the spiritual and cultural elements, the "Genius Loci" of a place, form part of its identity (Norberg-Schulz, 1979), which is perceived by the process of collective memory (such as reason and myth, narratives, literature, cinema, painting, photography, etc.). Even the name of a place often contains and expresses the history, the tradition, and the spatial peculiarities. Let us refer, for example, to the village of Lagadia in Peloponnese (Figure 3). The morphological configuration of the land on which they were built probably gave the name of the settlement (Lagadi means gorge, ravine, or torrent). The historical identity of a place is composed of the grid of the monuments, landmarks, archaeological sites, sites associated with historical events, which are, therefore, closely tied to the collective memory of its inhabitants.

However, apart from the tangible cultural heritage, we may also find out important intangible references, for example, in the case of Metsovo (Figure 4), with Vlach origins, scholars, national benefactors, creators of local art and crafts, and the production of livestock products and household appliances. All of them constitute elements of the identity of the place.

Figure 4: Metsovo, Epirus, Greece (Photo by Elena Konstantinidou)

Another important element of identity has to do with the professional activities of the inhabitants, which are often preserved through the centuries, as in the case of the settlement of Stemnitsa in the Peloponnese (Figures 5, 6). There, since the post-Byzantine years, metallurgy flourished, mainly silversmithing and goldsmithing, which still survives till today thanks to the craftsmen silversmiths, who continue to work and manufacture products of local tradition, but mainly thanks to the operation of the Technical Vocational School of Silver and Goldsmithing.

The identity of *built environments* concerns the typological, morphological, and structural elements of the sites (Konstantinidou, 2011). Each settlement forms a "composition" of buildings and free spaces. Key components of the spatial elements refer, among others, to the relationship of natural and built environments, the structure and organization of urban space, road and path network, squares and Free Spaces, reference points, as well as the features of buildings and public space. The form and function of the urban fabric are very important, as is the street grid and open space. In general, in the mountainous settlements of Greece, the public space, streets, squares, and gathering places, are all in complete interdependence with the natural element.

Figures 5 & 6: School of Silver Craftmanship, Stemnitsa, Arcadia, Peloponnese, Greece (Photos adapted from http://iek-stemn.ark.sch.gr/)

Buildings constitute a fundamental factor in the physiognomy of a place, especially houses that are the most prevalent type of buildings composing the settlements. Elements as scale, volume, proportion, size, shape, material, constitute an important part of the identity of a place. It is, therefore, important to recognize their structure, form, and construction. The components of the identity of a settlement, as suggested above through the identification procedure, avail the tools to design and define the parameters for the protection strategy and sustainable development.

Figure 7: Vathia, Mani, Peloponnese, Greece (Photo by Elena Konstantinidou)

Changes/Problems/Dangers

Various problems and dangers threaten mountain settlements. The problem underlies the *phenomenon of abandonment* related to social causes, natural disasters, or

emergencies, and also the geomorphological causes (e.g., the settlement of Vathia in Mani, see Figure 7). In Greece, the abandonment of mountain settlements (during the period 1950s to 1970s) is associated with the mass movement of their inhabitants to cities, resulting in the desertification of mountainous areas. The majority of abandoned mountain settlements remained "untouched" by interventions and alterations; there is thus a fertile ground through a suitable design for its strengthening or even reuse. Regarding *"alive"* settlements, in the effort to coordinate with contemporary needs, threats and problems are identified, some of which are environmental problems, natural disasters, and hyper-tourism. These problems are usually related to the alteration of the "image" and "contour" of the place, contemporary expansions, new constructions and additions, which are incompatible with the existing built environment. They also refer to a shift in the relation of built and non-built, natural and structured, due to inadequate building regulations, and also alterations of historic buildings as well as the form and function of public space.

Furthermore, problems are related to a lack of financial resources, a lack of will and incentives, and generally the socio-economic changes that often lead to the relocation of residents and the economically active population; thus, the loss of the traditional cultural expressions and characteristics of the local and topical way of life occurs.

Moreover, *changes* and *problems* occur in the intangible elements that constitute the cultural heritage of the place: customs and traditions, traditional techniques and cultural practices, functions acquired over time, activities of the inhabitants facing risks of extinction, alteration, or degradation due to socio-economic changes. Thus, there is often abandonment of settlements by permanent residents, as a consequence of immigration of the economically active population and young people, through the introduction of new intensive uses with catastrophic requirements for the scale of the place, occupation of public space, and alteration of its form and operation, and due to excessive increase in land prices. All the above problems and threats may be addressed through legislative and administrative measures resulting from planning and development strategies, as well as through incentives and tools for the activation of the residents.

Protection and Development Planning and Aspirations

The concepts of *Protection and Development* evolved through important international documents, Charters, Declarations, and Recommendations. Specifically for historical settlements, including several mountainous settlements, the declarations from international organizations (as Icomos, Unesco, Council of Europe) highlight the values, threats, and the process of planning for their protection.[4] International texts (see Box 1) highlight the trend that is gradually being imposed to address the problems concerning protection of cultural heritage, which combines the actions of preservation and protection of cultural property with sustainable development. The concept of "*Protection*" nowadays is identified with the concept of "*Active Development*", aiming to integrate mountainous settlements into the current reality and also ensuring viability in the future.

[4] Particular reference is made to Nairobi Recommendation, 1976, Charter of Historic Cities - map of Washington in 1987, Vienna Memorandum in 2005, and VALETTA Principles, Malta 2011

The *planning of protection and development* presupposes the management of the changes taking place in the settlements, while contemporary approaches accept today's reality for change and the need for its management. The methodology of a sustainable design process should be based on a deep understanding of the identity of the cultural context, its characteristics, mutations, and also its problems.

Box 1: Basic Principles Texts on the subject of the Protection and Management of Cultural Heritage

1964 - The Venice Charter
1972 - World Heritage Convention (Convention Concerning the Protection of the World Cultural and Natural Heritage, Paris)
1975 - European Charter of the Architectural Heritage, COUNCIL OF EUROPE
1975 - The Declaration of Amsterdam
1976 - Nairobi Charter (Recommendation concerning the Safeguarding and Contemporary Role of Historic Areas, Nairobi)
1987 - The Washington Charter (Charter on the Conservation of Historic Towns and Urban Areas), ICOMOS
1994 - The Nara Document on Authenticity, Japan
1998 - The New Charter of Athens (the principles of ECTP for the planning of cities)
2000 - European Landscape Convention, Florence, COUNCIL OF EUROPE
2005 - Vienna Memorandum (on "World Heritage and Contemporary Architecture – Managing the Historic Urban Landscape", UNESCO)
2005 - Faro Convention (Convention on the Value of Cultural Heritage for Society), Council of Europe
2011 - The Valletta Principles (for the Safeguarding and Management of Historical Cities, Towns and Urban Areas, ICOMOS)
2011 - Recommendation on the Historic Urban Landscape, Paris, UNESCO

An essential condition is the development of a *Protection Plan*, based on an Urban Plan with a comprehensive exploration and inquiry of cultural, technical, social, and economic values. The Protection Plan must cover all the tangible and intangible elements, establishing a proposal of Promotion, combined with a Management Plan, which is monitored. The respect and promotion of all values and the historicity of the place should be ensured while maintaining the overall image of the site and its relationship to the natural and built environment. It should also protect the structure, form, and function of the traditional urban fabric in its entirety, maintain the important historical buildings and elements in the wider environment, and protect the functional character of a settlement and its socio-economic identity. It is also important to consider and protect the cultural diversity and multiculturalism of the place.

An integrated protection plan (or an integrated renewal program) should include several measures: administrative measures to resolve operational, traffic, and other problems, while social measures to complement the social and cultural equipment, to enhance the functioning of housing, and maintain the quality of life of residents (Maistrou, 2012). Spatial projects also require the revival of abandoned neighborhoods, upgrading, and rehabilitation of significant parts of the public space, improvement of infrastructure networks, ensuring the amenities of contemporary life,

and highlighting the particular physiognomy of the place. Further, important are the legislative measures for the integration of contemporary structures and the protection of the settlement and its individual characteristics.

The strategy of management should aim at preserving the cultural heritage of the place, strengthening traditional occupations, and evaluating the introduction of foreign standards. Providing the inhabitants with the comforts of contemporary life and attracting investments that do not destroy the environment are crucial measures.

Conclusions

The settlements of the mountainous areas are associated to several important natural and cultural values: the mountainous landscape's quality aesthetics, historic and mnemonic references, traditional cultural formations, economic possibilities, and quality of human life. The importance of these settlements depends not only on its material status but also on the immaterial and intangible values associated with its history or traditions. In addition, it may be considered as par excellence formations for the application of sustainability strategies, as it usually incorporate many environmentally friendly features and bioclimatic elements.

It is, therefore, necessary to recognize the identity and understand the value system of mountain settlements - as total, natural-environmental, structural and man-made qualities - to formulate proposals for its protection and integrated development. The settlements should continue to live and develop as living organisms, utilizing their cultural potential, which can bring the necessary resources for its development. In particular, the advantage of these settlements is its cultural characteristics, which can be a driver for economic development and (possibly) special forms of tourism. Natural resources (natural environment, forests, arable land, landscape), cultural resources (e.g., churches, historic buildings, traditional cobbled streets, etc.), social environment (human scale, quality of life, cultural associations, etc.) are of paramount value. Moreover, the intangible heritage (local festivals, religious festivals, music events, traditional local products, arts, etc.) can be the necessary resources for their complete and sustainable development.

In addition, it is pointed out that the future of the mountainous settlements can be based on its function as a network (nature-loving, mountaineering, cultural, architectural, folk tradition, religious, sports, gastronomic, highlighting the primary sector).

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Authors' Declarations and Essential Ethical Compliances

Authors' Contributions (in accordance with ICMJE criteria for authorship)

Contribution	*Author 1*	*Author 2*
Conceived and designed the research or analysis	Yes	Yes
Collected the data	Yes	No
Contributed to data analysis & interpretation	Yes	Yes
Wrote the article/paper	Yes	Yes
Critical revision of the article/paper	Yes	Yes
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Research involving human bodies or organs or tissues (Helsinki Declaration)
The author(s) solemnly declare(s) that this research has not involved any human subject (body or organs) for experimentation. It was not a clinical research. The contexts of human population/participation were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or ethical obligation of Helsinki Declaration does not apply in cases of this study or written work.

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The author(s) solemnly declare(s) that this research has not involved any animal subject (body or organs) for experimentation. The research was not based on laboratory experiment involving any kind animal. The contexts of animals were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or ethical obligation of ARRIVE does not apply in cases of this study or written work.

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Research Involving Local Community Participants (Non-Indigenous) or Children
The author(s) solemnly declare(s) that this research has not directly involved any local community participants or respondents belonging to non-Indigenous peoples. Neither this study involved any child in any form directly. The contexts of different humans, people, populations, men/women/children and ethnic people were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or prior informed consent (PIC) of the respondents or Self-Declaration in this regard does not apply in cases of this study or written work.

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M – 00329 | Research Article

Commercialization of Home Gardens in Upland Farming Systems: Evidences from Cash Crop Regimes of Rural Meghalaya, Northeast India

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Abstract

In developing countries, home garden is essential part of rural ecosystem and cater multiple functions including household food security. However, home gardens are getting commercialized in the developing world including the uplands of northeast India. Hence, we look at the impacts of commercialization on home gardens of different farming systems of Meghalaya. In this exploratory assessment, authors have employed qualitative methods including in-depth interviews to collect primary information from seven different farming systems that include two subsistence, three traditional, and two modern cash crop-based farming systems. The study has investigated the traditional practices of home gardening and its extent in different farming systems, crop and livestock diversities, levels of commercialization and the driving factors. It was found that crop diversification in the home garden is maximum in the *jhum* (shifting) farming system followed by tea-strawberry farming system. Similarly, the highest number of commercial crops is grown under home gardens in broom farming system and it had also made inroad to *jhum* (shifting) farming system to some extent. It is also found that chicken and pig rearing is common to all farming systems with some variations. Cattle have been introduced in some villages, as a direct consequence of introduction of wet paddy in the narrow valleys and partly a response to gradual cultural diffusion from the nearby plains. Besides, housing pattern of some settlement or space between dwelling units determine the existence of home garden.

Keywords

Cash crops; Home garden; Tribal communities; Space; Food security; Indigenous knowledge

Introduction

Home Garden: Generalities

A home garden[1] refers to a space that is a culturally-controlled biological community around houses (Kimber, 2004), often composed of multi-species, multi-storeys and multi-purposes with solutions to the socio-economic and cultural needs of the people (Bennett-Lartey *et al.*, 2004). The roles of home garden are well recognized across the globe for its significant contribution to food and nutritional security, agro-biodiversity conservation, economics, socio-cultural and aesthetics values (Gautam, Sthapit and Shrestha, 2006; Gulluzz *et al.*, 2010; Galhena, Freed and Maredia, 2013). The roles of home garden even become more crucial during war and emergencies (Pothukuchi and Kaufman, 1999). Home garden has proved immensely helpful for household food security irrespective of rural and urban setup during the rapid outbreak of COVID-19 pandemic and consequent lockdowns (Lal, 2020; Mukiibi, 2020; Kingsley *et al.*, 2022). Recent studies found the connections of home garden with physical and mental wellbeing particularly among the elderly people (Corley *et al.*, 2021). No doubt, the structure, function and contribution of home garden vary over cultural settings and agro-climatic conditions. Traditional home gardens are relatively inconspicuous and less visually impressive than crop land (Whitmore and Turner, 2001), but are intrinsic part of local food system in the developing world. Home gardens have played a significant role particularly for rural communities with subsistence economy. Home garden generally cover a small area but serves profusely. Some of the important functions include providing a stable source of fresh and safe vegetables, fruits and other edibles, preserving social capital, enhancing biodiversity, and conserving ecosystems. In addition, it enhances the nutritional need particularly for low-income rural households in the developing countries (Forum for Food Sovereignty, 2007; Galhena, Freed and Maredia, 2013; Abdoellah *et al.*, 2020). In general, although home gardens are not formally managed and also small in areal extent compared to the developed world, yet they play a vital role in family nutrition, particularly for the poor households. Over recent decades, home gardens are getting commercialized in developing world in response to the market pressure (Abdoellah *et al.*, 2006).

Northeast India and Home Garden

The tribes of India's northeast connect their families with forest ecosystem and animal husbandry through the traditional home garden practices (Ramakrishnan, 1992). In the northeast, home garden as an agroforestry system optimizes the family wellbeing through integration of trees, shrubs, herbs, climbers, aromatic plants, timers, ornamental plants and domestic animals and birds. It provides the easy access to fruits, vegetables, leafy vegetables, meats, and eggs for household consumption and surplus is sold out. Numerous studies of home gardens across tribes in the region focus on the structure, function, composition, energy budget, economics, labour division and ecological aspects (Ramakrishnan, 1992; Shrivastava and Heinen, 2005; Sahoo, 2009; Tynsong and Tiwari, 2010; Singh *et al.*, 2014; Tangjang and Arunachalam, 2017). In

[1] It is also known as garden (Crouch, 2020), home garden (Bargali, 2015), kitchen garden, dooryard gardens, house-lot gardens, homestead (Kimber, 2004; Batjargal *et al.*and Zamir, 2013), edible backyard (Kortright and Wakefield, 2011) and nutrition gardens (Suri, 2020). Among the Khasi and Jaintia community of meghalaya, it is known as *ka'dew kyper* (Gurdon, 1907).

the last few decades, the agricultural systems of northeast India are under the process of commercialization and globalization owing to the expanding market and rapid demographic pressure. Further, home gardens under commercialization in the northeastern states of India are scantly researched. The home gardens of rural Meghalaya, a hill state of northeast India, are in the web of commercialization of two different versions such as traditional cash crop and modern cash crop (Ramakrishnan, 1999; Behera *et al.*, 2016). Based on the above background of home gardens, it is pertinent and essential to investigate the home gardens of commercial regimes in rural Meghalaya.

Study Area

Meghalaya is a hilly state, located in northeastern part of India. A significant proportion (86%) of the total population belongs to scheduled tribes (Census of India, 2011). Farming systems in Meghalaya are extremely diverse owing to varied agro-ecological conditions, prevailing social fabric and market linkages. For this study, all these farming practices are classified into two types of farming systems[2], which can be easily identified in the plateau; the *jhum* (shifting) based, and the cash-crop based farming system (Figure 1). The first focuses on growing for subsistence and self-sufficiency, whereas the latter emphasizes on cash earning and profit maximization. The households of earlier category of farming system are more or less food self-sufficient. The system includes varieties of foods, including cereals (millet, maize, and rice), vegetables, legumes, tubers, oilseeds, leafy vegetables and even non-food items like fiber for clothes and thatch grass for house construction. According to Ramakrishnan (1993), this system was until recent times the chief source of food, livelihood, dominant land-use practice and the way of life for all tribal groups in the hills of the northeast India. The primary objective of the commercial farming system is to grow for market and export, and only a small part of it is consumed by the producer.

In the context of Meghalaya, the cash-crop based farming system can further be divided into (a) traditional, and (b) modern, based on the types of crops (Figure1). The traditional cash crop-based farming systems are different from modern cash crop-based farming systems. The traditional crops have been grown in the plateau for a long time but only recently have been commercialized. This initial cash-crop system such as turmeric, pineapple, broom, areca nut etc. were characterized by cultivation of crops endogenous to the area aided by traditional knowledge base and evolved in response to varying agro-climatic conditions prevalent in the plateau. The modern cash crops are new for the farmers and recently introduced by governmental and non-governmental organization in the state. They include rubber, tea, strawberry, cashew nut, and coffee. Further, based on the above classification, 7 villages representing all the three types of farming systems for the field investigation were selected. Two

[2] A farming system is defined as a population of individual 'farm systems' (a 'farm system' refers to individual farm with specific resource endowments, family circumstances, existing social, economic and institutional environment and are organized to produced food and to meet other household goals, through a range of activities include interdependent gathering, production, post-harvest processes, livestock keeping, fishing, agro-forestry, hunting, gathering activities and off-farm incomes) that have broadly similar resource bases, enterprise patterns, household livelihoods and constraints and for which similar development strategies and interventions would be appropriate (Dixon, Gulliver and Gibbon*et al.*, 2001).

villages - Mawrynniaw (25°28′ 19′′ N and 91°04′ 41′′ E) and Jongchetpara Songma (25°30′ 26′′ N and 90°02′ 18′′ E) - were selected to represent the *jhum* (shifting) farming system, which are coded as *Jhum* I and *Jhum* II, respectively. Simultaneously, 5 villages were selected from cash crop-based farming system to represent traditional (3 villages) and modern cash crop systems (2 villages), respectively. Three villages of traditional cash crops system included Kshaid (25°12′ 34′′ N and 91°46′ 05′′ E), Nongtalang (25°12′ 32′′ N and 92°04′ 06′′ E) and Thadnongiaw village (25°44′ 19′′ N and 92°03′ 51′′ E), to represent broom, areca nut and ginger, respectively. The two villages that represented modern cash crop system were Machokgre (26°03′ 22′′ N and 91°50′ 25′′ E) and Sohliya Mawthoh (25°44′ 58′′ N and 91°59′ 33′′ E).

Methodology

A number of households having home garden was collected through the household survey conducted by the first author in selected farming systems. A crop and livestock module was prepared based on participant observation, in-depth interviews, focus group discussions and informal conversation with villagers. Crops/livestock grown in the home garden were grouped into subsistence and commercial based on its broad use at the level of farming systems. Further, PRA (participatory rural appraisal) was conducted with household heads in each farming systems to get a generalize picture at the level of farming system.

Altogether a sample of 250 home gardens from 7 farming systems was included for the study. The information on a number of households practicing home gardens, and the composition of livestock, were collected at household level through semi-structured interview method. The crop diversity of home gardens and subsistence/commercial uses of crops were collected at the level of farming systems through PRA method. A diversity index is calculated by simply adding all the crops found including subsistence and commercial at the level of farming systems. Further, coding was used for an easy and convenient understanding. Code ‘S’ and ‘C’ were assigned to subsistence and commercial, respectively, based on the use of different crops. Accordingly, the levels of commercialization were identified based on combination of subsistence crops and cash crops. Households have been grouped into 3 broad categories, such as households growing subsistence crop only, households growing cash crops, and the households who combined both subsistence and cash crops. Similarly, the diversification of livestock were classified into 7 types, such as (1) no livestock, (2) only chicken, (3) only pig, (4) chicken and pig, (5) only cattle, (6) chicken, pig and cattle (C+P+Ca), and (7) only goats. Besides, the above primary data gathered from the field, secondary data of the total population of selected villages was used under study with two reference points of time, i.e. 1981 and 2011 (Census of India years), for calculating the growth of population in the respective sample farming systems.

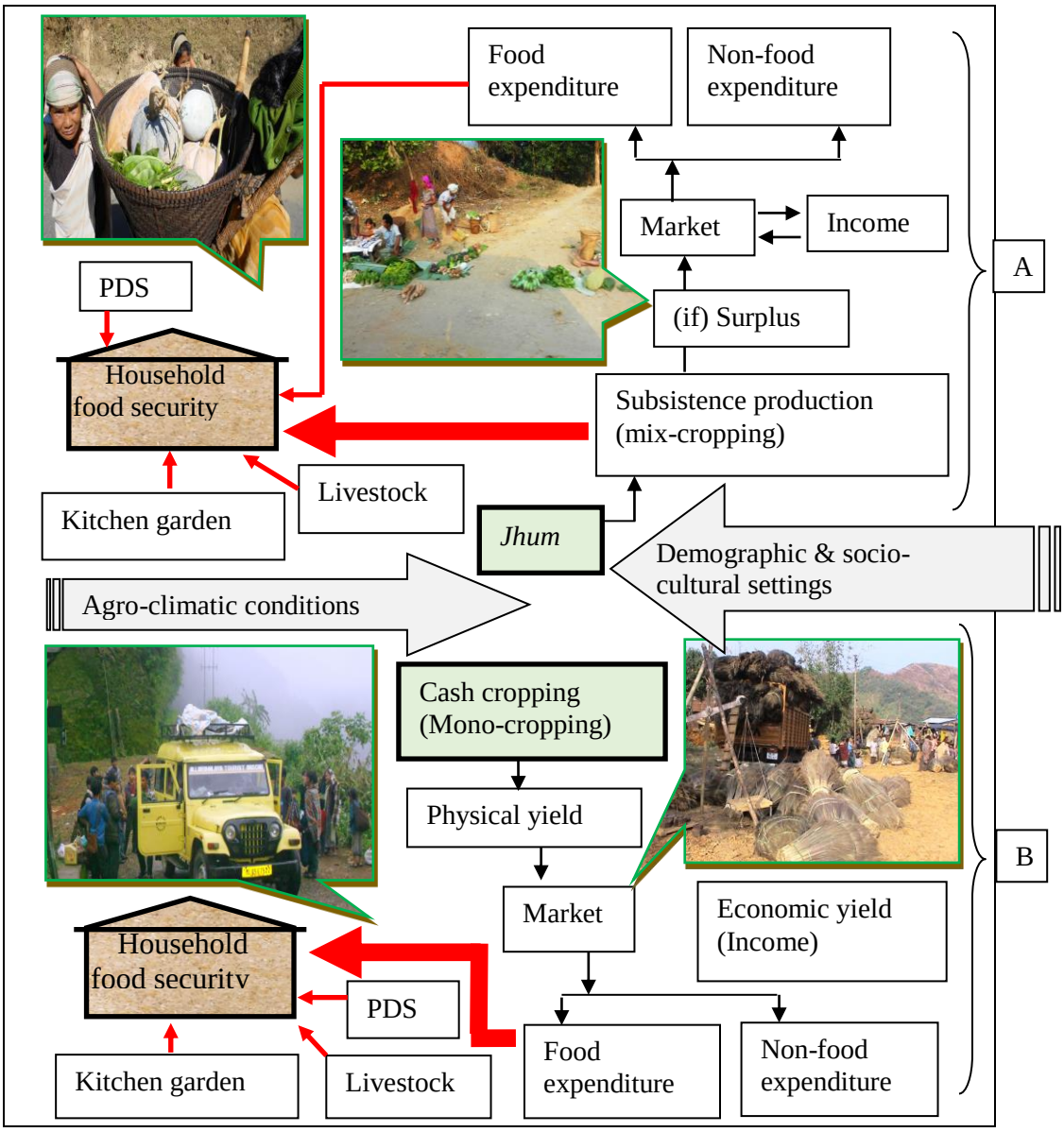

Figure 1: The farming systems: (A) represents traditional *jhum* system where the framers' objective is food self-sufficiency; (B) represents cash crop system where cash generation is the main objective

Results and Discussions

Home Gardens in Different Farming Systems

The study has found that each farming system has valued its home gardens distinctly and raise accordingly. The practice of home gardening is common among the household of *jhum* farming systems. Both the sample villages representing *Jhum* farming systems have shown similar picture. In this system, all households were engaged in home gardening devoted to diverse use ranging from growing of vegetables, fruits to livestock. The other five farming systems have households with

varying extent of home gardens. On the other hand, in case of the three traditional cash crop farming systems, two of these i.e., broom grass and ginger farming villages, contain a sizeable proportion of households with home gardens. However, unlike the above said two traditional cash crop farming systems, the areca nut farming system is devoid of home gardens. Further, there are also some divergences noticed in the two villages under modern cash crop-based farming systems. Most of the households have home gardens in tea-strawberry farming system while such households are very few in case of rubber farming system (Figure 2).

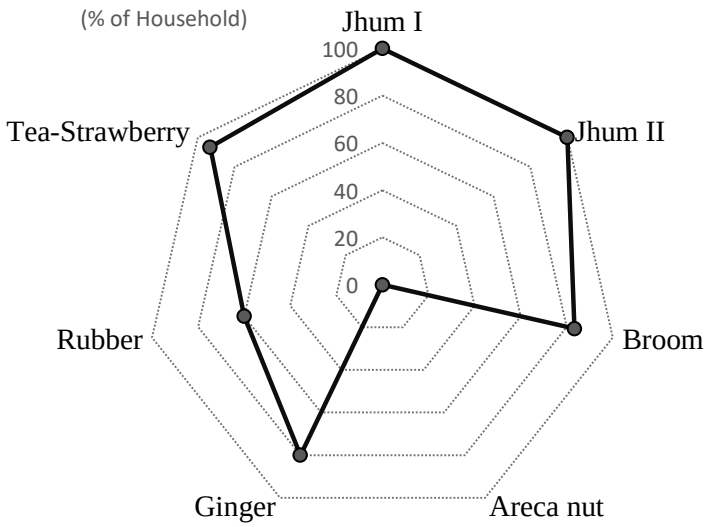

Figure 2: Percentage of household with home gardens in the sample farming systems, Meghalaya

In India, home garden is an important component of all local food systems irrespective of different agro-climatic regions, or, rural or urban settings or, even in tribal or non-tribal socio-cultural structure. Home gardens strengthen the local food system by directly influencing the consumption patterns including the immediate kitchen needs that improves food security and socio-economic wellbeing of the local communities across India (Girard *et al.*, 2012; Mazumdar and Mazumdar, 2012; Galhena, Freed and Maredia, 2013). Further, the home gardens of rural areas are functionally more attached to household food consumption pattern than in the urban setup where the functions often focus on aesthetic, environmental awareness, and urban sustainability (Cameron *et al.*, 2012; Khairnar; Zasada, Lawrence Benninger and Weltin, 2019; Zasada *et al.*, 2020). In the context of tribes, home gardens become more prominent as they were not traditionally used to market economy, and locationally they are away from the urban areas, often located in the hilly, forested tracts and spatially lesser accessible areas. Thus, the current changes in the practices of home garden among the tribes of Meghalaya in cash crop regime and particularly in the modern cash crop regimes may have short- and long-term implications.

Crop Component: Diversity in the Home Gardens

The plant diversities and taxonomic classification in the home gardens of different parts of India presenting different regions are well documented in various studies (Vijayakumari *et al.*, 2019; Shukla, Kumari and Chakravarty, 2017). Indians (including tribes) have rich heritage of practicing home gardens, as evident in different regions of Maharashtra (Khairnar, Patil and Patil, 2019), Kashmir (Islam *et al.*, 2021), Kerala (Peyre *et al.*, 2006; John, 2014), Tamil Nadu (Hudson, Krogman and Beckie, *et al.*, 2016 and 2019), Odisha (Pradhan *et al.*, 2018), Mizoram (Barbhuiya, Sahoo and Upadhyaya, 2016), Assam (Shrivastava and Heinen, 2005; Das *et al.*, 2015), Tripura (Das *et al.*, 2015), Nagaland (Singh *et al.*, 2013), West Bengal (Chakraborty and Basu, 2018) and Uttarakhand (Jethi *et al.*, 2020). However, a need for unravelling the commercialization processes in home gardens in general and with special reference to tribe is realized. Therefore, this study has attempted to understand the crop diversity of home gardens in terms of subsistence and commercial crops in different farming systems of Meghalaya.

Table 1 provides details about the crop diversity index by combining crop grown for home consumption (S) and for cash generation (C). Subsistence crops directly get added to the household food consumption while the commercial crops give economic accessibility to the household food purchase. Number of commercial crops grown in home garden gives an insight into the level of commercialisation of home gardens. As is evident from the table, cultivation of subsistence crops dominates in home gardens of *jhum* farming system whereas cash crops-based systems are showing varied patterns. Traditional cash crop cultivated areas represented by ginger and broom farming systems have continued with the cultivation of a variety of subsistence crops in their home gardens, whereas it was found a complete absence of practicing home gardens in areca nut farming system. However, traditional cash crop-based farming system, such as areca nut farming system, has a practice of cultivating tuber and leafy vegetable within the areca nut agroforestry in suitable patches. In turn, it supplements their household's daily requirements having a function similar to home gardens.

The broom grass growing village (Kshaid) grows three indigenous fruit crops and bay leaf as cash crops in home gardens besides the subsistence crops (Table 1). These cash crops are being transported by small cabs to nearby urban center for selling purpose (Figure 4c). It was observed that diversification of crops grown in the home garden has been maximum in the *jhum* farming system followed by tea-strawberry farming system. The latter represents a farming system based on modern cash crop cultivation. Number of crops produced in traditional cash crop areas is close to *jhum* system whereas the modern cash crop farming systems have varied experiences. For example, number of crops grown in home gardens of the households in tea-strawberry farming system is nearly identical to the *jhum* farming system, whereas number of crops grown in the homesteads of the households in the rubber farming system (Machokgree village) is very few.

Commercialisation of traditional fruits overtook the space of home gardens in the broom food system. Respondents from the broom farming system had experienced the recently emerged competition between cash crops and subsistence crop within the home garden. Earlier, the entire space in the home garden was allotted to growing

vegetables and leafy vegetables, but now the space is shared with the commercialized fruit crops as a monoculture. The traditional fruit crops recently commercialized in broom farming system include *Myricanagi*, *Prunus nepalensis*, *Eleagnuskhasianum, Flemingiavestita* and *Docynia indica* (Figure 4a,b). These fruits are perishable and without any value addition were transported to nearby urban centre by small passenger cabs.

Table 1: Crops grown in home gardens in the selected farming systems, Meghalaya

Farming system		*Subsistence (S)*	*Commercial (C)*	*Diversity Index*
Subsistence	*Jhum*-I	Plantain, papaya, pine apple, pumpkin, jackfruit, taro, beans, pine apple, bottle gourd, ridged gourd, lemon, cucumber and chili	0	S13+C0=13
	Jhum-II	Plantain, pineapple, papaya, pineapple, pumpkin, jackfruit, taro, chili, beans, bottle gourd, ridged gourd, cucumber, lemon, and coconut	Areca nut, black pepper	S14+C2=16
Traditional cash crop based	Broom	Pumpkin, bottle gourd, ash-guard, lemon, chills, plantain, taro, squash, cucumber	Bay leaf, bastard oleaster, blackberry, mulberry	S9+C4=13
	Areca nut	-	-	S0+C0=0
	Ginger	Beans, papaya, leafy vegetable, pineapple, brinjal, pumpkin, bottle gourd, ridged gourd, plantain, squash, ladies' finger, and tree tomatoes	-	S12+C0=12
Modern cash crop based	Rubber	Plantain, jack fruits, pineapple	Areca nut	S3+C1=4
	Tea-strawberry	Brinjal, plantain, taro, tapioca, coconut, mango, pineapple, guava, litchi, bottle gourd, papaya, peach, pears, cucumber	Bay leaf	S14+C1=15

Comparison across different farming system reveals that the highest number of commercial crops is grown under home gardens in broom farming system followed by the second *jhum* village (*jhum*-II). Areca nut plantation has occupied the space of home gardens in rubber farming system. Bay leaf is the most important cash crop produced in the home gardens of tea-strawberry farming system. Although the bay leaf as a cash crop is newly introduced in the northern side of the plateau i.e., in Ri-Bhoi area, yet it is a traditional practice in the southern precipitous slope of the plateau i.e., Ri-War areas. The introduction of bay leaf in the home gardens of Ri-Bhoi area

has happened because of permanent migration of people from the Ri-War areas as one of the prominent reasons.

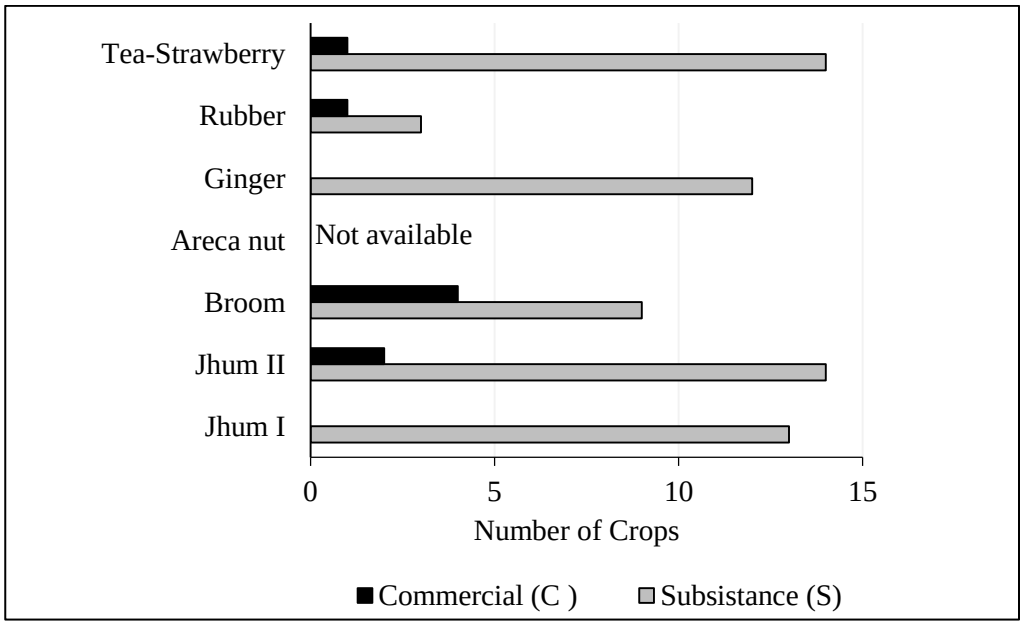

Figure 3: Crops grown in home gardens in the selected farming systems, Meghalaya

Diversities of the home gardens are well explained in the existing literature. Plant diversity in the home gardens of Palayamkottai urban space, Tamil Nadu (Vijayakumari *et al.*, 2019). Similarly, plant diversity in home garden was also studied (Shukla, Kumari and Chakravarty, 2017). Several such studies are also found in northeast India on plant diversity (Barbhuiya, Sahoo and Upadhyaya, 2016). Besides plant diversity, studies have also focused on diversity of vegetable crop (Chatterjee *et al.*, 2016), soico-economic and bio-physical character of plant diversity in home gardens (Das and Das, 2005; Sahoo, 2009), inventory of flora in North Bengal (Subba *et al.*, 2016) and plant characteristics with soil character (Singh *et al.*, 2013). Further, Das *et al.*, (2015) have argued that mushroom can be commercialised from the home garden. As the diversity is high in this farming system, home gardens, therefore, play a vital role in the food security (Jana and Roy, 2021).

Livestock Component: An Intrinsic Practice

Livestock has remained as a significant component of home gardens particularly in the subsistence economy (Kenneth-Obosi, 2019). In the context India, the livestock composition of home gardens is different from one region to another across the country. The difference is guided by cultural factors significantly including religious beliefs and practices besides the physical factors of the regions. The folk culture of Indian tribes has also reflected in home gardens in different regions of the country in terms of livestock composition. Further, the livestock composition in home gardens in the northeast India is different compared to rest of the tribal regions of India. Therefore, the need to explore the recent commercialization in different farming system of these regions in relation to livestock composition is realized in this study.

Livestock rearing is another vital component of home garden in Meghalaya. It is a common phenomenon that has been noticed across farming systems regardless of any crop cultivated whether on a subsistence or commercial basis. However, there is difference between *jhum* farming system and cash crop regime, as per the extent and quality of livestock rearing is concerned. Further, the difference within a farming system is minimal. As far as livestock rearing is concerned, as much as 23 per cent households in the village under rubber plantation do not rear any kind of livestock followed by the villages cultivating broom grass or ginger on a commercial basis (16-17%). Around 13 per cent households in tea and strawberry growing village do not own livestock. Interestingly, none of the households owned any livestock in areca nut growing village. This is in sharp contrast to the *jhum* villages where each of the household continues to own some livestock. As the livestock composition in a household is concerned, chicken and pigs rearing are common in all farming systems despite some variations. The highest proportion of this composition found in *jhum* farming system and the lowest is found in traditional cash crop-based farming system of areca nut. In broom grass cultivation village, fewer households had this combination as a majority went for chicken rearing only. It shows the continuity in the livestock rearing practices in spite of changes in the farming systems. Limited livestock diversification is found in modern cash crop systems. It was a coincidence to find cattle and wet paddy cultivation together in the tea-strawberry and ginger farming system. However, small-scale diversification has begun recently by a few households and mostly confined to cattle and farm chicken. For example, a household in the village with rubber plantation has recently started rearing cattle not for agricultural purpose but for selling milk in nearby urban center and another household has also started growing farm chicken in tea-strawberry farming system for the similar purpose. Goats and cows are recently added as livestock by a few households under cash crop regime only. Cattles, however, are found in far fewer households belonging to both subsistence and cash crop regimes.

Table 2: Percentage of households owning livestock to total the household

Farming system		*Livestock composition*						
		No livestock	*Only chicken*	*Only pig*	*Chicken & pig*	*Only cattle*	*C+P+Ca*	*Goats*
Subsistence	*Jhum* I	0	0	0	100	0	0	0
	Jhum II	0	3	0	80	0	17	0
Traditional cash crop	Broom	17	53	3	27	0	0	0
	Areca nut	100	0	0	0	0	0	0
	Ginger	16	10	21	39	10	0	4
Modern cash crop	Rubber	23	17	10	47	0	3	0
	Tea-Strawberry	13	3	0	44	0	30	10

Note: C- Chicken, P- Pig, Ca- Cattle

Beyond the Cattle Culture

Traditionally, livestock is part of rural agro-food system in Meghalaya. However, it was limited to pig and chicken. Dairy farming was never part of livestock among the Khasi, Garo and Jaintia, particularly in the hilly areas. Swan rearing is an important component of the village ecosystem functioning across the tribes in northeast India (Ramakrishna, 1992). This is largely due to the fact that the traditional agricultural practices in the hill regions are not associated with cattle unlike the rest of India. Besides, the dairy products were not part of traditional food preference[3] among the tribes. A century back, Gurdon (1907) had also observed that the tribes of Meghalaya as a rule to do not consume any dairy products. Accordingly, the consumption pattern had direct impact on the variety of livestock rearing in the home garden. Likewise, goat rearing was also not associated with traditional livestock rearing in Meghalaya. The findings of the present study do match with the overall livestock scenarios of the state. Combination of chicken and pig is a dominant pattern in five out of seven villages covered in this study. The remaining two villages are broom grass and areca nut growing villages. Basketry as a handicraft is a dominant subsidiary economic activity in broom grass areas, which is substituting livestock rearing. According to villagers, basketry is easier than pig rearing mainly because of scarcity of fodder for livestock. The case of areca nut plantation village is an exception where piggery is banned inside the village due to lack of space. However, a few households have established piggery away from the village. To keep the village clean and not to disturb the inhabitants is the key purpose behind the ban. However, there are also some other changes in different farming systems with regard to livestock. For instance, cattle have been introduced in some villages, as a direct consequence of introduction of wet paddy in the narrow valleys and partly a response to gradual cultural diffusion from the nearby plains.

Space: A Driving Factors of Home Gardens

The settlement pattern, particularly distribution of housing units relative to one another appears important, as it either permits space between housing units or it does not. In areas where houses are dispersed, it permits adequate space for maintaining home gardens. The dispersed dwelling units providing enough space around a home is one of the important driving factors. The denser housing structure under cash-crop regimes lead to the replacement of traditional practices of home gardens including the domestic livestock (pigs and chicken), which are integral part of this traditional agroforestry system, a unique characteristic of the subsistence farming system in northeast India. Home gardens are big enough in settlements with dispersed housing pattern as is the case in *jhum* areas with small size of population and fewer households as well as experiencing relatively small increase in number of households. This traditional practice of home garden around the housing unit, however, is getting altered on the face of rapid increase in the number of households, which is leading to more compact settlement (Table 3). These settlements are relatively large in size. For example, the Nongtalang village has turned into a compact settlement due to

[3] Tribes of rural Meghalaya do not prefer dairy products. This was evident from the experience of a rural young man who assisted during the field work conducted in the village. The young man was offered rice in Shillong which had a tinge of *ghee* (clarified butter). He consumed the rice but felt uncomfortable as he had never tasted any milk or milk products ever.

significant increase in the number of households from 158 in 1981 to 391 in 2011. At present hardly any space is left between housing units that can be used for home garden in the village growing areca nut, currently. In addition, the settlement is located on a small table top plateau where it is not possible for further expansion. Besides, the village council does not permit pig rearing inside the village. In other cases where the housing units are scattered as found in the case of the *jhum* as well as ginger farming system, enough space is available for home gardens. Here, the space between houses was adequate and used widely for home gardens (Behera *et al.*, 2016).

Table 3: Growth rate in number of households in selected farming system, Meghalaya

Farming system		*Number of HH*		*Growth (in %)*
		1981	*2011*	
Subsistence	*Jhum* I	28	32	14.29
	Jhum II	36	59	63.89
Traditional cash crop based	Broom	36	59	63.89
	Areca nut	158	391	147.47
	Ginger	41	102	148.78
Modern cash crop based	Rubber	14*	40	185.75
	Tea-strawberry	30	62	106.66

Source: Census of India, 1981, 2011

Note: There was no separate census enumeration for the village in 1981; the information provided is based on data supplied by the concerned headman (*Rangbah Shnong*) of the village.

Figure 4: Home gardens: (a, b) Plantation of indigenous fruits (as cash crops) in the home garden in broom farming system of Kshaid village, (c) transport of fruits grown in home gardens as cash crops to Shillong by passenger vehicles, and (c) shrinking size of home garden in Kshaid; (e) cultivation of tuber crops in a home garden of tea-strawberry farming system, (f) intensive home gardening in ginger area; (g) bay leaf plantation in tea-strawberry farming system Sohliya Mawthoh village; (h) areca nut has occupied the space of home garden in rubber farming system, Machokgre village, Meghalaya (Photos by first author).

Conclusion

Impacts of commercialisation on home gardens are reflected in the previous sections extending its relevance though the effects are different in each farming systems. It can, however, be generalized that the traditional farming systems continue to have higher dependence on home gardens and traditional cash crop-based systems having mixed experiences as these are yet to be fully commercialized. Besides, crop diversification and change in livestock rearing in home garden of different farming system, the housing pattern of a settlement also sturdily determines the existence and practice of home garden.

Though the cash crop system is invading to the traditional subsistence farming systems, the intricacies of home gardens with a sizable proportion of household in the traditional system reveal the contributions to produce food and nutritional secure villages. Most importantly, home gardens are the intrinsic part of the local food system, which is again relevant due to the hilly and difficult terrains that the people live with. Despite having several important functions such as providing a stable source

of fresh and safe vegetables, fruits and other edibles, preserving social capital, enhancing biodiversity, and conserving ecosystems particularly for low-income rural household, home gardens are getting commercialized in response to the market pressure for profit maximizations. Therefore, it intends that a large section of tribal societies in Meghalaya are becoming food and nutritionally insecure, increasing chance of loss of agro-biodiversity and loss of indigenous knowledge system of the communities. In Meghalaya, the share of landless household is highest amongst all the states of northeast India. The current tenure practices, land ownership systems and tribal customary laws do have enough implications for commercialisation of home garden. As a huge number of households belong to landless category and majority are small and marginal farmers, they probably might have started commercializing home gardens as a copping strategy, which attracts further detail investigation.

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Authors' Declarations and Essential Ethical Compliances

Authors' Contributions (in accordance with ICMJE criteria for authorship)

Contribution	*Author 1*	*Author 2*	*Author 3*
Conceived and designed the research or analysis	Yes	Yes	No
Collected the data	Yes	No	No
Contributed to data analysis & interpretation	Yes	Yes	Yes
Wrote the article/paper	Yes	Yes	Yes
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Research involving human bodies or organs or tissues (Helsinki Declaration)
The author(s) solemnly declare(s) that this research has not involved any human subject (body or organs) for experimentation. It was not a clinical research. The contexts of human population/participation were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or ethical obligation of Helsinki Declaration does not apply in cases of this study or written work.

Research involving animals (ARRIVE Checklist)
The author(s) solemnly declare(s) that this research has not involved any animal subject (body or organs) for experimentation. The research was not based on laboratory experiment involving any kind animal. The contexts of animals were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or ethical obligation of ARRIVE does not apply in cases of this study or written work.

Research on Indigenous Peoples and/or Traditional Knowledge
The author(s) solemnly declare(s) that this research has involved households of Indigenous Peoples as participants or respondents. Some contexts of Indigenous Knowledge are also indirectly covered through literature review. Therefore, a Self-Declaration is appended for the same purpose.

Research involving Plants
The author(s) solemnly declare(s) that this research has involved the plants for experiment or field studies. The contexts of plants are also indirectly covered through literature review. Thus, during this research the author(s) obeyed the principles of

the Convention on Biological Diversity and the Convention on the Trade in Endangered Species of Wild Fauna and Flora.

Research Involving Local Community Participants (Non-Indigenous) or Children
The author(s) solemnly declare(s) that this research has not directly involved any local community participants or respondents belonging to non-Indigenous peoples. Neither this study involved any child in any form directly. The contexts of different humans, people, populations, men/women/children and ethnic people were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or prior informed consent (PIC) of the respondents or Self-Declaration in this regard does not apply in cases of this study or written work.

(Optional) PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses)
The author(s) has/have NOT complied with PRISMA standards. It is not relevant in case of this study or written work.

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SELF-DECLARATION FORM
Research on Indigenous Peoples and/or Traditional Knowledge

The nature and extent of community engagement should be determined jointly by the researcher and the relevant community or collective, taking into account the characteristics and protocols of the community and the nature of the research.

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1.1 Was the research conducted on (an) Indigenous land, or community?

Yes

1.2 Did any of the criteria for participation include membership in an Indigenous community, group of communities, or organization, including urban Indigenous populations?

No

1.3 Did the research seek inputs from participants (members of the Indigenous community) regarding a community's cultural heritage, traditional knowledge, biocultural or biological resources or unique characteristics/practices?

Yes

1.4 Did/will Aboriginal identity or membership in an Indigenous community used or be used as a variable for the purposes of analysis?

No

2. Community Engagement

2.1 If you answered "Yes" to questions 1.1, 1.2, 1.3 or 1.4, have you initiated or do you intend to initiate an engagement process with the Indigenous collective, community or communities for this study?

Yes

2.2 If you answered "Yes" to question 2.1, describe the process that you have followed or will follow with respect to community engagement. Include any documentation of consultations (*i.e., formal research agreement, letter of approval, PIC, email communications, etc*.) and the role or position of those consulted, including their names if appropriate:

Verbal consents were taken from all the heads of the village councils prior to collect the data from the villagers (respondents). Further, all the respondents were clearly informed by the first author that the information collected would be used for research and academic purpose only. Therefore, no such data/information were collected that may violate any ethical aspects of the concerned communities.

3. No Community Consultation or Engagement

If you answered "No" to question 2.1, briefly describe why community engagement will not be sought and how you can conduct a study that respects Aboriginal/ Indigenous communities and participants in the absence of community engagement.

Not Applicable.

Sd.
(Rabi Narayan Behera)
Name of Principal Researcher: Rabi Narayan Behera
Affiliation of Principal Researcher: Fakir Mohan University, Odisha, India

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M – 00330 | Review Article

Agricultural Vulnerability to Climate Change: A Critical Review of Evolving Assessment Approaches

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Abstract

The cumulative negative effects of climate change make agriculture increasingly vulnerable, with severe food security challenges, especially for developing nations. A robust research approach and a logical methodical framework can holistically assess the occurrence and intensity of agricultural vulnerability in a bid to strategize mitigation measures. This paper includes an in-depth review of the existing body of literature on agricultural risk and vulnerability, apart from recent studies and metric measurements of vulnerability having an emphasis on agriculture. Unlike the high priority on climate indicators in the past, contemporary research is progressively comprehensive and multidisciplinary where socioeconomic factors are integrated to make the assessment all-encompassing. Though this review paper found six major types of methodologies, the current vulnerability studies are predominantly index-based experiments adapted from the IPCC vulnerability concept. However, there is considerable variation across experiments concerning vulnerability conceptualization, selection of indicators, weight assignment and indexing techniques. Majority of the indexes encapsulate expert-recommended variables under sensitivity, exposure, and adaptive capacity. Such index-based measurements describe and compare vulnerability over space and time in order to formulate actionable policy measures. Uniform and robust techniques in indicator selection and statistically tenable weight allocation should be pursued in future research. To make the index highly representative and validated, the inadequacy of community perception should be minimized through the integration of PRA techniques within the experimental framework. Emerging threats such as loss of labour productivity in agriculture should be included in the analysis. The components of vulnerability also need to be analysed to comprehend their individual share in overall vulnerability for well-targeted mitigation measures. Constraints of data insufficiency required for vulnerability studies need attention for quality vulnerability research in the future. With such set priorities and focus, future research outcomes in vulnerability evaluation should be more meaningful and policy-focused.

Keywords

Vulnerability; Sensitivity; Adaptive capacity; Labour productivity; Climate

Introduction

The impact of climate change is the leading global threat endangering the existence and development of humanity. The increasing occurrence of climate extremes in the last five decades has shaken the civil conscience and awakened man for climate-appropriate actions across the globe. The pervasive nature of climate change effects has impacted every sector. At the Earth's surface, successive decades in the last 50 years have been felt noticeably warmer than preceding decades (IPCC2, 2013). The scale, intensity, and projected harms, in the long run, have united various countries, researchers, practitioners, and policy makers for deep deliberation to formulate and implement actionable measures to reduce vulnerability. Climate change has far-reaching and complex bearings on biophysical and socioeconomic systems; however, its specific impact on agriculture is enormous and multifaceted since food security remains a concern for several low and medium income countries like India. Agriculture production is severely impacted by climate extremes (IPCC1, 2001). The resultant adverse consequences will be far more severe and frequent in the coming years making the planet more climate-vulnerable (Pattnaik and Naryanan, 2009). The regions that fail to adopt adequate and effective adaptation measures will bear the brunt of food insecurity (Lobell *et al*., 2008). The large population, geo-spatial location, and bio-physical diversity make India one of the most vulnerable countries in the world (Sakhare, 2019). The high incidence of flood, submergence, drought, and saltwater intrusion in coastal areas will impact the overall welfare of the nation with an estimated 3 million persons facing coastal flooding (IPCC4, 2022). Vulnerability analysis is a dominant analytical tool that describes susceptibility to potential risks and remedial actions for risk reduction (Adger, 2006). The global research on climate change and associated vulnerability are, therefore, now more institutionalized, integrated and evolving at a faster pace with the engagement of a multidisciplinary team of academicians and experts. Significant research progress until now has been made to comprehend the nature, magnitude, and interplay of different dimensions of vulnerability to climate shocks. Climate vulnerability research accelerated in 1988 with the creation of the Intergovernmental Panel on Climate change (IPCC) by the World Meteorological Organization (WMO) and the United Nation Environment Programme (UNEP). Since then, IPCC with its scientific findings derived from contemporary research is positively influencing governments for climate-smart policy and helping them with several climate change negotiations. The growing body of knowledge in this field is highly concentrated on assessing the current overall vulnerability status of a region, and to alert stakeholders about the potential adversities. IPCC periodically evaluates and releases the risk and vulnerability assessment frameworks, which are largely employed by researchers to carry out climate studies. These experiments usually follow quantitative methods to produce index-based measurements making them comprehensive and comparable.

The evolving trend and focus of climate change research increasingly recognize agricultural vulnerability as a distinct research theme requiring a well-conceptualized research focus. There exists a dearth of studies globally that exclusively explore and enrich the scientific basis and knowledge to capture how agriculture is vulnerable to different climate events. The study of agriculture vulnerability needs more intensive investigation on account of its direct and linear linkages between agriculture production and climate parameters. The large spatial variation in agricultural

outcomes due to differences in biophysical and socioeconomic factors further stresses the importance of research efforts in this domain.

The challenge of feeding over 10 billion people by 2050 (UN, 2015) in the face of the negative effects of climate events is enormous. With the ever-shrinking resources, like land, and dominance of a large number of poor and small scale farmers in developing countries, like India, this challenge is even more complex. Therefore, it is a call for concern for an in-depth research approach quantifying agricultural vulnerability with greater precision. The present review study emphasized a structured reflection of past thematic works, current practices, and recommendations for future research. In addition, this study intends to help the scientific community, especially researchers, organize their research approaches for quality outcomes. This paper has intensively reviewed and presented an updated status of research direction on some major components — risk analysis and vulnerability measurement approaches, the evolving concept of vulnerability to climate change, the analytical framework of and recent research on agricultural vulnerability to climate change effect, currently used measurement techniques for agricultural vulnerability, research gaps, and priorities. Emphasis is, however, laid on evolving concepts, approaches, and metric measurement of agricultural vulnerability.

Methodology

A review of available literature without any pre-set publication date criteria was the methodology adopted for composing this paper. The paper extensively reviewed the status of vulnerability, especially agricultural vulnerability, generalized the research trend, inferred new knowledge, and identified research gaps and constraints to foster innovation in future research. The peer-reviewed literature carries relevant terms or combinations of terms, such as “vulnerability analysis methods”, “climate change”, “climate vulnerability”, “agriculture vulnerability”, “sensitivity”, “exposure”, “adaptive capacity”, “GIS and vulnerability analysis”, “IPCC vulnerability analysis”, “indexation methods”, etc. were searched from online sources like Scopus, PubMed, Google Scholar, Web of Science and Copernicus. A total of 1,174 papers were extracted from various electronic searches. Subsequently, duplicated articles were excluded and 64 distinctly relevant articles were shortlisted and categorized based on their exclusivity. The adequate representation of literature on aforesaid review topics was ensured for extensive coverage and interpretation.

The authors used the standard practice of full-text reading followed by backward and forward snowball techniques to avoid the exclusion of any important article. The selected articles were published in different journals and produced from disciplines like agricultural economics, environmental economics, climate research, applied geology, environmental sciences, marine and coastal research, geospatial studies, ecological indicators, humanities and social sciences, natural resource management, and development studies.

Results

Risk Analysis

Risk analysis is the basis for assessing a system's vulnerability to climate change. The connotation of risk varies across disciplines, though in climate science it is "the potential loss of life, injury, or damage of a system, society or community arising out of a hazard (UNDRR, 2015). Risk is also defined as a combination of the probability of a disaster event and its negative consequences (UNISDR, 2009). Sometimes, the losses caused on account of climate risk are difficult to quantify. In disaster management discourse, the risk is often described as a function of hazard, vulnerability, and coping capacity where the hazard is understood as a disastrous phenomenon, a condition that may cause loss of life and livelihoods, social and economic disruption, or environmental damage.

According to IPCC, the concept of risk and working definition has evolved since its first assessment report (AR) in 1990. In its 6th AR (2022), IPCC has postulated risk as "the potential for adverse consequences for human or ecological systems, recognizing the diversity of values and objectives associated with such systems". The 5th AR of IPCC released in 2014 has recognized risk as the intersection of hazard, vulnerability, and exposure. These three factors determine risk and interact with climate systems (natural variability and anthropogenic climate change) socio-economic processes, and emission and land use chance (Oppenheimer, 2013). In an enhancement, the current assessment outlines expanded scope of these three risk determinants and emphasizes responses that modulate each of these determinants (IPCC4, 2022). Therefore, the secondary factors influencing three determinants are now more stressed in analyzing the risk of a system. The risk, thus, defined and placed in the overall conceptual framework, according to AR 5, takes two major forms — key and emergent risks. The key risks are the direct and severe consequences; a vulnerable system confronts a hazard. On the other hand, emergent risks are indirect consequences of a hazard resulting from the responses to climate change (e.g., migration due to drought). Spatial linkages and temporal dynamics in the reaction to climate events are the major determinants of emergent risks (Rama *et al*., 2019)

Vulnerability to Climate Change

The vulnerability concept and its assessment first originated in natural hazards research (Marco and Ostrom, 2006) and subsequently evolved to be integrated into climate science. In recent research discourse, vulnerability to climate change (climate vulnerability or climate risk vulnerability) is one of the major components of risks for quantification and assessment. The third IPCC assessment report first time defined vulnerability as "the degree to which a system is susceptible to and unable to cope with adverse effects of climate change, including climate variability and extremes". Vulnerability secured a pivotal place in the climate crisis studies since the correct capture of this parameter has a huge implication on policy design. The first step toward climate change adaptation is to reduce vulnerability to current climate extremes (IPCC, 2014). The evolving concept and expanding boundary of vulnerability can be observed in the first IPCC AR report and its subsequent editions till the recent AR 6 report. There are two approaches widely followed to conduct

vulnerability analysis and both of them have quantitative leaning. First, the endpoint or outcome method where vulnerability is mapped through a pre-post exercise after a system is affected by a hazard. Research works with this approach usually take place following a hazard. Damage assessment is an important exercise under this approach. A system that showed better resistance post a hazard is considered less vulnerable. Conversely, the starting point approach — most commonly used — intends to measure the pre-existing level of a vulnerability that a system is exposed to. The results obtained from starting point approach, typically identify the current gaps and weakness and their sources in a system where course correction measures are required. Thus, this approach is policy-relevant and worthwhile in the plan and operation of preventive measures against a possible hazard. Vulnerability is often read with concepts like community resilience, the marginality of a system, susceptibility, adaptability, fragility, and risk (Liverman, 1990). Of late, the concept of vulnerability is gradually expanded to be directly linked with exposure, sensitivity, coping capacity, and criticality (Füssel, 2007)

The UNDP (2004) distinctly classified four groups of vulnerability factors — social, economic, physical, and environmental. While social factors largely include population and its characteristics, economic factors focus on the resource endowment of the community or individual relevant to the assessment of vulnerability, especially in disaster risk reduction. Contact with the vulnerability-causing components is considered a physical factor and all environmental parameters are closely linked to ecology and the environment. Thus, appropriate measurement of the vulnerability requires a balanced analysis of both biophysical and socio-economic factors.

Since the third AR of IPCC, vulnerability was adequately defined and elaborated in a methodical framework and subsequent assessment reports of IPCC (till the most recent one) have further elaborated the components, but the core definition remains unaltered. Vulnerability here is presented as a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity" (IPCC, 2001). Mathematically, vulnerability is often expressed as:

> Vulnerability = f (Exposure, Sensitivity, and Adaptive capacity). The three components that determine the degree and direction of vulnerability occupy an extensive significance in climate research. IPCC has acknowledged the differing views in contextualizing vulnerability and recognized it may differ across societies and time (Jurgilevich, Räsänen and Juhola, 2017; Kienberger, Blaschke and Zaidi, 2013). Exogenous, biophysical, and social dimensions of vulnerability are the key evaluation elements in vulnerability studies.

Exposure in this context is defined as the "presence of people, livelihoods, species or ecosystems, environmental services and resources, infrastructure, or economic, social, or cultural assets in places that could be adversely affected" (IPCC, 2014). Glick, Stein and Edelson (2011) defined sensitivity as the degree to which a system is affected, either adversely or beneficially, by climate variability or change. Adaptive capacity is the ability of a system to deploy management strategies for the reduction of risk associated with climate change (Heltberg, Siegel and Jorgensen, 2009).

Füssel and Klein (2006) further integrated this model by combining the first two elements - exposure and sensitivity and named potential impact. Thus, according to them, the vulnerability function is represented as:

> Vulnerability = f (Potential Impact and Adaptive capacity). However, the vulnerability equation developed by IPCC is widely employed and referred to in contemporary research.

According to Doch, Diepart and Heng (2015) vulnerability studies combine the social and biophysical aspects of environmental change. Füssel (2007) further elaborated on the classification of vulnerability factors. He categorized these factors based on scale and discipline. According to him, all factors causing vulnerability can be of two scales — internal and external. Furthermore, these factors can be categorised into two distinct domains — socioeconomic and biophysical. The classification of vulnerability factors is presented in table 1.

Table 1: Classification of vulnerability factors

Scale	*Domain*	
	Biophysical	*Socio-economic*
Internal	Sensitivity — land, topography, climatic conditions	Adaptive capacity — family income, social inclusion, access to information etc.
External	Exposure — large disaster (Tsunami, earthquake) sea level rise	Policy priority, political environment, the economic stability of the state etc.

The IPCC-given vulnerability equation is widely followed for quantitative measurement of these parameters. The term exposure in the equation denotes the degree to which a system is exposed to a climate event, while the adverse or beneficial impact resulting from climate variability or change is stated as sensitivity. Both exposure and sensitivity are positively correlated with vulnerability. The adaptive capacity of a system or individuals is to adjust to potential damage, take advantage of opportunities, or respond to consequences (IPCC, 2014). These three interconnected elements of exposure, sensitivity and adaptive capacity are represented by multiple relevant biophysical and social factors with the first-order connection with vulnerability.

The Research Practice and Progress

In view of the enormity of vulnerability as a research theme, different approaches have been attempted to explore and broaden this subject matter. Researchers in the past have contextualized vulnerability in a specific study domain e.g., household, ecology, livelihood, poverty, etc., and illuminated the process and factors that determine the magnitude of vulnerability. "Vulnerability assessments should include a predictive function (Naudé, Amelia, and McGillivray, 2009) to define vulnerability in relation to a socially acceptable level of outcome". Frankenberger *et al.* (2002) stated that easy and feasible data disaggregation and integration are important to measure at the regional and national levels. However, data deficiency is often a challenge in vulnerability assessment, especially in developing countries (Naudé, Amelia, and

McGillivray, 2009). USAID in 2013 observed that data feasibility, reliability and utility must be adequately met for an index-based measurement of vulnerability.

Selection and employing a particular approach should ideally be based on the purposes, contexts, and resources of the assessment.

Agricultural Vulnerability: The concepts and framework

The specific case of vulnerability owing to climate extremes has challenged farm outputs globally. However, this is a comparatively new research discipline gaining momentum in recent times. Agriculture is the base for food security globally and livelihoods for millions of rural households, particularly in the agrarian economies of developing countries. There is mounting burden from the increasing population to produce more food from fewer resources like land. Moreover, the rapid aberration of climatic factors has threatened the crop productivity of all major crops (IANS, 2022). Thus, a huge challenge worldwide today is to produce more food from lesser resources in the face of a productivity-limiting climate crisis. Such a predicament has intensified the research on agriculture-specific climate vulnerability. In countries like India and Bangladesh, the impact of climate on agriculture is even more pronounced since rainfed farming, fast depletion of groundwater, and shortage of farm labourers are coming due to out-migration (Kareemulla, Venkattakumar and Samuel, 2017). .

The generally accepted definition of agricultural vulnerability is how an agricultural system is prone to damages and losses due to the probability of climatic events. It is the degree to which the system (the crops and farmers) is susceptible, and cannot cope with adverse effects of extreme temperatures, drought, cyclones, flooding, storm surge, and other climate extremes that supposedly arise out of climate change. The predisposition of individual farmers or groups along with coping capacity determines the severity and extent of agricultural vulnerability (Palanisami *et al.* 2010). Agricultural vulnerability in climate science focuses on the physiological impact on crops resulting from climate extremes or variability. The socio-economic factors, such as education, household wealth, crop insurance, etc., constitute the adaptive capacity that negatively interacts with vulnerability level.

The evolving body of knowledge around suggests agriculture system is impacted by its climate vulnerability in three major ways. First, alterations in temperature and precipitation resulting from climate change can cause variation in cropping patterns. Second, because of climate extremes (drought, flood, soil salinity), crop productivity is reduced and lost. Third, farm income is considerably affected, and livelihood is adversely impacted that brings down the adaptive capacity and makes agriculture more vulnerable (Mitter *et al.*, 2014). Thus, analysis of agricultural vulnerability assumes huge policy implications where the peasantry is a mass occupation. Like general vulnerability exercise, agricultural vulnerability manifests through the interaction of environmental and socio-economic processes (Berry *et al*., 2006). Noticeably, a large body of research works is inclined toward the analysis of climate factors with lesser stress on investing socioeconomic parameters (Wu *et al.*, 2017). The combination of a climate and socioeconomic perspective to look into agricultural vulnerability is lacking in the current research discourse (Dwarakish, Vinay and Natesan, 2009)). In addition, the majority of the available studies on agricultural

vulnerability analysis in India have focused on the predicted effect of climate variation (Panda, 2017).

Komali (2016) identified three major research gaps in the assessment of agricultural vulnerability. First, in the Indian context, the existing research efforts are largely concentrated on assessing drought and its consequences; the vulnerability associated with farming in coastal areas is markedly ignored. Moreover, the usage of primary data and a combination of quantitative and qualitative tools is limited. Secondly, the deficit in efforts to factor both climate and the socio-economic parameter is now noticeable. Finally, the research in its current pattern is spatial in nature largely while ignoring the time factor. Thus, the insight into how vulnerability has responded and evolved is insufficient and temporal analysis needs more research attention. The approaches to study the climatic vulnerability also vary depending on the context, nature of the vulnerability and research objectives. Table 2 presents a brief account of the commonly followed vulnerability study approaches.

Table 2: Approaches to vulnerability studies

Vulnerability approach	*Proponent*	*Definition*	*Purpose*	*Major features*	*Benefits*
Household vulnerability index (HVI)	FAO and Natural Resources Policy Analysis Network (FANRPAN, 2004), South Africa	Vulnerability is the "presence of factors that place households at risk of becoming food insecure or malnourished	Used to measure vulnerability at the household level in HIV-hit areas.	Identification of most vulnerable and sustainable ways to assist vulnerable Monitoring food security during a vulnerable context (Kureya, 2013)	15 "impact areas" of vulnerability are assessed using indicators
Local Vulnerability index (LVI)	Naude, McGillivray and Roussouw (2008)	It measures subnational regional vulnerability to identify "spatial poverty traps" and covariate risks	Improves vulnerability assessment methodologies	Captures regional variation of the vulnerability and identifies spatial poverty gaps. It employs principal component analysis (PCA) and extracts the most relevant factors causing vulnerability. The index is helpful for regional	Status of the local economy, international trade capacity, peripherally, income volatility, demography and health, environment and geography, and the financial system are the evaluation indicators

Vulnerability approach	*Proponent*	*Definition*	*Purpose*	*Major features*	*Benefits*
				planning with an estimated level of vulnerability.	
Household Livelihood Security Analysis (HLSA)	Developed in 1994 by CARE as framework for program analysis, design, monitoring and evaluation" (Frankenberger, Mock and Jere (2005)	It is asset-based, and multidisciplinary to widen the understanding of livelihood vulnerability (Cannon and Twigg, 2005).	Originally the analytical framework used only PRA and RRA tools, later quantitative surveys were included to assess the vulnerability based on a reasonable sample	It measures the attainment of a geography on economic security, food security, health security, educational security and empowerment. Extensively used qualitative techniques to understand vulnerability hence should be generalized carefully.	The analysis is used to capture the change an intervention created in the target geography
Household Economy Approach (HEA)	A livelihood based methodical framework by Save the Children UK (Holzman *et al*., 2008)	Forecast the potential impact of a disaster across different income groups	Widely used by National Vulnerability Assessment Committees in southern Africa (SADC FANR Vulnerability Committee, 2004)	It is a mixed method approach, includes quantitative secondary and primary data, and employs participatory and qualitative techniques to generate qualitative insights. It guides who, where needs responses during a disaster	It requires extensive disaggregation of data for vulnerability mapping at individual and household levels. Strong inclination to qualitative tools and non-probability sampling, dilutes, at times the statistical validity of the findings
Social vulnerability	Brooks (2003)	Describe all the factors linked to a potential hazard of	Strong emphasis on social capacity of the	Social vulnerability encompasses physical	Social factors are highly focused

Vulnerability approach	*Proponent*	*Definition*	*Purpose*	*Major features*	*Benefits*
		a certain nature and severity.	community take on a vulnerable situation	environment like soil topography, water reservoirs, land characteristics etc. that determine the outcome of a hazard	

Methodical Approach to Vulnerability Research

The experiment on vulnerability in the context of agriculture is carried out by employing different research methodologies deemed fit by the researchers. Selection of a methodology is often guided by the research purpose, nature of the problems and end users' requirements. Besides, time, resources and data availability especially in developing countries are important consideration in selecting a best-fit method (Naudé, Amelia and McGillivray, 2009). All the methods have their own benefits and certain shortcomings, but nevertheless, some in several ways, are robust based on sound reasoning, and explore scientific facets to conceptualize agricultural vulnerability and its complexities. Though index-based methods are most commonly employed, there are other handful techniques to capture and analyse the concept of climate vulnerability. The plurality of technical dimensions in assigning weight to the climate variables is also observed. Contemporary agricultural vulnerability research is more inclined towards quantitative calculation. However, when such quantitative studies are complemented by qualitative tools, the research results becomes more accurate and reliable (Banerjee, Duflo and Chattopadhyay, 2007). An account of major methodologies being followed in contemporary vulnerability research specific to agriculture is presented below (Table 3).

Table 3: Major methods for vulnerability research in agriculture

Methodology	*Method description*	*Major advantage and disadvantage*
Descriptive methods	Descriptive methods identify key vulnerability drivers and nature, frequency and intensity of climate events and their adverse impacts on agricultural systems. Such a methodology emphasizes to map a geography based on the attainment of different climate parameters and then categorization of different regions based on the threshold marks is used to depict the spatial vulnerability (Kelly and Adger, 2000). Interdependence of vulnerability	*Advantages* -This is the simplest way to present vulnerability of an area -It encompasses several qualitative information *Disadvantages* -Normally it is void of metric measurements, thus it is not quantitatively tenable at times.

Methodology	*Method description*	*Major advantage and disadvantage*
	parameters are not deeply covered, however detailed account of vulnerability causing triggers are researched and documented.	
Analysis of variance	For long, analysis of variance of important weather and production parameters served as standard research methods to capture and analyse the extent of vulnerability. Quite often, fluctuation in rainfall, temperature, humidity and the trend of agricultural production were correlated to quantify the vulnerability and its impact. Furthermore, the crop production is regressed against vulnerability causing weather parameters to build a causal relationship which reveals the facets of vulnerability (Liang, Zhang and Qin, 2021).	*Advantages* -Easy to conceptualize and assess -Normally, data is available. *Disadvantages* The major disadvantage with this method is Interdependence of vulnerability parameters is usually not deeply investigated.
PRA techniques	Participatory rural appraisal techniques (PRA) are widely followed qualitative techniques to generate social perspective about community vulnerability, its dimensions, impact and interplay with other socio-economic factors. Conventionally, such tools are employed before or after any planned quantitative exercise. Qualitative insights built through these participatory tools consummate the research conclusions obtained in quantitative studies (Kang and Holbert, 2005). Under this technique, risk analysis, resource map, mobility mapping, vulnerability maps, resource maps are sketched to build the understanding about vulnerability.	*Advantages* -In-depth analysis and building community perspective, which are insufficiently captured in metric measurements. -It helps in formulating community-centric adaptation measures *Disadvantages* -PRA techniques are highly focused on qualitative assessment -Conduct of PRA methods come with several operational challenges e.g resources requirements, constraints to organize many PRAs
Indicator based computations	Indicator based measurements are the most common methodology in vulnerability research. In line with the IPCC method, three vulnerability components are exposure, sensitivity and adaptive capacity. However, each of these components encompasses a different set of indicators based on the	*Advantages* -Metric measurements, makes the analysis objective, easily comprehensible and comparable across times and space. -The vulnerability

Methodology	*Method description*	*Major advantage and disadvantage*
	research areas e.g., indicators under exposure for agriculture vulnerability study will supposedly vary from that of a livelihood vulnerability analysis. Since the data metrics of different indicators are in different units, first those that are normalized (mostly by HDI method) and then appropriate weightage is assigned. One methodical argument in this index-based measurement is fixation of weightage to different selected indicators under each of those components. Many researchers tend to distribute weightage equally. However, for statistical robustness and research logic, many scientists now follow Iyengar-Sudarshan vulnerability index (Kumar, Solmon and Vishnu-Sankar, 2014)) equation since the weights vary inversely with variance over regions in the respective indicators on vulnerability. In other cases, researchers use the fuzzy-AHP technique in assigning appropriate indicator-weightage (Larrhoven and Pedrycz, 1983). Based on the research objectives and experimental type, selection of components differs. In another indexation technique, vulnerability index is constructed by combining relative rating assigned to identified risk variables (e.g sea level change) according to their varying ability to cause damages (e.g., 1 for low, 2 for medium, 3 for high). Mathematically, the vulnerability index is calculated taking square root of product of rating of all risk variables divided by the number of variables. (Pendleton *et al*., 2004).	components are adequately defined and followed by researchers across the globe, thus indexation with those components is broadly accepted. -Based on sound mathematical reasoning, thus widely accepted among key stakeholders -Highly data centric, thus, making the experiment more evidence based. *Disadvantages* -Fixation of indicators and assignment of weightage are sometimes subjective and thus accepted or criticised by different groups of researchers. -At times, such indexation has computational complexities that deter researcher to fully employ these methods.
Simulation method	Several crop growth simulators and climate change models have been developed by scientists to observe the crop growth responses to changing climate, soil and other management	*Advantages* -image based simulation of climate events, therefore credible and highly scientific

Methodology	*Method description*	*Major advantage and disadvantage*
	factors. Such simulation-based models help in projection of climatic events and the possible impacts. Besides, GIS based images are often used to map regions based on intensity, frequency and nature of the climate events as captured by satellites. Some of the models previously used for the vulnerability assessment are: The Crop Environment Resource Synthesis (CERES) for wheat. PRECIS is developed at the Hadley Centre at the UK Met Office. EPIC plant growth model (Tao, Xu and Liu, 2011).	-With satellite images, vulnerability can be depicted for any target area *Disadvantage* -Purely account for climate factors, socio-economic scenario is ignored in vulnerability studies. -Access to images is expensive thus restricting the reach of the researchers.
Objective and quantitative assessment method	This analytical tool was recently proposed by a group of researchers from China Agricultural University. In this method, unit vulnerability is measured as the ratio of sensitivity and adaptive capacity. It further computes two types of yields — crop yield (normal) and sensitive yield (yield during climate shocks). The reported difference between these two yields defines the adaptive capacity in the region. Exposure degree is defined by the ratio of the crop area in the study period and the average planting area reported in a base year, which shows spatial scale of the climate effect. Thus, agricultural vulnerability is computed as Sensitive yield divided by adaptive capacity and exposure degree (Hhiqiang *et al.*, 2015)	*Advantages* -This is a relatively new metric method to quantify agricultural vulnerability, which opens up a new metric measurement to assess vulnerability. -Purely quantitative measurement and data driven *Disadvantage* -The measurement doesn't include social aspect in the vulnerability analysis.

Discussion

The Trend of Agricultural Vulnerability Studies

In line with the general vulnerability measurement, agricultural vulnerability studies are largely quantitative and index-based assessments. Scientists, based on the previous studies and research objectives, select and define relevant indicators distributed across social and climate domains. It has become a common practice to measure vulnerability to climate change or natural hazards in several sectors (tourism, energy and finance), including agriculture (Kalli and Jena, 2022). The index constructed after indicator

standardization and assignment of weightage lends itself to spatial and temporal comparison.

The first structured study on agricultural vulnerability can be traced back to 1989 when Gornitz and Kanciruk (1989) mapped and developed an index to evaluate the vulnerability of coastal regions of the United States. Hareau, Hofstadter and Saizar (1999) studied the agriculture, industry and service sectors of Vietnam and developed vulnerability indices applying Iyengar and Sudarshan method[1]. Gbetibouo and Ringler (2009) used 19 indicators for exposure, sensitivity, and adaptive capacity to map South African farmers based on agricultural vulnerability to climate effects. Kumar, Kumar and Kunte (2012) developed a coastal vulnerability index by considering eight indicators to estimate coastal vulnerability to physical changes emanating from the future rise in sea level. Huq, Boon and Gain (2015) analyzed the impacts of climate change and other pertinent factors on coastal agricultural communities with soil erosion as an adverse consequence. He made a scientific account of three orders of the impact of agricultural vulnerability. Shukla, Kamna and Joshi (2016) studied the mountainous region in the Himalayas and assessed the inherent vulnerability of agricultural communities. In 2017, Panda (2017) constructed an index to enumerate farmers' vulnerability to drought. Jose *et al.* (2017) evaluated the vulnerability of crops to floods in the Philippines. They grouped physical, agroecological and socioeconomic indicators under the components of exposure, adaptive capacity, and sensitivity. Komali *et al.* (2018) observed that coastal vulnerability as a research aspect is understudied and more attached to geomorphological and, to an extent, socioeconomic domain. They, in England, constructed a physical coastal vulnerability index and compared it with a fiscal coastal vulnerability index to form a combined coastal vulnerability index. Kantamaneni *et al.* (2018) developed Combined Coastal Vulnerability Index CCVI to compute vulnerability using physical and fiscal parameters. Ducusin *et al*. (2019) did an extensive research to scientifically illuminate vulnerability as a function of exposure sensitivity and adaptive capacity using a total of 28 indicators. The study conclusively found terraces to be moderately vulnerable, mostly in sensitivity and adaptive capacity, to climate change extremes. Sneessens *et al*. (2019) designed an analytical framework to assess the financial vulnerability of farming systems. They implemented the framework in French farms and showed that diversification alone is not a risk-mitigating strategy. Less vulnerable mixed crop-livestock systems create less dependency on markets. Bangladesh is one of the countries. Mahmood *et al*. (2020) applied RS and GIS techniques and constituted a coastal vulnerability index (CVI) to suggest intervention areas along with the Meghna coastal areas in Bangladesh. In 2019, Sekovski, Rio and Armaroli (2019) experimented with and designed an index of physical vulnerability caused by sea-level rise and marine floods in the low-lying coastal area of Ravenna Province in Italy. In Nile delta of Egypt, Mohamed (2020) used GIS-based multi-criteria analysis and mapped the relative coastal vulnerability level in the form of an index (CVI). A significant portion of the shoreline was found to face a moderate to the high degree of vulnerability.

[1] After indicator value normalisation, the Iyengar Sudarshan vulnerability index equation was applied and in the index weights are assumed to vary inversely with variance over regions in the respective indicators on vulnerability. For further information on this can be accessed from http://ir.cut.ac.za/bitstream/handle/11462/2122/J79%20%20%20Iyenga%20Sudershan.pdf?sequence=1&isAllowed=y

Research Gaps and Future Priority Settings

Climate change is a fast-evolving phenomenon and, thus, vulnerability analysis is a research priority. Globally, the concept of vulnerability and its measurement approaches are rapidly evolving due to the growing impact of climate change. During the last two decades, agricultural vulnerability has gained high research attention; therefore, the research approaches and analytical framework have been going through a fast transformation. The development and implementation of different research approaches and techniques have not only strengthened the subject matter but also encouraged researchers to deeply experiment and explore its subtlety and nuances. The policy measures adopted by vulnerable regions are often aided and guided by the findings and recommendations of vulnerability research. However, like many other disciplines, agricultural vulnerability analysis is seriously constrained by a set of challenges that warrant scientific redressal to fortify vulnerability studies. Multitude of definitions, assessment approaches and application of several methods to depict the "vulnerability" and "adaptation" is a concern and it is related to complex nature of climate impact and strategies used to deal with them (Bedeke, 2023). Ishtiaque *et al*. (2022) highlighted concerns in conceptualizing of 'vulnerability', as introduced in the IPCC Fifth Assessment Report (AR5) and it has not been well accepted by the vulnerability researchers. Farmers' perception about the climate vulnerability also differs spatially. However, majority of the Indian farmers have perceived a risen temperature, and erratic and decreased rainfall are vulnerability indicators (Datta *et al*., 2022)

Defining Vulnerability in Research

The vulnerability of the whole agriculture system (including livestock, fisheries, etc.) is a broader research theme and needs to be differentiated from the vulnerability of just crop production in a region. Even within crop outputs, all-important crops having a major share in the farm outputs should be included for analysis purposes. Thus, type of vulnerability for research needs to be precisely defined and stated.

Indicator Selection and Weightage Assignment

Choice of indicators for different variables of sensitivity, exposure, and adaptive capacity needs to be executed through a statistical process. Arbitrary selection of a set of indicators without sufficient scientific exercise may dangerously mislead the analytics. There is a noticeable gap in this particular aspect that is to be reflected in future research. The growing deliberation on labour productivity loss owing to climate change has far-reaching consequences to making agriculture vulnerable. Future research should be more focused to investigate and bring out the factual information in suggesting remedial measures.

The climate change vulnerability index is used to assess the vulnerability of humankind to extreme climate events and variations in climate over the decades (Rana *et al.*, 2021). Several vulnerability studies are biasedly focused on biophysical parameters and unreasonably discount social dynamism rooted in gender, social class, economic capacity, and social cohesion of a community (Dong *et al.*, 2015). This is more relevant while agricultural vulnerability is studied since social dynamics in a

rural area is a prime determinant of vulnerability. The shifting focus from a natural ecosystem to an integrated system (socio-ecological) focus of the research will be more representative of vulnerability (Li *et al*., 2013). The collaborative research engagement between climate scientists and social researchers will enrich the studies and make them multidimensional. Vulnerability assessed through a perfect combination of bio-physical and socio-economic factors will be experimentally robust and holistic to present the real life scenario.

Researchers also need to be cautious to differentiate between underlying and manifest indicators for correct representation and avoidable duplication of risk variables. To cite an example if opting for crop insurance is recorded as an indicator of adaptive capacity, further inclusion of awareness and education about crop insurance as a variable perhaps will not add value but rather increase the load of the vulnerability model. Each indicator has a varying contribution to the combined vulnerability index. The relative importance of different indicators and assigning weightage accordingly is also tricky and generally subjective. For instance, an area with sufficient irrigation facilities is supposedly not impacted much by rainwater deficit, unlike a rainfed area. Therefore, the relevance and significance of an indicator need to be contextualized under different circumstances for appropriate weightage allocation. Expert analysis often used for this purpose is unavoidably biased, thus, increasing the application of better techniques, such as AHP analysis, artificial neural network techniques, weightage fixation. In the times to come, research should be directed to eliminate disadvantages associated with these methods and facilitate to building and apply more scientific techniques.

Contribution of Components to Vulnerability

Contemporary vulnerability researchers largely adopt IPCC analytical framework and evaluate it on three major components — sensitivity, exposure, and adaptive capacity. The estimated combined score quantifies the vulnerability magnitude; however, there is a substantial research gap in decomposing the contribution of these three components to the overall vulnerability measurement (Eddoughri *et al.*2022). This is essential in formulating targeted policy measures to reduce vulnerability. The research discourse should set the priority on this particular aspect.

Data Constraints

Metric measurement of agricultural vulnerability sets a precondition of access to quality of data on different indicators. Such datasets in advanced countries are well managed and in use for multiple purposes. However, data constraint is a serious challenge in developing nations where scientists struggle to access the data, even where it is available, quality is always a concern (Choudhary and Sirohi, 2022). This particular constraint can be mitigated with scientific storage and management of key indicators data to enrich future studies on agricultural vulnerability.

The Mixed Method in Vulnerability Analysis

There is a growing consensus to adopt a mixed method to study a subject matter like agricultural vulnerability and it necessitates the importance of employing qualitative

approaches and techniques. The application of the participatory rural appraisal technique offers tremendous advantage of validating conclusions generated in the quantitative section. The robustness, reliability and acceptability of vulnerability research increase when results are substantiated through a combination of the research approaches.

Conclusion

In the coming years, the research on the vulnerability of agriculture due to climate change will see innovation, enhancement, and development in adopting holistic multidisciplinary approaches to emerging research and policy questions. The scope of vulnerability and its components will be widened and measured through robust scientific methods. However, selection and application of a particular approach should be guided by the nature of the research problem and contextual comprehension of the research needs. However, in depth analysis of the research questions shall be the guiding principle to adopt approaches for studying vulnerability. In case of agricultural vulnerability, it has its own computation challenges because of the nature of indicators and their measurements. Elements that constitute vulnerability in agriculture in a particular context remain contentious. Therefore, further standardization of measurement methods and research approaches are strongly advised. Selection of methodology is critical, as it has bearing on accuracy and robustness of the assessment. The increasing application of simulation methods and software-enabled assessment should be further refined and adjusted for real time quantification of vulnerability with higher degree of accuracy. The importance of people's perception about vulnerability in agriculture is another area often ignored and under-represented in vulnerability model. The participatory appraisal tools can be beneficial in defining and then assessing vulnerability in agriculture. The paucity and inaccuracy of data pertaining to selected indicators is an impediment to estimate correctly the extent and intensity of vulnerability, especially when measured for smaller geography. Nevertheless, such challenges can be significantly overcome by employing a mixed method of analysis including participatory rural techniques. These will contribute to the ultimate purpose of enriching the discipline with a fast-paced scientific innovation in the concept, content, and quantification of agricultural vulnerability.

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Authors' Contributions (in accordance with ICMJE criteria for authorship)

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Conceived and designed the research or analysis	Yes	Yes	Yes
Collected the data	Yes	No	Yes
Contributed to data analysis & interpretation	Yes	Yes	Yes
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Research involving human bodies or organs or tissues (Helsinki Declaration)
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M – 00331 | Methods Article

Using Multispectral Images to Establish Land Categories

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Abstract

At the present stage, the dominant means of obtaining information is space shooting, which is carried out from space carriers with the help of special shooting equipment, and makes it possible to obtain high-quality images covering a significant area of the earth's surface. Methods combining multi-criteria analysis and GIS technologies can be used to make appropriate environmental decisions. At the same time, an important component for all interested parties is obtaining the original information at the lowest cost. In this regard, this publication provides a methodology for constructing maps of land categories, which is based exclusively on a free basis. This methodology includes free and open FOSS software, space images of the Landsat 8 satellite, and multi-criteria analysis of space image processing. The procedure of the methodology includes the creation of a database based on available land management documents, cadastral plans and maps, satellite images, etc.; processing of the database using multi-criteria analysis; analysis of the results and decision-making. The database is created using QGIS software, and PostgreSQL with the PostGIS extension is used for modeling and data storage. MultiSpec software was used to create multispectral images, perform satellite image classification and evaluation. Using a set of the above software products and Landsat 8 satellite images, a pilot project on an area of 615 km2 was carried out to determine the capabilities of this methodology for establishing land categories. It was established that the multispectral image of the combination of 6-5-2 channels best represents land categories. The accuracy of the classification is 96.2%, and the User Accuracy for arable land is almost 100%, for orchards 55%, and for hayfields and pastures 61.3%.
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Keywords

Land categories; Space images; Multi-criteria analysis

Introduction

Land resources are characterized by a multifaceted nature of use. They, along with other natural resources, are a component of the environment, means of production, and a source of satisfying

human needs. Activities related to the use of land resources are particularly important for economic relations, but have led to a number of environmental and economic problems, the most important of which are inefficient land use, soil deterioration, degradation, water and wind erosion, and so on. Land is a limited natural resource; so human society must manage its national wealth wisely and sparingly. Special attention should be paid to the justification of proposals for the rational use and protection of land, improvement of the conditions, and mechanisms of effective land use (maximum involvement in the economic circulation of all lands and implementation of their effective use).

A quick and high-quality assessment of land resources through a comprehensive analysis of available spatial data will help provide the process of land resource administration with reliable information (Koeva, Bennett and Persello, 2022). In the modern world, these important tasks are solved on the basis of aerospace information and innovative technologies for its processing and use. Space shooting, which is carried out from space carriers with the help of special shooting equipment, makes it possible to obtain high-quality images covering a significant area of the Earth's surface. Space and aerial photography materials are widely used for mapping and solving applied problems in various fields of science and technology: ecology (Young *et al*., 2017; Zhe, Shi and Su, 2022), medicine (Maxwell, 2010), agriculture (Boryan, 2011), (Stupen, Stupen and Stupen, 2018), solar energy (Kereush and Perovych, 2017; Kereush and Perovych, 2019; Sanchez-Lozano *et al*., 2013) and others. Every year, the volume of cartographic and geo-information products increases, new areas of application of space survey data appear. Currently, many algorithms for processing space images have been developed, and satellite monitoring systems of agricultural lands have been created at the global level (Eastman *et al*., 1995; Tso and Mather, 2009).

In the United States, a number of laws, including the Landsat program, have been adopted to ensure the leading role of the country in obtaining and using remote Earth observation data. Within these documents, at the apex legislative level, the importance of the Landsat operational program of the satellite data obtained within it is described and established. A system that combines multi-criteria analysis and the application of GIS technologies and takes into account the ecology, orography, location and climatic factors can be applied to take appropriate environmental decisions (Aran Carrion *et al*., 2008).

Thus, it can be articulated that the combination of GIS and multi-criteria analysis generates an *analysis tool* that allows creating an extensive cartographic database, which will later be used to make effective decisions. In the land management, a number of important tasks arise in terms of prompt determination of land categories and their registration in the cadastral system. From this point of view, to obtain reliable cadastral information in a short period of time that can be quickly implemented into the cadastral system, it is important factor in the effective administration of land resources. In particular, this applies to determine the combination of spectral channels to form an effective multispectral image of land categories.

The use of these approaches to the definition of land categories allows in the future carrying out constant monitoring of their conditions, which will contribute to the

increase in the efficiency of the use of land resources in terms of individual categories and to the reduction of risks related to the deterioration of their condition. At the same time, it becomes possible to optimize the ratio of land categories not only with the aim of minimizing the impact on the environment, but also ensuring the socio-economic development of a certain territory.

This study is devoted to aspects of the possibility of applying this methodology to determine land categories.

Methods and Materials

In order to provide an opportunity for all interested investors, entrepreneurs and executive authorities to create their own land structure map for free. A technology for processing space images of the Earth's surface using FOSS software with freely available data sources is proposed. Free access to the archive of satellite images taken over different periods of time and by different imaging systems (including data from the Landsat, Sentinel-2, NOAA CDR, eMODIS LST missions) is available on the website of the United States Geological Survey. Appropriate images were selected for research using the navigation functions of the Earth Explorer data request tool (https://earthexplorer.usgs.gov). It provides an opportunity to customize the data request by selecting the type of satellite, the level of processing of the space image, the coordinates of the studied area, the date of obtaining the image and the percentage of cloud cover.

Creation of the proposed database is implemented exclusively using FOSS (free and open source software). It is suggested to use PostgreSQL database with PostGIS extension. The main advantage of PostGIS is that it is free and it combines the SQL programming language with spatial operators and functions. In addition to simple data storage, PostGIS allows to perform all kinds of operations on data, and also has a strong connection with QGIS Software. For this purpose, PostgreSQL Open Source Database with PostGIS extension, QGIS and MultiSpec software were used. PostgreSQL Open Source Database with PostGIS extension is used for modeling and data storage. QGIS is for uploading, managing, sharing, analyzing and visualizing the data. Therefore, the application of FOSS software consisted of PostgreSQL Open Source Database with PostGIS extension, QGIS and MultiSpec software.

To determine the land cover, it is necessary to classify the satellite image. The classification of satellite images involves the grouping of pixels into meaningful classes to represent land cover features. Automated satellite image classification methods use algorithms that group pixels into meaningful categories (classes). For this study, it is proposed to use the method of maximum likelihood and controlled classification of satellite images due to its better accuracy and quality of presentation of results. Maximum likelihood method is a statistically controlled approach for pattern recognition (Tso and Mather, 2009). It separates pixels into appropriate classes based on the likely values of the pixels. The maximum likelihood method is an efficient common method for classifying satellite image pixels. An important element of this methodology is the creation of a multispectral image based on combinations of individual spectral channels. From the list of combinations of spectral channels, the best can be chosen to contribute to solving the task at hand. For that, the MultiSpec

software was used. Supervised classification consisted of analyzing pixels within each reference polygon and creating spectral signatures for each land cover type. Image classification was performed by comparing the spectral values of pixels with the generated signatures (training samples). Actually, the accuracy of the method largely depends on the accuracy of the definition of the training sample. So, the training samples consisted of two types, one of which was used for classification and the other for checking the accuracy of the classification. For this purpose, the accuracy of the manufacturer and the accuracy of the user and the reliability coefficient of the classification were determined. It created an accuracy matrix representing the distribution of pixels. Producer Accuracy shows the percentage of a certain basic class that is correctly classified. User Accuracy is an indicator of classification efficiency. It indicates the percentage of probability that the class to which a pixel is classified actually represents that class in the area (Story and Congalton, 1986). The classification reliability indicator was determined by the k coefficient (Cohen, 1960).

The procedure for implementing the methodology involved the analysis of the structure of land resources under the research, collection of raw data, creating a database, data processing, and, at the final stage, analysis of the received map of land categories with verification of its reliability and appropriate decision making. One of the most important problems of land management is obtaining reliable geospatial information with accuracy of geometric parameters of land plots and land. This aspect is absent in this methodology, which calls for additional research to address this issue. The use of this methodology to determine the categories of land covered by different types of vegetation definitely has some limitations. To eliminate the limitations, the identification of land plots was conducted by their direct survey on the ground.

Results

The implementation of this technology was carried out in an area of 615 km^2, which is covered by one satellite image. The Landsat 8 OLI / TIRS Collection 1 satellite image received on 19 August 2016, the data of which is presented in DN units, is geometrically corrected the processes of georeferencing and orthorectification (correction of effects due to the influence of the terrain). The Landsat 8 satellite has two sensors: the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS). Wavelengths and spatial resolution of each spectral channel of Landsat 8 OLI/TIRS (US Geological Survey, Landsat 8 Imagery) are presented in the table 1.

Multispectral images were created for satellite image classification. At the same time, it is important to find such a combination of spectral channels, which can best identify different types of land categories. Creation of multispectral images was performed in the MultiSpec software environment. For this, all necessary spectral channels were imported into it, and the procedure for combining separate files of spectral channels into a single multispectral image file (Combining Separate Image Files into a Single Multispectral Image File) was performed. Particular attention was attached to defining the category of agricultural land with the allocation of certain types of land (arable land, pastures and hayfields, perennial plantations - gardens), stony land and land of forest and water areas. In other words, most attention was given to the dominant land categories in the project area.

Table 1: Wavelengths and spatial resolution of Landsat 8 OLI/TIRS spectral channels

Spectral channel Wavelengths	*Spatial resolution (size 1 pixel), μm*	*OLI ranges, m*
Channel 1 Coastal / Aerosol, New Deep Blue	0.433 - 0.453	30
Channel 2 – Blue	0.450 - 0.515	30
Channel 3 – Green	0.525 - 0.600	30
Channel 4 – Red	0.630 - 0.680	30
Channel 5 – Near Infrared	0.845 - 0.885	30
Channel 6 - Short Wavelength Infrared, SWIR 1	1.560 - 1.660	30
Channel 7 Short Wavelength Infrared, SWIR 2	2.100 – 2.300	100
Channel 8 – Panchromatic, PAN	0.500 - 0.680	15
Channel 9 – Cirrus	1.360 - 1.390	30
Channel 10 - Long Wavelength Infrared (TIR1)	10.30 – 11.30	100
Channel 11 - Long Wavelength Infrared (TIR2	11.50 - 12.50	100

As a result, five multispectral images were obtained with a spatial resolution of 30 m. The analysis of multispectral images showed that the multispectral image "channels 6-5- 2" best represents land categories (Figure 1).

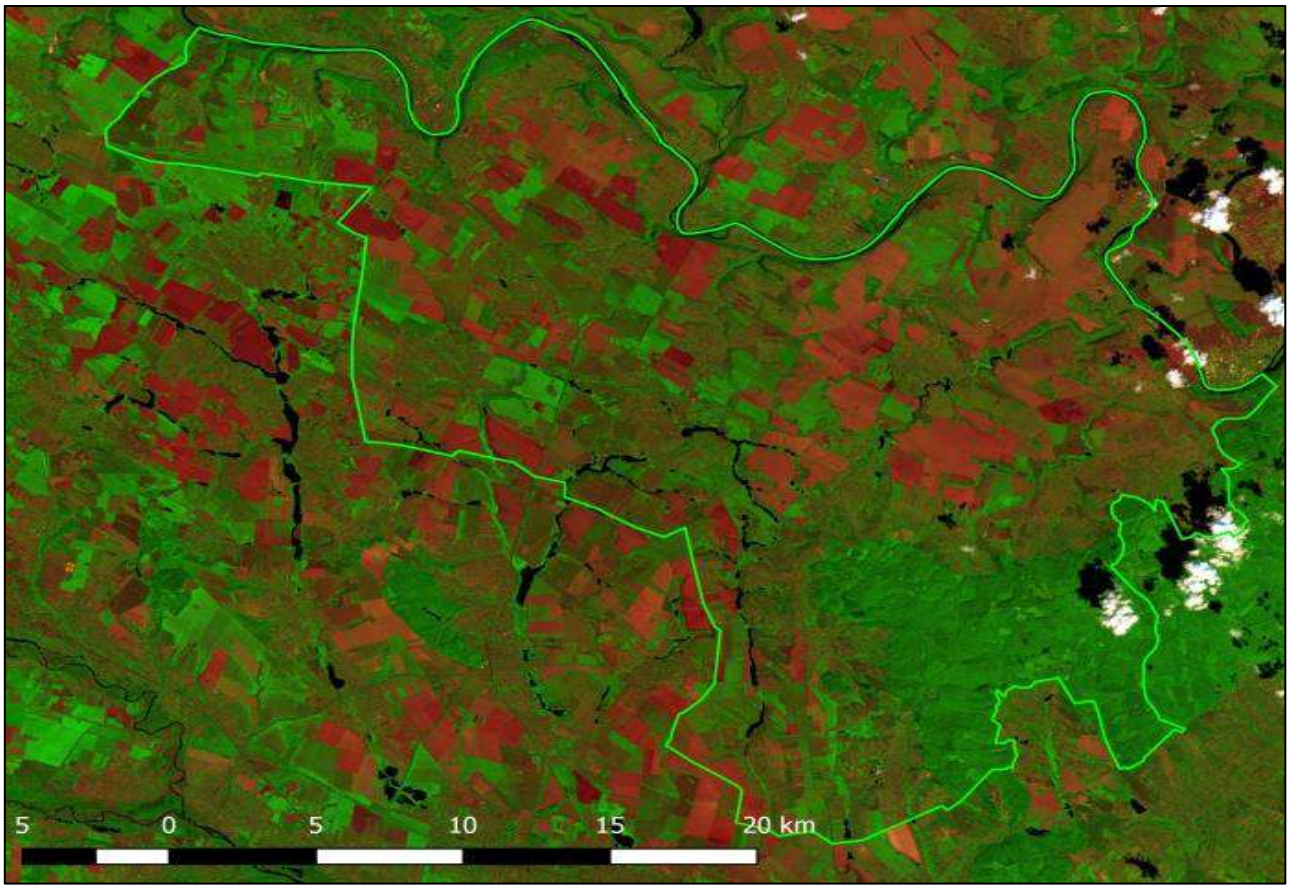

Figure 1: Multispectral image of the Earth's surface

On this multispectral image (Figure 1), arable land with green vegetation is displayed in bright green colors; arable land with dry vegetation (in burgundy color); arable land with open soil appears in pink; hayfields and pastures in green-brown color; forest in green and dark green colors; and stony lands in light pink color. The method of maximum likelihood was used for the controlled classification of the satellite image. For this, the multispectral image “channels 6-5-2" was imported into the MultiSpec software in order to create training samples (regions of interest) according to the land category. Supervised classification was used to identify classes and to calculate their signatures. In the research process, the following 11 training samples were created with the appropriate signature sizes:

1. Water bodie - 108 pixels;
2. Forest – 4,871 pixels;
3. Gardens – 300 pixels;
4. Rocky lands - 10 pixels;
5. Hayfields and pastures - 780 pixels;
6. Arable lands with open soil – 4,338 pixels;
7. Arable lands with dry vegetation – 3,104 pixels;
8. Arable lands with green vegetation – 1,940 pixels;
9. Arable lands with semi-dry vegetation – 2,502 pixels.

After creating the samples, the procedure of controlled classification was performed using the method of maximum likelihood. As a result of the procedure, a table of the results of the "Training Class Performance" classification (accuracy matrix for each class) was created along with the coefficient k (Cohen's kappa). Producer Accuracy and User Accuracy were also determined for each class. At the final stage, a resulting map of land categories was created in GeoTIFF format (Figure 2).

As a result of the processing of the initial data, the coefficient κ equal to 0.962 was determined, which indicates the high accuracy of the performed classification - 96.2%. User Accuracy - almost 100% - was achieved for most reference areas, with the exception of gardens (55%) and hayfields and pastures (61.3%). From the "garden" class, 135 pixels were classified into the "Forest" class, because they have very similar spectral brightness values of the classes. The same problem arose during the classification of hayfields and pastures. The spectral brightness values of this class and the "arable land with semi-arid vegetation" class are also similar; so, out of the total number of 780 pixels of the "hayland and pasture" class, 286 pixels were classified into the "arable land with semi-dry vegetation" class. In this case, it is proposed to evaluate each set of pixels of the "arable land with semi-arid vegetation" class for visual determination of the real type of the Earth's surface, according to Google Satellite Map data.

Thus, as a result of the implementation of the proposed methodology, the resulting land map was obtained, which includes the lands of water and forest lands, stony lands, as well as such agricultural lands as hayfields and pastures, arable lands covered and not covered with vegetation. Experience shows that, for the reliable identification of land plots covered with high vegetation (gardens, forests), as well as of the same type (pastures, hayfields), it is advisable to make field surveys in advance.

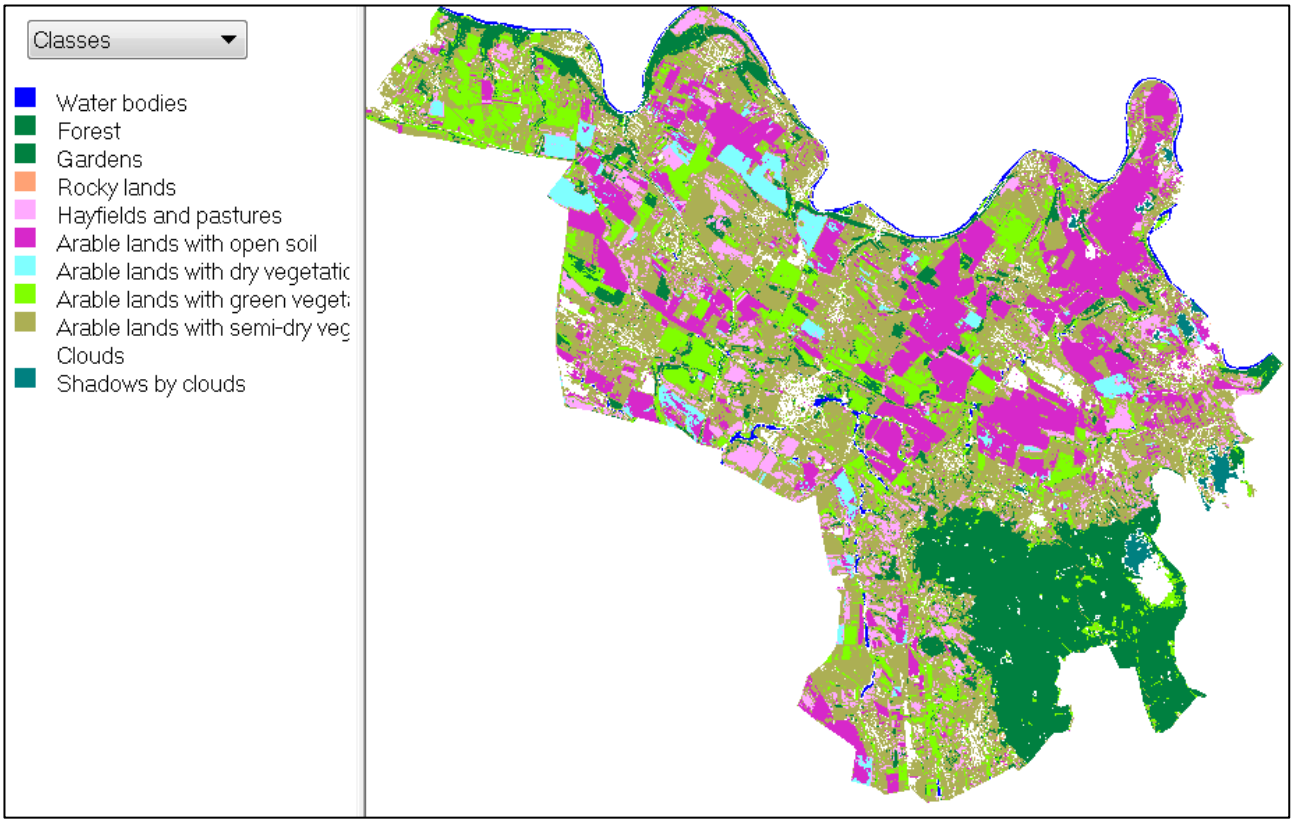

Figure 2: Map of land categories

Conclusion

The structure of land resources is an important factor in determining development of territories. To this end, the possibility of applying the methodology for determining land categories on a free-of-charge basis was investigated. This methodology provides for a holistically theoretically grounded mechanism for determining land categories. It involves the use of LANDSAT 8 OLI/TIRS satellite imagery and freely available QGIS, PostgreSQL, PostGIS and MultiSpec software products and the selection of a combination of spectral channels to build a multispectral image that would meet the task of mapping land categories, evaluating the results, and making the decisions.

In the process of implementing this methodology, it was found that the multispectral image of the 6-5-2 spectral channel combination best represents land categories. User Accuracy for most of the reference plots (arable, water and stone) is almost 100%, which indicates the correct classification of pixels. However, for the land plots covered with tall vegetation, in particular, for gardens, hayfields and pastures, this figure is 55% and 61%, respectively. This allows us to conclude that this methodology is effective in determining the categories of open land, and that field surveys should be carried out beforehand to identify closed land.

The application of this methodology in land management at different epochs will lead to an improvement in the result of its use, as it will allow for operational control over the state and dynamics of changes in the structure of land categories, which in turn will facilitate the adoption of informed decisions on their land protection and use. In the future, the results of the research can be used primarily by specialists of the agro-industrial complex, investors and private entrepreneurs to monitor the state of the structure of land resources and determine the feasibility of their use for the intended purpose, as well as by a wide range of specialists in the field of land management in the course of land inventory and cadastre registration, etc.

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Authors' Declarations and Essential Ethical Compliances

Authors' Contributions (in accordance with ICMJE criteria for authorship)

Contribution	*Author 1*	*Author 2*	*Author 3*	*Author 4*
Conceived and designed the research or analysis	Yes	Yes	Yes	Yes
Collected the data	Yes	Yes	No	No
Contributed to data analysis & interpretation	Yes	Yes	Yes	Yes
Wrote the article/paper	Yes	No	No	No
Critical revision of the article/paper	Yes	Yes	Yes	Yes
Editing of the article/paper	Yes	Yes	Yes	Yes
Supervision	Yes	No	No	No
Project Administration	Yes	No	Yes	No
Funding Acquisition	No	No	No	No
Overall Contribution Proportion (%)	50	20	20	10

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Research involving human bodies or organs or tissues (Helsinki Declaration)
The author(s) solemnly declare(s) that this research has not involved any human subject (body or organs) for experimentation. It was not a clinical research. The contexts of human population/participation were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or ethical obligation of Helsinki Declaration does not apply in cases of this study or written work.

Research involving animals (ARRIVE Checklist)
The author(s) solemnly declare(s) that this research has not involved any animal subject (body or organs) for experimentation. The research was not based on laboratory experiment involving any kind animal. The contexts of animals not even indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or ethical obligation of ARRIVE does not apply in cases of this study or written work.

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The author(s) solemnly declare(s) that this research has not involved any Indigenous Peoples as participants or respondents. The contexts of Indigenous Peoples or Indigenous Knowledge, if any, are only indirectly covered, if any, through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or prior informed consent (PIC) of the respondents or Self-Declaration in this regard does not apply in cases of this study or written work.

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(Optional) Research Involving Local Community Participants (Non-Indigenous)
The author(s) solemnly declare(s) that this research has not directly involved any local community participants or respondents belonging to non-Indigenous peoples. Neither this study involved any child in any form directly. The contexts of different humans, people, populations, men/women/children and ethnic people are only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or prior informed consent (PIC) of the respondents or Self-Declaration in this regard does not apply in cases of this study or written work.

(Optional) PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses)
The author(s) has/have NOT complied with PRISMA standards. It is not relevant in case of this study or written work.

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Pastoralists' Socioecological Trends: The Case of Laikipia County in Kenya

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Abstract

Pastoralism is a complete way of life involving ecological, political, economic and social dimensions, and is dependent on a continuous balance of diverse factors. However, pastoral systems are faced with emerging and accelerating shocks and stresses that challenge their resilience and the ability to meet household livelihood needs sustainably. In response to these pressures, pastoralist socioecological systems in Africa are undergoing a process of rapid transformation that is marked by positive and negative socio-ecological trends. This study, therefore, analyzed the socioecological trends of pastoral systems with a focus on Laikipia County, Kenya. The study used a participatory action research design and multi-stage sampling design. Data collection and analysis were done using the participatory trend analysis method, while Mann-Kendall Z Test and Kendall's correlation coefficient were used to test the trends and their relationships. This study finds that pastoralists' culture and lifestyles are changing as shown by the negative trend in observation of cultural practices (Z = - 4.22, P<0.001) and effectiveness of customary governance systems (Z = - 0.401, P<0.001). Secondly, although the total number of livestock is increasing (Z = 3.11, P<0.01), there is a downward trend in the livestock holding per household (Z = -3.83, P<0.001), and, hence increasing diversification to non-pastoral livelihoods (Z = 4.28, P<0.001). These changes are caused by the growing pressure on pastoral resources and ecological stresses due to various factors, including the increasing human population (Z = 4.22, P<0.001), land degradation (Z = 4.17, P<0.001), and climate change and variability (Z = 4.05, P<0.001). Therefore, the study enabled an understanding of pastoralists' socioecological trends and the underlying drivers. Moreover, the study showed the impacts of the drivers, their feedback on each other, and the responses of the pastoral system. The study will strengthen pastoral development planning and policy-making processes.

Keywords

Pastoralist; Trend; Livelihood; Livestock; Resources

Introduction

Pastoralism is a complete way of life involving ecological, political, economic and social dimensions, and is dependent on a continuous balance of diverse factors (FSAU, 2001). Pastoral livelihood systems are, thus, able to deal with a delicate balance of

factors, which make them relatively resilient to temporary shocks and stresses (FSAU, 2001). However, pastoral systems are faced with emerging and accelerating political, economic, social, political, ecological and climate shocks and stresses that challenge their resilience and ability to adapt (Dong *et al*., 2011; Turner, 2011; Reid, Fernandez-Gimenez and Galvin, 2014).

Therefore, many pastoral systems are failing to meet households' livelihood needs and sustainably managing the natural resource base (Kaye-Zwiebel and King, 2014). This is evidenced by several studies that observed that pastoralism is increasingly becoming vulnerable to the effects of climate change and variability (Ouma *et al*., 2018). In addition, although pastoralists' socioecological systems have historically been very resilient, recently there has been a trend of an increasing frequency and magnitude of sudden livestock production losses (Cottrell *et al*., 2015).

In Sub-Saharan Africa, such breakdowns in resilience are a complex legacy of the last century (Kaye-Zwiebel and King, 2014). Colonization, nation formation, population growth, social and economic modernization, and the imposition of statutory land tenure systems have frequently impinged on the pastoralist's way of life (Kaye-Zwiebel and King, 2014). These factors have tended to decrease pastoralists' capacity for customary governance and grazing management, and to restrict the traditional strategies for coping with disturbances such as drought (Fratkin, 2001; Catley, Lind and Scoones, 2013). Besides, the sustainable management of pastoralism in many countries has been impeded by the political, social and economic marginalization of pastoralists (Davies *et al*., 2010; Wynants *et al*., 2019). This marginalization has resulted in chronic under-investment and under-development in pastoralist communities, inappropriate plans and policies, the resultant constraints on pastoralism growth and viability, and an increase in vulnerability (Kirkbride, 2008; Davies *et al*., 2010).

Pastoralists are, thus, facing more pressure on their way of life than ever before (Fratkin and Mearns, 2003). In response to these pressures, pastoralists' socioecological systems in Africa are undergoing a process of rapid transformation (Galvin, 2009; Korf, Hagmann and Emmenegger, 2015). For example, socioecological transformation in Kenya's Arid and Semi-Arid Lands is associated with population growth, in-migration, rapid sedentarization, changes in traditional land use and land tenure regimes, high poverty levels, natural resource-based conflicts, and changes in gender roles, among others (Njoka *et al*., 2016). Moreover, pastoralism is evolving in response to land degradation, increasing frequency of droughts, overgrazing (Kassahun, Snyman and Smit, 2008), the decline in livestock holdings (Elias, 2014), agricultural expansion (Schmidt and Pearson, 2016), and the increasing commoditization and inequality in the livestock economy (Fratkin and Mearns, 2003).

In light of above, any development planning or policymaking in pastoral areas should be based on a sound understanding of the ongoing socioecological trends (Rodgers, 2021). According to ODI (2009), pastoralist trends need to be part of the agenda in drylands development so that the changes and their consequences are taken into account. Besides, Wynants *et al*. (2019) noted that taking the complex drivers of change into consideration and building upon existing linkages between social, economic and ecological demands are keys to the attainment of sustainable land management in pastoral systems. Therefore, understanding the challenges and

opportunities associated with transitions in pastoralism is paramount for the development of appropriate policies and informing interventions (ODI, 2009). Nagash (2021) noted that a holistic understanding of a pastoral system and its transition and the likely trade-offs associated with different livelihood strategies in the system are prerequisites to developing supportive plans and policies that are consistent with existing situations and future expectations. Additionally, Jiang, Niu and Wu (2019) in a study of Inner Mongolia deduced that an improved understanding of changes and the potential drivers may help foster strategies to sustain the pastoral system.

This calls for participatory analysis of the pastoral system to enable a deeper understanding of issues and identification of effective approaches for the management of pastoral resources (Gelan, Getahun and Beyene, 2017). Moreover, Boles *et al*. (2009) pointed out that understanding the connections between different agents and pressures demands nuanced evidence-based analyses rather than a priori generalization. Such an analysis should involve a long timescale and be informed by an interdisciplinary analysis to account for the diverse drivers of change (Boles *et al*., 2009). Furthermore, the analysis should acknowledge the spatiotemporal context and account for historical variability in landscape ontogenies (Boles *et al*., 2019). According to ODI (2009), though pastoralists are regarded as homogenous groups with the livestock economy at the core of their livelihood systems, the transformation processes in pastoral communities are different. It is also important to note that the potential impacts of the drivers of pastoral transformations, their feedback on each other, and the responses of the pastoral systems vary greatly within and across socioecological contexts (Fratkin and Mearns, 2003; Steinfels, Wassenaar and Jutzi, 2006;). Manzano *et al*. (2021) observed that knowledge gaps caused by studying diverse systems under a single umbrella and a lack of interdisciplinary integration are the reasons behind the development of unfavorable pastoral policies and plans.

This study, therefore, aimed to analyze the socioecological trends of pastoral systems with a focus on Laikipia County, Kenya. The study analyzed how pastoral systems have evolved across demographic, social, economic, environmental and economic dimensions. This was by studying the status of various aspects of pastoral socioecological systems in the past, how they changed along the years, and their current state. Moreover, the study analyzed the drivers behind the observed trends, including the relationships and influences between the various factors under study, feedbacks of these influences, and the ongoing responses within the system. Therefore, the study led to an understanding of the factors that led to the current state of the pastoral socioecological system, and thus how the various challenges facing the community could be addressed and existing opportunities strengthened. The study is, thus, key to informing development planning and policy-making processes in pastoral communities.

Methodology

Description of the Study Area

Laikipia County (Figure 1) lies on the leeward side of Mount Kenya and covers an area of 9,462 km^2 (Government of Kenya, 2015). The county has a population of 518,560 people and a population density of 74 people per square kilometer, and average household size is 4 people (Government of Kenya, 2019). Laikipia County

experiences a relief type of rainfall whose distribution is strongly influenced by Mount Kenya and the Aberdares Ranges (GLOPP, 2007; Roden *et al*., 2016). The rainfall ranges between 300 mm in the North to 1,000 mm per annum in the West, and is bimodal but generally erratic (Gichuki *et al*., 1998; Mwiti, 2006; Roden *et al.*, 2016). The mean temperature in the county is 24^{o}C (Kohler, 1987) and ranges between 16^{o}C and 26^{o}C (Mwangi, 2014). Most of the county falls within the arid and semi-arid agroecological zones with small areas on the foot of the mountain's slopes falling in the sub-humid zone (Sombroek, Braun and Van der Pauw, 1980). Large parts of the county lie in ecological zone IV, but the Northern part falls in agroecological zone V and VI (FAO, 1996).

The soils in the county include volcanic soils, clay loams, black cotton soils, sandy soils, and sandy loam soils (Mwangi, 2014). The soil groups include lavisols, regosols, and lexisols to the North, phaezoms, and vertisols to the East, West, and Southeast, and nitisols in the forest complex near Nyahururu and the surrounding areas (Mwiti, 2006). The geology of the area includes pre-Cambrian, tertiary extrusive and intrusive, and quaternary extrusive and intrusive rocks.

Laikipia County comprises a mosaic of grasslands, bushlands, woodlands, and dry forests in the higher altitude areas (Butynski and De Jong, 2014; Witt, 2017). The County lies at the overlap of the Somali-Maasai bushland biotic zone and the Afromontane-Afro alpine biotic zone (Butynski and De Jong, 2014). Moreover, it falls under two eco-regions, including the Northern Acacia-Commiphora bushlands and thicket and the East African montane forest. The resultant great diversity of vegetation types, ecotones, and mosaics accounts for the high biological diversity of Laikipia County (Butynski and De Jong, 2014). Laikipia County is, thus, home to over 62 large mammal species, i.e. 21 carnivore species, 28 species of ungulates, 8 species of primates, and over 560 bird species (Butynski and De Jong, 2014). However, these habitats are threatened by a host of invasive alien species that are rapidly replacing indigenous vegetation (Witt, 2017).

Laikipia County was originally occupied by specialized hunters and gatherers (LWF, 2012). Early Laikipians included the Cushitic-speaking Yaaku People from Southern Ethiopia who co-existed with indigenous foragers until they were displaced and assimilated by the Nilotic Maa-speaking Laikipiak Maasai in the Eighteenth Century (Carrier, 2011). The original inhabitants were assimilated into the pastoral culture of the Laikipiak Maasai which they also considered to be superior to theirs, although they still practice beekeeping (Cronk, 2004). The arrival of the Europeans as settlers after the establishment of the British East Africa Protectorate in 1895 resulted in a major change in land tenure and use in Laikipia (LWF, 2012). This was, particularly, through the Anglo-Maasai treaties of 1904 and 1911, which led to the Maasai being moved to a Southern Kenya Maasai Reserve and others being confined in the Mukogondo Maasai Native Reserve in the Northern part of Laikipia by the colonial government (Mwiti, 2006; Hughes, 2007; Evans and Adams, 2016). The post-independence period also saw the arrival of other people, mainly from Central Kenya, through government-sponsored land redistribution programs and later on through land-buying companies in the 1960s and the 1970s. Over time, the population of Laikipia continued to grow as people were attracted by the availability of cheap land, grazing resources, and livelihood opportunities.

The settlement patterns in the county are uneven as influenced by their land potential, livelihood zones, infrastructural development, land use systems, river drainage systems, and availability of social amenities (Mwangi, 2014; Government of Kenya, 2015). The more agriculturally favourable landforms an arc around the Eastern, Southern, and Western boundaries of the county hosting most of its population (Weismann, 1998) while the Northern Arid and Semi-arid Lands area has the least population (Government of Kenya, 2015). The population in the county is largely rural (Government of Kenya, 2011).

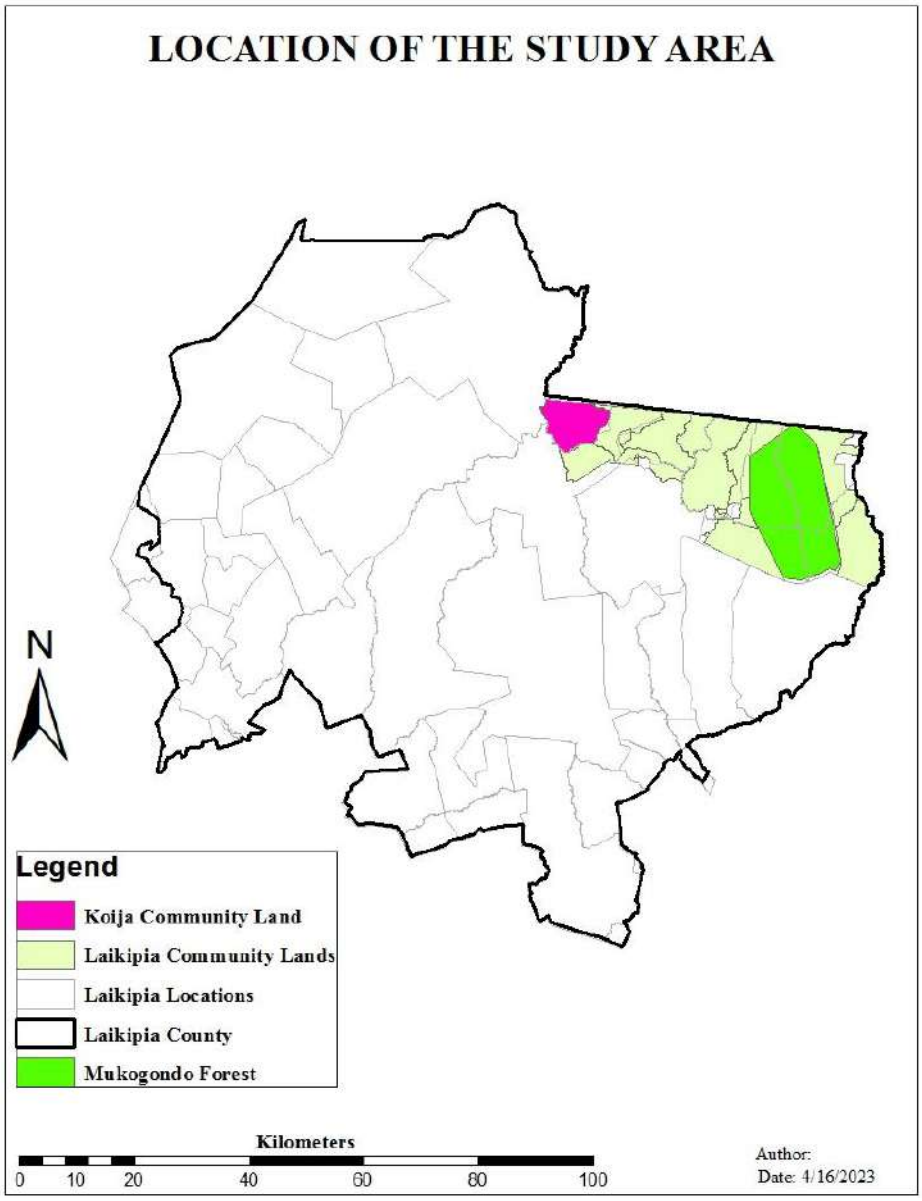

Figure 1: Location of the study area

The average land ownership varies, including smallholders (0.8 hectares), large-scale farmers (80 hectares), community group ranches (23 hectares), and commercial ranchers (10,000 hectares). The land tenure regimes include private, communal, and

public land tenure (Evans and Adams, 2016; LWF, 2012). Although the land was previously held communally, communal land tenure currently only exists in the pastoralists owned Mukogondo community lands in the Northern part. Agriculture is the dominant economic activity and is practiced by 85% of the population (Mwangi, 2014). The area under small-scale farming covers 33% of Laikipia County (Mwiti, 2006). Large-scale farms cover about 2% of Laikipia, mainly located along the rivers where irrigation agriculture is practiced (Mwiti, 2006).

The livestock sector constitutes a major economic activity in Laikipia (Kenya Association of Manufacturers, 2014). A large portion of Laikipia is utilized for ranching, with 43 large-scale ranches occupying about 60% of the county (Mwiti, 2006; Government of Kenya, 2013). These constitute 30 privately owned ranches and 13 community group ranches. The community group ranches are occupied by pastoralists and lie to the North in the Mukogondo Native reserve where the Maasai were restricted during the colonial era and are under communal land tenure (Mwiti, 2006; Government of Kenya, 2013). Most of the ranches in the county host wild animals and engage in wildlife-based, particularly tourism, enterprises.

Sampling Methods

The study used a multi-stage sampling design. First, Laikipia County was purposively chosen for the study. Secondly, Koija community land in Laikipia County was purposively chosen for the study given its wider representation of the Laikipiak Maasai Community and early settlement in the area. Thirdly, purposive sampling was used to choose a diverse group of 20 knowledgeable participants from the community land. The group had representatives from different sections of the community, including women, men, and youth from different age groups.

Research Tools

Data collection and analysis were done using the participatory trend analysis method. The participatory trend analysis was transdisciplinary and focused on changes regarding demographic, social, institutional, environmental and economic dimensions. It involved a participatory quantification of the changes that have occurred over a period of 12 decades, i.e. 1900s to the 1910s. The quantification of the changes was done by rating the status of a given variable in a specific decade against the other decades on a scale of 1 to 10. This yielded a trend line that helped to learn what was getting better and what was getting worse over time. In doing this, the participants first engaged in discussions to identify the most relevant period and intervals for the study. They also identified and settled upon the variables whose changes were to be analyzed for each of the study dimensions. More trends were identified as the discussions proceeded. Discussions were also involved in quantifying the state of the variables. The participants then discussed the interactions and linkages between the different trends to establish their causes and effects. This helped to establish the relationships between the trends. Further, the participants discussed the solutions that have been tried in the past to address the causes, how effective they were, and what could be done better to address the causes based on the analysis.

The trends arrived at through the participatory analysis were tested using the Mann-Kendall statistical Test. The Mann-Kendall statistical test is used to test the direction and significance of increasing or decreasing trends (monotonic trend) in time series data (Pal *et al*., 2017; Asfaw *et al*., 2018). The test was computed using MEKESENS, an MS excel template developed by the Finnish Meteorological Department for the detection and estimation of trends (Weldegerima *et al*., 2018). Further, Kendall's "tau-b correlation coefficient" was used to analyze the relationship between the trends, including their causes and effects. Kendall's "tau-b correlation coefficient" is a measure of rank correlation that measures the similarity of the orderings of the data when ranked by each of the quantities in paired observations (Kendall, 1955).

Measurement of Major Indicators

The measurement of indicators involved a participatory quantification of the changes that have occurred over a period of 12 decades, i.e. 1900s to the 1910s. The quantification of the changes was done by rating the status of a given variable in a specific decade against the other decades on a scale of 1 to 10.

Results

Demographic Trends

The human population in the study area was found to have a significant positive trend ($Z = 4.22$, $P<0.001$). The number of households also had a significant positive trend ($Z = 4.22$, $P<0.001$). Human population had a significant positive correlation with in-migration ($\tau b = 0.944^{**}$, $P<0.01$), and access to government services ($\tau b = 0.907^{**}$, $P<0.01$). Besides, human population had a significant positive correlation with the growth of urban areas ($\tau b = 0.944^{**}$, $P<0.01$), access to employment opportunities ($\tau b = 0.890^{**}$, $P<0.01$), and access to transport services ($\tau b = 0.933^{**}$, $P<0.01$). A significant negative correlation was found between the human population and mortality rates ($\tau b = -0.959^{**}$, $P<0.01$), and livestock mobility ($\tau b = -0.952^{**}$, $P<0.01$).

The size of the households had a significant negative trend ($Z = -4.16$, $P<0.001$). The size of the households was found to have a significant positive correlation with the birth rate ($\tau b = 0.924^{**}$, $P<0.01$). Moreover, the size of the household had a significant negative correlation with access to health services ($\tau b = 0.906^{**}$, $P<0.01$), access to education ($\tau b = -0.942^{**}$, $P<0.01$), and women empowerment ($\tau b = 0.932^{**}$, $P<0.01$). A significant positive correlation was also found between the size of the households and land adequacy ($\tau b = 0.984^{**}$, $P<0.01$), livestock ownership per capita ($\tau b = 0.876^{**}$, $P<0.01$), and food security ($\tau b = 0.882^{**}$, $P<0.01$). The birth rate had a significant negative trend ($Z = -3.88$, $P<0.001$). The birth rate was found to have a significant negative correlation ($\tau b = -0.891^{**}$, $P<0.01$) with access to health services, access to education ($\tau b = -0.897^{**}$, $P<0.01$), access to information ($\tau b = -0.926^{**}$, $P<0.01$), and women empowerment ($\tau b = -0.881^{**}$, $P<0.01$). The birth rate, however, had a significant positive correlation with livestock ownership per capita ($\tau b = 0.828^{**}$, $P<0.01$), food security ($\tau b = 0.903^{**}$, $P<0.01$), and observation of cultural practices ($\tau b = 0.992^{**}$, $P<0.01$).

The mortality rate in the study area had a significant negative trend (Z = - 4.17, *P*<0.001). The mortality rate was found to have a significant negative correlation with access to health services (τb = - 0.889**, P<0.01). Nevertheless, the morbidity rate was found to have a significant positive trend (Z= 3.44, P<0.001). The morbidity rate had a significant positive trend (Z = 3.44, *P*<0.001). The study revealed that morbidity rate had a significant positive correlation with climate change and variability (τb = 0.821**, P<0.01), drought frequency and severity (τb = 0.821**, P<0.01), land degradation (τb = 0.824**, P<0.01), and in-migration (τb = 0.827**, P<0.01). Moreover, morbidity had a significant negative correlation with food security (τb = - 0.870**, P<0.01), water availability, (τb = -0.794**, P<0.01), and observation of moral values (τb = - 0.817**, P<0.01).

The rate of out-migration was found to have a significant positive trend (Z = 4.05, *P*<0.001). Outmigration had a significant positive correlation with access to formal education (τb = 0.958**, P<0.01), access to transport services (τb = 0.938**, P<0.01), access to communication services (τb = 0.939**, P<0.01), and livelihoods diversification (τb = 0.935**, P<0.01). Similarly, outmigration had a significant negative correlation with conflicts (τb = 0.845**, P<0.01), climate change and variability (τb = 0.949**, P<0.01), drought frequency and severity (τb = 0.949**, P<0.01), and land degradation (τb = 0.933**, P<0.01). Conversely, outmigration was found to have a significant negative correlation with security (τb = - 0.815**, P<0.01), land adequacy (τb = - 0.968**, P<0.01), and livestock ownership per capita (τb = - 0.924**, P<0.01).

The rate of in-migration had a significant positive trend (Z = 4.17, *P*<0.001). In-migration was found to have a significant positive correlation with access to government services (τb = 0.900**, P<0.01), access to education (τb = 0.960**, P<0.01), and access to health services (τb = 0.874**, P<0.01). Moreover, in-migration had a significant positive correlation with access to transport services (τb = 0.943**, P<0.01), access to communication services (τb = 0.909**, P<0.01), growth of urban areas (τb = 0.968**, P<0.01), and access to markets (τb = 0.976**, P<0.01). A significant positive correlation was also found between in-migration and livelihoods diversification (τb = 0.952**, P<0.01), ecotourism (τb = 0.880**, P<0.01), and sand harvesting (τb = 0.961**, P<0.01). In addition, in-migration had a significant positive correlation with access to veterinary services (τb = 0.886**, P<0.01), and a significant negative correlation with incidences of livestock diseases (τb = - 0.815**, P<0.01).

The number of female-headed households in the study area was found to have a significant positive trend. The number of female-headed households had a significant positive correlation with access to education (τb = 0.943**, P<0.01), outmigration (τb = 0.935**, P<0.01), livelihood diversification (τb = 1.000**, P<0.01), and women empowerment (τb = 0.900**, P<0.01). Conversely, the number of female-headed households had a significant negative correlation with observation of moral values (τb = - 0.944**, P<0.01), and observation of cultural practices (τb = - 0.944**, P<0.01).

The analysis of the demographic trends was as shown in table 1.

Table 1: Analysis of demographic trends

#	*Trend*	*1900s*	*1910s*	*1920s*	*1930s*	*1940s*	*1950s*	*1960s*	*1970s*	*1980s*	*1990s*	*2000s*	*2010s*	*Mann-Kendall (Z) Test*	*Sig*
1	Human population	2	2	3	3	4	4	5	6	7	7	8	9	4.22	***
2	Number of households	1	2	2	3	3	4	5	6	7	7	8	8	4.22	***
3	Size of the households	9	8	8	7	7	6	6	5	5	4	4	3	-4.16	***
4	Birth rate	10	9	9	9	8	8	8	7	7	7	6	6	-3.88	***
5	Mortality rate	9	8	8	8	7	7	6	6	5	4	3	2	-4.17	***
6	Morbidity rate	3	4	5	5	5	6	6	6	8	8	7	7	3.44	***
7	Out-migration	1	1	1	2	2	3	3	4	4	5	5	6	4.05	***
8	In-migration	1	2	2	3	4	5	6	6	7	8	8	9	4.17	***
9	Number of female-headed households	1	1	2	2	3	3	4	6	7	8	9	10	4.28	***

Social Trends

Access to formal education had a significant positive trend (Z = 4.17, *P*<0.001). Access to education had a significant positive correlation with access to government services (τb = 0.940**, P<0.01), urban growth (τb = 0.960**, P<0.01), women empowerment (τb = 0.904**, P<0.01), infrastructure development (τb = 0.908**, P<0.01), in-migration, (τb = 0.960**, P<0.01), out-migration (τb = 0.958**, P<0.01), and access to information (τb = 0,943**, P<0.01). Access to education had a non-significant positive correlation with community participation in decision-making (τb = 4.10, P<0.01).

Access to modern health services in the area was also found to have a significant positive trend (*Z* = 3.88, *P*<0.001). Access to health services had a significant positive correlation with access to government services (τb = 0.841**, P<0.01), access to formal education (τb = 0.878**, P<0.01), access to formal education (τb = 0.878**, P<0.01), women empowerment (τb = 0.878**, P<0.01), infrastructure development (τb = 0.938**, P<0.01), access to transport services (τb = 0.873**, P<0.01), and access to information (τb = 0,926**, P<0.01). Access to health services had a non-significant positive correlation with community participation in decision-making (τb = 4.15, P>0.1).

The study found food security to be declining significantly in the study area (*Z* = -3.80, *P*<0.001). The study revealed that food security had a significant positive correlation with number of livestock per household (τb = 0.838**, P<0.01), land adequacy (τb = 0.868**, P<0.01), land tenure security (τb = 0.671**, P<0.01), effectiveness of land management (τb = 0.739**, P<0.01), livestock mobility (τb = 0.942**, P<0.01), and social cohesion (τb = 0.899**, P<0.01). In addition, food security had a significant positive correlation with security (τb = 0.739**, P<0.01), rainfall amount (τb = 0.805**, P<0.01), stream flow (τb = 0.884**, P<0.01), pasture availability (τb = 0.884**, P<0.01), and honey production (τb = 0.918**, P<0.01). However, food security had a significant negative correlation with climate change and variability (τb = - 0.931**, P<0.01), drought frequency and severity (τb = - 0.931**, P<0.01), land degradation (τb = - 0.950**, P<0.01), and conflicts (τb = - 0.772**, P<0.01).

Food diversity had a significant positive trend (Z = 4.28, P<0.001). The study revealed that food diversity has a significant positive correlation with livelihood diversification (τb = 0.968**, P<0.01), urban growth (τb = 0.968**, P<0.01), human population (τb = 0.960**, P<0.01), in-migration (τb = 0.968**, P<0.01), outmigration (τb = - 0.968**, P<0.01), formal education access (τb = 0.960**, P<0.01), and access to health services (τb = 0.909**, P<0.01). Further, food diversity had a significant positive correlation with drought frequency and severity (τb = 0.951**, P<0.01), climate change and variability (τb = 0.951**, P<0.01), land degradation (τb = 0.968**, P<0.01), conflicts (τb = 0.818**, P<0.01), farming activities (τb = 0.960**, P<0.01), access to markets (τb = 0.960**, P<0.01), access to information (τb = 0.988**, P<0.01), access to transport services (τb = 0.943**, P<0.01), and access to communication services (τb = 0.909**, P<0.01). Besides, food diversity had a significant negative correlation with livestock mobility (τb = - 0.960**, P<0.01), number of livestock per household (τb = - 0.911**, P<0.01), observation of cultural practices (τb = - 0.976**, P<0.01), and food security (τb = - 0.901**, P<0.01).

Women empowerment also had a significant positive trend (Z = 3.74, P<0.001). The study found that women empowerment has a significant positive correlation with access to formal education (τb = 0.904**, P<0.01), access to information (τb = 0.900**, P<0.01), community participation in decision making (τb = 0.491*, P<0.05), and access to government services (τb = 0.943**, P<0.01). Further, women empowerment also had a significant positive correlation with out-migration (τb = 0.948**, P<0.01), in-migration (τb = 0.900**, P<0.01), access to credit (τb = 0.932**, P<0.01), and livelihoods diversification (τb = 0.900**, P<0.01).

The observation of moral values had declined significantly over time (Z = - 4.22, P<0.001). The observation of moral values had a significant positive correlation with observation of cultural practices (τb = 0.952**, P<0.01), effectiveness of customary governance systems (τb = 0.934**, P<0.01), social cohesion and (τb = 0.959**, P<0.01). However, observation of moral values had a significant negative correlation with in-migration (τb = - 0.976**, P<0.01), out-migration (τb = 0.942**, P<0.01), and urban growth (τb = 0.944**, P<0.01). The observation of cultural practices has also declined significantly over time (Z = - 4.22, P<0.001). The observation of cultural practices was found to have a significant positive correlation with the effectiveness of customary governance systems (τb = 0.917**, P<0.01), observation of moral values (τb = 0.952**, P<0.01), and social cohesion (τb = 0.943**, P<0.01). Conversely, the observation of cultural practices had a significant negative correlation with access to government services (τb = - 0.872**, P<0.01), access to formal education (τb = - 0.935**, P<0.01), access to communication services (τb = - 0.916**, P<0.01), and access to information (τb = - 0.944**, P<0.01). Still, the observation of cultural practices had a significant negative correlation with in-migration (τb = - 0.960**, P<0.01), out-migration (τb = - 0.976**, P<0.01), livelihoods diversification (τb = - 0.944**, P<0.01), access to markets (τb = - 0.935**, P<0.01), and the growth of urban areas (τb = - 0.944**, P<0.01).

Social cohesion in the community was found to have a significant negative trend (Z = - 4.17, P<0.001). The study found that social cohesion has a significant positive correlation the observation of cultural practices (τb = 0.943**, P<0.01), observation of moral values (τb = - 0.959**, P<0.01), and the effectiveness of customary governance

systems (τb = 0.917**, P<0.01). However, social cohesion had a significant negative correlation with outmigration (τb = - 0.976**, P<0.01), in-migration (τb = - 0.952**, P<0.01), urban growth (τb = - 0.952**, P<0.01), access to markets (τb = - 0.976**, P<0.01), land privatization (τb = - 0.926**, P<0.01), income inequality (τb = - 0.943**, P<0.01), and livelihood diversification (τb = - 0.944**, P<0.01).

Income inequality was found to have a significant positive trend (Z = 4.22, P<0.001). Income inequality had a significant positive correlation with urban growth (τb = 0.976**, P<0.01), climate change and variability (τb = 0.942**, P<0.01), drought frequency and severity (τb = 0.942**, P<0.01), land degradation (τb = 0.959**, P<0.01), conflicts (τb = 0.807**, P<0.01), and privatization of land (τb = 0.967**, P<0.01). Conversely, income inequality had a significant negative correlation with number of livestock per household (τb = - 0.885**, P<0.01), social cohesion (τb = - 0.943**, P<0.01), security (τb = - 0.778**, P<0.01), livestock mobility (τb = 0.935**, P<0.01), land tenure security (τb = - 0.644**, P<0.01), and land adequacy (τb = - 0.960**, P<0.01).

The analysis of social trends was as shown in table 2.

Table 2: Analysis of social trends

#	*Trend*	*1900s*	*1910s*	*1920s*	*1930s*	*1940s*	*1950s*	*1960s*	*1970s*	*1980s*	*1990s*	*2000s*	*2010s*	*Mann-Kendall (Z) Test*	*Sig*
1	Access to formal education	0	0	0	1	1	2	3	3	4	4	5	6	4.11	***
2	Access to health services	0	0	1	1	1	1	1	2	2	3	5	6	3.88	***
3	Food security	8	8	7	7	7	6	6	5	4	5	4	4	-3.80	***
4	Food diversity	2	2	3	4	4	5	6	7	8	9	9	10	4.28	***
5	Women empowerment	1	1	1	1	1	2	2	3	3	4	4	5	3.74	***
6	Observation of moral values	10	9	9	8	8	7	6	6	5	5	4	3	-4.22	***
7	Observation of cultural practices	10	9	8	7	7	6	6	5	5	4	4	3	-4.22	***
8	Social cohesion	10	10	10	9	8	7	6	6	5	5	4	3	-4.17	***
9	Income inequality	3	3	4	4	5	5	6	7	8	9	9	10	4.22	***

Institutional Trends

Access to government services was found to have a significant positive trend in the study area (*Z* = 3.74, *P*<0.001). Access to government services has a significant positive correlation with community participation in decision making (τb = 0.509*, P<0.05), urban growth (τb = 0.917**, P<0.01), human population (τb = 0.907**, P<0.01), infrastructure development (τb = 0.858**, P<0.01), access to transport services (τb = 0.899**, P<0.01), access to communication services (τb = 0.899**, P<0.01), and access to information (τb = 0.900**, P<0.01). Additionally, access to government services has a significant positive correlation with access to markets (τb = 0.925**, P<0.01), demand for livestock and livestock products (τb = 0.932**, P<0.01), sand harvesting (τb = 0.910**, P<0.01), and ecotourism activities (τb = 0.855**, P<0.01). Access to government services had a significant negative correlation with the effectiveness of customary governance systems (τb = - 0.866**, P<0.01).

Security in the area had a significant negative trend (Z = - 3.22, P<0.001). The study found security has a significant positive correlation with observation of moral values (τb = 0.778**, P<0.01), observation of cultural practices (τb = 0.760**, P<0.01), effectiveness of customary governance systems (τb = 0.733**, P<0.01), and social cohesion (τb = 0.819**, P<0.01). Moreover, security has a significant positive correlation with adequacy of land (τb = 0.754**, P<0.01), food security (τb = - 0.739*, P<0.01), water availability (τb = 0.772**, P<0.01), and pasture availability (τb = 0.772**, P<0.01). Conversely, security has a significant negative correlation with land degradation (τb = - 0.801**, P<0.01), in-migration (τb = - 0.772**, P<0.01), income inequalities (τb = - 0.889**, P<0.01), and conflicts (τb = - 0.973**, P<0.01).

Conflict incidences were found to have a significant positive trend (Z = 3.39, P<0.001). Conflict incidences were found to have a significant positive correlation with land degradation (τb = 0.831**, P<0.01), droughts frequency and severity (τb = 0.828**, P<0.01), climate change and variability (τb = 0.828**, P<0.01), and income inequalities (τb = 0.931**, P<0.01). Also, conflict incidences have a significant positive correlation with in-migration (τb = 0.784**, P<0.01), outmigration (τb = 0.845**, P<0.01), human population (τb = 0.807**, P<0.01), land privatization (τb = 0.752**, P<0.01), crop production (τb = 0.841**, P<0.01), establishment of nature conservation areas (τb = 0.811**, P<0.01), and number of livestock (τb = 0,526*, P<0.05). On the other hand, conflict incidences have a significant negative correlation with security (τb = - 0.973**, P<0.01), observation of moral values (τb = - 0.791**, P<0.01), effectiveness of customary governance systems (τb = - 0.730**, P<0.01), and social cohesion (τb = - 0.848**, P<0.01). Further, conflict incidences have a significant negative correlation with water availability (τb = - 0.801**, P<0.01), pasture availability (τb = - 0.801*, P<0.01), number of livestock per household (τb = - 0.906*, P<0.01), food security (τb = - 0.772*, P<0.01), and land adequacy (τb = - 0.784**, P<0.01).

Community participation in decision-making had a non-significant positive trend (Z = 1.41, P>0.1). Community participation in decision-making was found to have a non-significant positive correlation with access to formal education (τb = 0.410, P>0.05) and access to information (τb = 0.367, P>0.05). Besides community participation in decision-making has a significant positive with women's empowerment (τb = 0.491*, P<0.05) and access to government services (τb = 0.509*, P<0.05). Community participation in decision-making had a non-significant negative correlation with the effectiveness of customary systems (τb = - 0.261, P>0.05). The effectiveness of customary governance systems had a significant negative trend (Z = - 0.401, P<0.001). The effectiveness of customary governance systems was found to have a significant positive correlation with the observation of cultural practices (τb = 0.917**, P<0.01), observation of moral values (τb = 0.934**, P<0.01), security (τb = 0.733**, P<0.01), land tenure security (τb = 0.685**, P<0.01), and social cohesion (τb = 0.908**, P<0.01). However, the effectiveness of customary governance systems had a significant negative correlation with access to government services (τb = - 0.866**, P<0.01), in-migration (τb = - 0.926**, P<0.01), outmigration (τb = - 0.889**, P<0.01), urban growth (τb = - 0.926**, P<0.01), privatization of land (τb = 0.915**, P<0.01), climate change and variability (τb = - 0.906**, P<0.01), and conflicts (τb = - 0.730**, P<0.01).

The effectiveness of land management was also found to have significantly declined over time (Z = - 3.37, P<0.001). The effectiveness of land management has a significant positive correlation with security (τb = 0.611*, P<0.05), effectiveness of traditional governance systems (τb = 0.911**, P<0.01), observation of moral values (τb = 0.812**, P<0.01), and social cohesion (τb = 0.767**, P<0.01). In addition, the effectiveness of land management has a significant positive correlation with livestock mobility (τb = 0.812**, P<0.01), land adequacy (τb = 0.772**, P<0.01), and land tenure security (τb = 0.649*, P<0.05). Conversely, the effectiveness of land management has significant negative correlation with conflicts (τb = - 0.577*, P<0.05), human population (τb = - 0.795**, P<0.01), and climate change and variability (τb = - 0.762**, P<0.01).

Land tenure security was found to have a significant negative trend (Z = -2.57, P<0.1). Land tenure security had a significant positive correlation with effectiveness of customary governance systems (τb = 0.685**, P<0.01), effectiveness of land management (τb = 0.649*, P<0.05), social cohesion (τb = 0.630**, P<0.01), and land adequacy (τb = 0.620*, P<0.05). A non-significant positive correlation was found between land tenure security and security (τb = 0.426, P>0.05). In addition, a significant negative correlation was found between land tenure security and human population (τb = - 0.644**, P<0.01), in-migration (τb = - 0.657**, P<0.01), establishment of nature conservation reserves (τb = - 0.652**, P<0.01), and privatization of land (τb = - 0.693**, P<0.01). Moreover, a significant negative correlation was found between land tenure security and farming activities (τb = - 0.606**, P<0.01), income inequality (τb = - 0.644**, P<0.01), access to markets (τb = - 0.625**, P<0.01), and the growth of urban areas (τb = - 0.657**, P<0.01). A non-significant negative correlation was found between land tenure security and conflicts (τb = - 0.415, P>0.05).

The establishment of nature conservation reserves had a significant positive trend (Z = 4.34, P>0.1). The establishment of nature conservation reserves had a significant positive correlation with access to government services (τb = 0.910**, P<0.01), ecotourism (τb = 0.937**, P<0.01), livelihood diversification (τb = 0.976**, P<0.01), and land degradation (τb = 0.960**, P<0.01). The establishment of nature conservation reserves had a significant negative correlation with wildlife abundance (τb = - 0.961*, P<0.05), and security (τb = - 0.782*, P<0.05).

The privatization of land had a significant positive trend (Z = 4.11, P>0.1). The privatization of land had a significant positive correlation with urban growth (τb = 0.943**, P<0.01), access to markets (τb = 0.918**, P<0.01), human population (τb = 0.951**, P<0.01), access to government services (τb = 0.869**, P<0.01), crop production (τb = 0.918**, P<0.01), and livelihood diversification (τb = 0.960**, P<0.01). Besides, privatization of land had a significant negative correlation with land tenure security (τb = - 0.693**, P<0.01), effectiveness of customary governance systems (τb = - 0.915**, P<0.01), social cohesion (τb = - 0.926**, P<0.01), and livestock mobility (τb = - 0.935**, P<0.01).

The study found that access to extension services had a significant positive trend (Z = 3.77, P<0.001). Access to extension services was found to have a significant positive correlation with access to government services (τb = 0.876**, P<0.01), access to

education (τb = 0.874**, P<0.01), access to information (τb = 0.886**, P<0.01), access to communication services (τb = 0.818**, P<0.01), and access to transport services (τb = 0.852**, P<0.01). Furthermore, access to extension services had a significant positive correlation with human population (τb = 0.876**, P<0.01), total number of livestock (τb = 0.638**, P<0.01), and farming activities (τb = 0.860**, P<0.01). Access to extension services had a non-significant positive correlation with community participation in decision-making (τb = 0.310, P>0.05).

Access to veterinary services had a significant positive trend (Z = 3.77, P<0.001). Access to veterinary services was found to have a significant positive correlation with access to government services (τb = 0.876**, P<0.01), access to education (τb = 0.874**, P<0.01), access to information (τb = 0.886**, P<0.01), access to communication services (τb = 0.818**, P<0.01), and access to transport services (τb = 0.852**, P<0.01). Furthermore, access to veterinary services had a significant positive correlation with the human population (τb = 0.876**, P<0.01), and the total number of livestock (τb = 0.638**, P<0.01). Access to veterinary services had a non-significant positive correlation with community participation in decision-making (τb = 0.310, P>0.05). Livestock mobility had also decreased significantly (Z = 3.81, P<0.001). Livestock mobility was found to have a significant positive correlation with land adequacy (τb = 0.944**, P<0.01), observation of cultural practices (τb = 0.968**, P<0.01), effectiveness of customary governance systems (τb = 0.951**, P<0.01), social cohesion (τb = 0.959**, P<0.01), and security (τb = 0.760**, P<0.01). Conversely, livestock mobility had a significant negative correlation with human population (τb = - 0.952**, P<0.01), urban growth (τb = - 0.944**, P<0.01), access to government services (τb = - 0.907**, P<0.01), infrastructure development (τb = - 0.926**, P<0.01), conflicts (τb = - 0.791**, P<0.01), land privatization (τb = - 0.935**, P<0.01), establishment of nature conservation reserves (τb = - 0.968**, P<0.01), and farming activities (τb = - 0.952**, P<0.01).

The analysis of institutional trends was as shown in table 3.

Environmental Trends

Climate change and variability in the study area have a significant positive trend (Z = 4.05, P<0.001). Rainfall amount was found to be declining significantly (Z = - 3.62, P<0.001). The rainfall amount was found to have a significant negative correlation with climate change and variability (τb = - 0.884**, P<0.01). In addition, the frequency and severity of drought were observed to be having a significant positive trend (Z = 4.05, P<0.001). The frequency and severity of drought were found to have a significant positive correlation with climate change and variability (τb = 1.000**, P<0.01). The study found that climate change and variability had a significant positive correlation with human population (τb = 0.942**, P<0.01), livestock numbers (τb = 0.724**, P<0.01), growth of urban areas (τb = 0.961**, P<0.01), farming activities (τb = 0.926**, P<0.01), and land degradation (τb = 0.967**, P<0.01). Conversely, climate change and variability had a significant negative correlation with tree cover (τb = - 0.926**, P<0.01), and the effectiveness of land management (τb = - 0.762**, P<0.01).

Land degradation had a significant positive trend (Z = 4.17, P<0.001). A significant positive correlation was found between land degradation and human population (τb =

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0.976**, P<0.01), urban growth (τb = 0.968**, P<0.01), climate change and variability (τb = 0.967**, P<0.01), and number of livestock (τb = 0.695**, P<0.01). Still, land degradation had a significant positive correlation with sand harvesting (τb = 0.976**, P<0.01), demand for livestock products (τb = 0.951**, P<0.01), demand for wood tree products (τb = 0.943**, P<0.01), and demand for herbs products (τb = 0.933**, P<0.01). Further, land degradation was found to have a significant negative correlation with livestock mobility (τb = - 0.959**, P<0.01), land adequacy (τb = - 0.936**, P<0.01), land tenure security (τb = - 0.649**, P<0.01), effectiveness of customary governance systems (τb = - 0.908**, P<0.01), and effectiveness of land management (τb = - 0.767**, P<0.01).

Table 3: Analysis of institutional trends

#	*Trend*	*1900s*	*1910s*	*1920s*	*1930s*	*1940s*	*1950s*	*1960s*	*1970s*	*1980s*	*1990s*	*2000s*	*2010s*	*Mann-Kendall (Z) Test*	*Sig*
1	Access to government services	1	1	1	1	1	2	3	3	4	4	5	5	3.74	***
2	Security	8	9	9	9	9	8	8	8	7	6	5	4	-3.22	**
3	Conflicts incidences	3	2	2	2	2	3	3	4	6	7	8	9	3.39	***
4	Community Involvement in decision making	5	4	3	3	2	2	3	3	4	5	6	7	1.41	
5	Effectiveness of customary governance systems	10	8	7	6	5	5	5	5	4	4	3	3	-4.01	***
6	Effectiveness of land management	10	8	7	6	5	5	5	6	5	5	4	4	-3.37	***
7	Land tenure security	9	7	4	4	4	4	3	4	3	3	3	4	-2.57	*
8	Establishment of nature conservation reserves	0	0	1	2	3	4	5	6	7	8	9	9	4.34	***
9	Land privatization	0	4	5	5	6	6	7	8	8	9	9	9	4.11	***
10	Access to extension services	0	0	1	1	1	2	3	3	4	5	5	4	3.77	***
11	Access to veterinary services	0	0	1	1	1	2	3	3	4	5	5	4	3.77	***
12	Livestock mobility	10	9	7	6	6	5	5	4	3	3	2	2	-4.22	***

The prevalence of invasive species was also found to have a significant positive trend (Z = 4.28, P<0.001). The prevalence of invasive species had a significant positive correlation with land degradation (τb = 0.968**, P<0.01), climate change and variability (τb = 0.951**, P<0.01), and drought frequency and severity (τb = 0.951**, P<0.01). Likewise, the prevalence of invasive species had a significant positive correlation with the number of livestock (τb = 0.734**, P<0.01), human population (τb = 0.992**, P<0.01), and in-migration (τb = 0.952**, P<0.01). Contrariwise, the prevalence of invasive species had a significant negative correlation with land adequacy (τb = - 0.952**, P<0.01), land tenure security (τb = - 0.639**, P<0.01), the effectiveness of customary governance systems (τb = - 0.926**, P<0.01), and the effectiveness of land management (τb = - 0.789**, P<0.01).

Stream flows in the study area were found to have a significant negative trend (Z = - 4.28, P<0.001). Stream flow was found to have a significant positive correlation with

tree cover (τb = 0.960**, P<0.01), rainfall amount (τb = 0.873**, P<0.01), effectiveness of customary governance systems (τb = 0.926**, P<0.01), effectiveness of land management (τb = 0.789**, P<0.01), and land adequacy (τb = 0.984**, P<0.01). Conversely, stream flow had a significant negative correlation with climate change and variability (τb = - 0.951**, P<0.01), drought frequency and severity (τb = - 0.951**, P<0.01), and land degradation (τb = - 0.936**, P<0.01). Similarly, stream flow had a significant negative correlation with human population (τb = - 0.944**, P<0.01), farming activities (τb = - 0.960**, P<0.01), and sand harvesting (τb = - 0.961**, P<0.01). The study found that water availability had a significant negative trend (Z = - 4.28, P<0.001). Water availability had a significant positive correlation with rainfall amount (τb = 0.873**, P<0.01), river flow (τb = 1.000**, P<0.01), tree cover (τb = 0.960**, P<0.01), effectiveness of land management (τb = 0.789**, P<0.01), and effectiveness of customary land management (τb = 0.926**, P<0.01). On the contrary, water availability had a significant negative correlation with climate change and variability (τb = - 0.951**, P<0.01), drought frequency and severity (τb = - 0.951**, P<0.01), sand harvesting (τb = - 0.961**, P<0.01), farming activities (τb = - 0.960**, P<0.01), human population (τb = - 0.944**, P<0.01), privatization of land (τb = - 0.943**, P<0.01), establishment of conservation reserves (τb = - 0.961**, P<0.01), and urban growth (τb = - 0.952**, P<0.01).

Tree cover was found to be decreasing significantly (Z = - 4.22, P<0.001). Tree cover was found to have a significant positive correlation with rainfall amount (τb = 0.844**, P<0.01), effectiveness of customary land governance (τb = 0.951**, P<0.01), land adequacy (τb = 0.960**, P<0.01), land tenure security (τb = 0.682**, P<0.01), and effectiveness of land management (τb = 0.839**, P<0.01). Contrarily, tree cover had a significant negative correlation with drought frequency and severity (τb = - 0.926**, P<0.01), climate change and variability (τb = - 0.926**, P<0.01), land degradation (τb = - 0.943**, P<0.01), number of livestock (τb = - 0.690**, P<0.01), and farming activities (τb = - 0.968**, P<0.01). Additionally, tree cover had a significant negative correlation with human population (τb = - 0.952**, P<0.01), urban growth (τb = - 0.960**, P<0.01), demand for wood tree products (τb = - 0.968**, P<0.01), and access to transport services (τb = - 0.933**, P<0.01).

The availability of pasture was observed to be decreasing significantly over time (Z = - 4.28, P<0.001). Pasture availability was found to have a significant positive correlation with rainfall amount (τb = 0.891**, P<0.01), social cohesion (τb = 0.952**, P<0.01), security (τb = 0.772**, P<0.01), and effectiveness of customary governance systems (τb = 0.926**, P<0.01). Moreover, pasture availability had a significant positive correlation with land adequacy (τb = 0.968**, P<0.01), livestock mobility (τb = 0.944**, P<0.01), land tenure security (τb = 0.620*, P<0.05), and the effectiveness of land management (τb = 0.789**, P<0.01). Besides, pasture availability was found to have a significant negative correlation with drought frequency and severity (τb = - 0.951**, P<0.01), climate change and variability (τb = - 0.951**, P<0.01), prevalence of invasive species (τb = - 0.984**, P<0.01), land degradation (τb = - 0.952**, P<0.01), and the total number of livestock (τb = - 0.751**, P<0.01). Also pasture availability had a significant negative correlation with human population (τb = - 0.976**, P<0.01), in-migration (τb = - 0.952**, P<0.01), land privatization (τb = - 0.960**, P<0.01), farming activities (τb = - 0.960**, P<0.01), and establishment of nature conservation reserves (τb = - 0.976**, P<0.01).

The availability of herbs in the area had a significant negative trend (Z = - 4.22, P<0.001). The availability of herbs was found to have a significant positive correlation with rainfall amount (τb = 0.862**, P<0.01), land adequacy (τb = 0.944**, P<0.01), land tenure security (τb = 0.663**, P<0.01), effectiveness of customary governance systems (τb = 0.934**, P<0.01), and effectiveness of land management (τb = 0.812**, P<0.01). To the contrary, the availability of herbs had a significant negative correlation with land degradation (τb = - 0.976**, P<0.01), drought frequency and severity (τb = - 0.942**, P<0.01), climate change and variability (τb = - 0.942**, P<0.01), human population (τb = - 0.984**, P<0.01), and demand for herbs products (τb = - 0.942**, P<0.01).

Wildlife abundance in the study area had a significant negative trend (Z = -4.28, P<0.001). Wildlife abundance was found to have a significant positive correlation with rainfall amount (τb = 0.873**, P<0.01), water availability (τb = 0.968**, P<0.01), pasture availability (τb = 0.984**, P<0.01), livestock mobility (τb = 0.944**, P<0.01), and tree cover (τb = 0.944**, P<0.01). Likewise, the study found wildlife abundance to have a significant positive correlation with security (τb = 0.737**, P<0.01), effectiveness of customary land governance systems (τb = 0.926**, P<0.01), land adequacy (τb = 0.984**, P<0.01), observation of cultural practices (τb = 0.976**, P<0.01), observation of moral values (τb = 0.944**, P<0.01), and effectiveness of land management (τb = 0.789**, P<0.01). Further, wildlife abundance had a significant negative correlation with human population (τb = - 0.960**, P<0.01), number of households (τb = - 0.944**, P<0.01), urban growth (τb = - 0.952**, P<0.01), total number of livestock (τb = - 0.784**, P<0.01), conflicts (τb = - 0.768**, P<0.01), farming activities (τb = - 0.944**, P<0.01), and land privatization (τb = - 0.976**, P<0.01). Also, wildlife abundance had a significant negative correlation with drought frequency and severity (τb = - 0.935**, P<0.01), climate change and variability (τb = - 0.935**, P<0.01), land degradation (τb = - 0.936**, P<0.01), prevalence of invasive species (τb = - 0.968**, P<0.01), and stream flow (τb = - 0.968**, P<0.01).

The abundance of bees also had a significant negative trend (Z = - 4.11, P<0.001). Bee's abundance was found to have a significant positive correlation with tree cover (τb = 0.935**, P<0.01), water availability (τb = 0.960**, P<0.01), rainfall amount (τb = 0.895**, P<0.01), effectiveness of land management (τb = 0.755**, P<0.01), and effectiveness of customary governance systems (τb = 0.898**, P<0.01). To the contrary, bee's abundance had a significant negative correlation with human population (τb = - 0.951**, P<0.01), land degradation (τb = - 0.926**, P<0.01), climate change and variability (τb = - 0.924**, P<0.01), and drought frequency and severity (τb = - 0.924**, P<0.01).

The analysis of environmental trends was as shown in table 4.

Economic Trends

The total number of livestock owned in the study area was found to have a significant positive trend (Z = 3.11, P<0.01). The total number of livestock was found to have a significant positive correlation with access to extension services (τb = 0.638**, P<0.01), access to veterinary services (τb = 0.638**, P<0.01), human population (τb =

0.723**, P<0.01), human population (τb = 0.690**, P<0.01), in-migration (τb = 0.734**, P<0.01), and demand for livestock and livestock products (τb = 0.678**, P<0.01). Besides the total number of livestock had a significant negative correlation with livestock disease incidences (τb = - 0.536*, P<0.05). The number of livestock owned per household had a significant negative trend (Z = -3.83, P<0.001). The number of livestock per household was found to have a significant positive correlation with pasture availability (τb = 0.895**, P<0.01), water availability (τb = 0.878**, P<0.01), rainfall amount (τb = 0.876**, P<0.01), land management (τb = 0.720**, P<0.01), effectiveness of customary governance systems (τb = 0.848**, P<0.01), and land adequacy (τb = 0.878**, P<0.01). Also, the number of livestock per household had a significant positive correlation with livestock mobility (τb = 0.885**, P<0.01), security (τb = 0.896**, P<0.01), and observation of cultural practices (τb = 0.869**, P<0.01). Contrarily, the number of livestock per household was found to have a significant negative correlation with land degradation (τb = - 0.893**, P<0.01), drought frequency and severity (τb = - 0.891**, P<0.01), climate change and variability (τb = - 0.891**, P<0.01), and conflicts (τb = - 0.906**, P<0.01). In addition, the number of livestock per household had a significant negative correlation with livelihood diversification (τb = - 0.895**, P<0.01), land privatization (τb = - 0.850**, P<0.01), farming activities (τb = - 0.935**, P<0.01), and the establishment of nature conservation reserves (τb = - 0.920**, P<0.01).

Table 4: Analysis of environmental trends

#	*Trend*	*1900s*	*1910s*	*1920s*	*1930s*	*1940s*	*1950s*	*1960s*	*1970s*	*1980s*	*1990s*	*2000s*	*2010s*	*Mann-Kendall (Z) Test*	*Sig*
1	Climate change and variability	3	3	4	4	4	5	5	7	7	8	9	9	4.05	***
2	Rainfall amount	9	9	9	9	9	9	8	7	7	6	5	4	-3.62	***
3	Drought frequency and severity	3	3	4	4	4	5	5	7	7	8	9	9	4.05	***
4	Land degradation	1	1	2	2	2	3	4	5	7	7	1	1	4.17	***
5	Invasive species prevalence	1	1	2	2	3	3	4	5	6	7	8	9	4.28	***
6	Stream flows	9	8	8	7	6	5	5	4	4	3	2	1	-4.28	***
7	Water availability	9	8	8	7	6	5	5	4	4	3	2	1	-4.28	***
8	Tree cover	10	9	9	8	7	6	5	5	4	4	3	3	-4.22	***
9	Pasture availability	9	9	8	7	6	6	5	4	4	3	2	1	-4.28	***
10	Herbs availability	10	10	9	9	8	7	6	6	5	5	4	3	-4.22	***
11	Wildlife abundance	10	9	8	7	6	6	5	4	4	3	3	2	-4.28	***
12	Bees abundance	10	10	10	9	8	8	7	6	6	5	5	4	-4.11	***

Incidences of livestock diseases were found to be declining significantly (Z = - 3.41, P<0.001). Incidences of livestock diseases had a significant negative correlation with access to extension services (τb = - 0.843**, P<0.01), access to veterinary services (τb = - 0.843**, P<0.01), access to education (τb = - 0.818**, P<0.01), access to information services (τb = - 0.815**, P<0.01), and access to government services (τb = - 0.815**, P<0.01).

The study found the demand for livestock and livestock products had a significant positive trend (Z = 4.17, P<0.001). The demand for livestock and livestock products

was found to have a significant positive correlation with human population (τb = 0.943**, P<0.01), in-migration (τb = 0.952**, P<0.01), urban growth (τb = 0.952**, P<0.01), access to markets (τb = 0.972**, P<0.01), and livelihood diversification (τb = 0.952**, P<0.01). Additionally, the demand for livestock and livestock products was found to have a significant positive correlation with employment opportunities (τb = 0.950**, P<0.01), infrastructure development (τb = 0.917**, P<0.01), access to transport services (τb = 0.941**, P<0.01), and access to communication services (τb = 0.924**, P<0.01). The demand for livestock and livestock products was found to have a significant negative correlation with livestock disease incidences (τb = - 0.811**, P<0.01).

There was a significant positive trend in the diversification of livelihoods in the study area (Z = 4.28, P<0.001). The study found the livelihoods diversification had a significant positive correlation with human population (τb = 0.992**, P<0.01), in-migration (τb = 0.952**, P<0.01), outmigration (τb = 0.935**, P<0.01), food diversification (τb = 0.968**, P<0.01), urban growth (τb = 0.984**, P<0.01), access to markets (τb = 0.960**, P<0.01), and access to credit (τb = 0.891**, P<0.01). Still, livelihoods diversification had a significant positive correlation with access to formal education (τb = 0.943**, P<0.01), employment opportunities (τb = 0.900**, P<0.01), women empowerment (τb = 0.900**, P<0.01), number of female-headed households (τb = 0.900**, P<0.01), and conflicts (τb = 0.818**, P<0.01). Further, the study found that livelihoods diversification had a significant positive correlation with access to government services (τb = 1.000**, P<0.01), infrastructure development (τb = 0.968**, P<0.01), access to transport services (τb = 0.926**, P<0.01), access to communication services (τb = 0.943**, P<0.01), and access to information (τb = 1.000**, P<0.01). Also, livelihoods diversification had a significant positive correlation with drought frequency and severity (τb = 0.951**, P<0.01), climate change and variability (τb = 0.951**, P<0.01), and land degradation (τb = 0.968**, P<0.01). On the other hand, livelihood diversification had a significant negative correlation with observation of cultural practices (τb = - 0.944**, P<0.01), security (τb = - 0.789**, P<0.01), food security (τb = - 0.901**, P<0.01), land adequacy (τb = - 0.952**, P<0.01), and number of livestock per household (τb = - 0.895**, P<0.01).

Honey production in the study area has declined significantly over time (Z = - 4.28, P<0.001). The study found that honey production had a significant positive correlation with bee abundance (τb = 0.943**, P<0.01), tree cover (τb = 0.960**, P<0.01), land adequacy (τb = 0.952**, P<0.01), rainfall amount (τb = 0.873**, P<0.01), effectiveness of land management (τb = 0.806**, P<0.01), effectiveness of customary land governance (τb = 0.943**, P<0.01), and observation of cultural practices (τb = 0.944**, P<0.01). On the other hand, honey production had a significant negative correlation with land degradation (τb = - 0.968**, P<0.01), climate change and variability (τb = - 0.935**, P<0.01), drought frequency and severity (τb = - 0.935**, P<0.01), and human population (τb = - 0.992**, P<0.01). The demand for honey had a significant positive trend (Z = 4.28, P<0.001). The study found that the demand for honey had a significant positive correlation with human population (τb = 0.992**, P<0.01), in-migration (τb = 0.952**, P<0.01), urban growth (τb = 0.984**, P<0.01), and employment opportunities (τb = 0.900**, P<0.01). Further, the demand for honey had a significant positive correlation with access to markets (τb = 0.960**, P<0.01), access to transport services (τb = 0.926**, P<0.01),

access to communication services (τb = 0.926**, P<0.01), and access to information services (τb = 0.984**, P<0.01). The demand for honey had a significant negative correlation with honey production (τb = - 0.990**, P<0.01).

The demand for herbal products had a significant positive trend (Z = 4.06, P<0.001). The demand for herbs products was found to have a significant positive correlation with human population (τb = 0.942**, P<0.01), in-migration (τb = 0.951**, P<0.01), urban growth (τb = 0.951**, P<0.01), and employment opportunities (τb = 0.930**, P<0.01). Further, the demand for herbs products had a significant positive correlation with access to markets (τb = 0.976**, P<0.01), access to transport services (τb = 0.974**, P<0.01), access to communication services (τb = 0.922**, P<0.01), and access to information services (τb = 0.951**, P<0.01). The demand for herb products had a significant negative correlation with the availability of herbs (τb = - 0.947**, P<0.01).

The demand for wood tree products had a significant positive trend (Z = 4.17, P<0.001). The demand for wood tree products was found to have a significant positive correlation with human population (τb = 0.952**, P<0.01), in-migration (τb = 0.976**, P<0.01), urban growth (τb = 0.976**, P<0.01), and employment opportunities (τb = 0.942**, P<0.01). Further, the demand for wood tree products had a significant positive correlation with access to markets (τb = 1.000**, P<0.01), infrastructure development (τb = 0.926**, P<0.01), access to transport services (τb = 0.950**, P<0.01), access to communication services (τb = 0.933**, P<0.01), and access to information services (τb = 0.928**, P<0.01), and access to communication services (τb = 0.933**, P<0.01). The demand for wood tree products had a significant negative correlation with the tree cover (τb = - 0.976**, P<0.01).

A significant positive trend was also observed as appertains to ecotourism activities in the study area (Z = 3.95, P<0.001). Ecotourism activities had a significant positive correlation with access to government services (τb = 0.855**, P<0.01), infrastructure development (τb = 0.893**, P<0.01), access to information services (τb = 0.866**, P<0.01), and access to transport services (τb = 0.849**, P<0.01). Besides, ecotourism activities were found to have a significant positive correlation with livelihood diversification (τb = 0.928**, P<0.01), urban growth (τb = 0.912**, P<0.01), access to markets (τb = 0.887**, P<0.01), and establishment of nature conservation areas (τb = 0.937**, P<0.01). Ecotourism activities had a significant negative correlation with livestock holding per household (τb = - 0.853**, P<0.01).

Sand harvesting was also found to have a significant positive trend (Z = 4.34, P<0.001). The study revealed that sand harvesting has a significant positive correlation with population growth (τb = 0.984**, P<0.01), urban growth (τb = 0.992**, P<0.01), access to markets (τb = 0.968**, P<0.01), and access to government services (τb = 0.910**, P<0.01). Additionally, sand harvesting had a significant positive correlation with livelihood diversification (τb = 0.992**, P<0.01), infrastructure development (τb = 0.960**, P<0.01), access to information (τb = 0.992**, P<0.01), access to communication services (τb = 0.935**, P<0.01), and access to transport services (τb = 0.919**, P<0.01). Sand harvesting had a significant negative correlation with livestock holding per household (τb = - 0.904**, P<0.01).

Employment opportunities in the study were found to have increased significantly (Z = 3.83, P<0.001). The study found out that employment opportunities had a significant positive correlation with formal education (τb = 0.940**, P<0.01), access to government services (τb = 0.889**, P<0.01), urban growth (τb = 0.917**, P<0.01), access to markets (τb = 0.942**, P<0.01), and livelihood diversification (τb = 0.900**, P<0.01). Moreover, employment opportunities had a significant positive correlation with infrastructure development (τb = 0.895**, P<0.01), information access (τb = 0.900**, P<0.01), sand harvesting (τb = 0.910**, P<0.01), ecotourism activities (τb = 0.856**, P<0.01), and establishment of nature conservation reserves (τb = 0.927**, P<0.01).

Access to credit was found to be increasing significantly over time (Z = 3.62, P<0.001). The study revealed that access to credit had a significant positive correlation with access to government services (τb = 0.913**, P<0.01), livelihood diversification (τb = 0.891**, P<0.01), urban growth (τb = 0.873**, P<0.01), formal education (τb = 0.876**, P<0.01), and access to markets (τb = 0.880**, P<0.01). Besides access to credit had a significant positive correlation with women empowerment (τb = 0.932**, P<0.01), access to information services (τb = 0.891**, P<0.01), access to transport services (τb = 0.869**, P<0.01), and access to communication services (τb = 0.907**, P<0.01).

The study found the practice of farming activities to have a significant positive trend (Z = 4.23, P<0.001). The practice of farming activities was found to have a significant positive correlation with livelihood diversification (τb = 0.960**, P<0.01), food diversity (τb = 0.960**, P<0.01), in-migration (τb = 0.960**, P<0.01), land privatization (τb = 0.918**, P<0.01), urban growth (τb = 0.960**, P<0.01), human population (τb = 0.968**, P<0.01), infrastructure development (τb = 0.926**, P<0.01), and information access (τb = 0.960**, P<0.01). Moreover, farming activities had a significant negative correlation with number of livestock per household (τb = - 0.935**, P<0.01), livestock mobility (τb = - 0.952**, P<0.01), food security (τb = - 0.908**, P<0.01), and observation of cultural practices (τb = - 0.935**, P<0.01).

Access to wood fuel was also found to be decreasing significantly (Z = - 4.05, P<0.001). Access to firewood was found to have a significant positive correlation with tree cover (τb = 0.976**, P<0.01), effectiveness of land management (τb = 0.797**, P<0.01), and land adequacy (τb = 0.935**, P<0.01). Besides, access to wood fuel had a significant negative correlation with (τb = - 0.950**, P<0.01), human population (τb = - 0.942**, P<0.01), urban growth (τb = - 0.951**, P<0.01), privatization of land (τb = - 0.908**, P<0.01), farming activities (τb = - 0.976**, P<0.01), and establishment of nature conservation reserves (τb = - 0.960**, P<0.01).

Infrastructure development was found to have a significant positive trend (Z = 4.05, P<0.001). The study revealed that infrastructure development had a significant positive correlation with access to government services (τb = 0.858**, P<0.01), urban growth (τb = 0.951**, P<0.01), access to markets (τb = 0.926**, P<0.01), population growth (τb = 0.959**, P<0.01), and demand for livestock and livestock products (τb = 0.917**, P<0.01). Additionally, infrastructure development had a significant positive correlation with sand harvesting (τb = 0.960**, P<0.01), ecotourism activities (τb = 0.893**, P<0.01), farming activities (τb = 0.926**, P<0.01), and establishment of

nature conservation reserves (τb = 0.944**, P<0.01). Infrastructure development had a non-significant positive correlation with community involvement in decision-making (τb = 0.310, P>0.05).

Access to transport services was found to have a significant increasing trend (Z = 3.88, P<0.001). Access to transport services was found to have a significant positive correlation with access to government services (τb = 0.899**, P<0.01), infrastructure development (τb = 0.905**, P<0.01), human population (τb = - 0.943**, P<0.01), and urban growth (τb = 0.952**, P<0.01). Moreover, access to transport services had a significant positive correlation with demand for livestock and livestock products (τb = 0.941**, P<0.01), access to markets (τb = 0.950**, P<0.01), sand harvesting (τb = 0.919**, P<0.01), and ecotourism (τb = 0.849**, P<0.01). Access to transport services had a non-significant positive correlation with community involvement in decision-making (τb = 0.407, P>0.05).

Access to communication services was also found to have a significant increasing trend (Z = 3.90, P<0.001). The study revealed that access to communication services had a significant positive correlation with access to government services (τb = 0.899**, P<0.01), infrastructure development (τb = 0.957**, P<0.01), access to markets (τb = 0.933**, P<0.01), access to information (τb = 0.943**, P<0.01), access to formal education (τb = 0.914**, P<0.01), urban growth (τb = 0.926**, P<0.01), and human population (τb = 0.933**, P<0.01). Further, access to communication services had a significant positive correlation with community involvement in decision-making (τb = 0.407, P>0.05).

Access to information services such as electronic media was found to have a significant positive trend (Z = 4.28, P<0.001). The study revealed that access to information services had a significant positive correlation with access to government services (τb = 0.900**, P<0.01), access to education (τb = 0.943**, P<0.01), infrastructure development (τb = 0.968**, P<0.01), access to communication (τb = 0.943**, P<0.01), access to extension services (τb = 0.886**, P<0.01), urban growth (τb = 0.984**, P<0.01), and access to transport services (τb = 0.926**, P<0.01).

Access to markets has also increased significantly (Z = 4.28, P<0.001). A significant positive correlation was found between market access and access to government services (τb = 0.925**, P<0.01), infrastructure development (τb = 0.926**, P<0.01), access to information services (τb = 0.876**, P<0.01), access to communication services (τb = 0.933**, P<0.01), access to transport services (τb = 0.950**, P<0.01), human population (τb = 0.952**, P<0.01), employment opportunities (τb = 0.942**, P<0.01), and urban growth (τb = 0.976**, P<0.01).

Urban growth had a significant positive trend (Z = 4.28, P<0.001). Urban growth was found to have a significant positive correlation with human population (τb = 0.976**, P<0.01), in-migration (τb = 0.968**, P<0.01), access to government services (τb = 0.917**, P<0.01), education (τb = 0.960**, P<0.01), employment opportunities (τb = 0.917**, P<0.01), and livelihood diversification (τb = 0.984**, P<0.01). Furthermore, urban growth had a significant positive correlation with (τb = 0.943**, P<0.01), access to transport services (τb = 0.926**, P<0.01), access to communication services (τb = 0.926**, P<0.01), ecotourism (τb = 0.912**, P<0.01), sand harvesting (τb =

0.992**, P<0.01), demand for livestock and livestock products (τb = 0.952**, P<0.01), and conflict incidences (τb = 0.818**, P<0.01). Urban growth, on the other hand, was found to have a significant negative correlation with livestock mobility (τb = - 0.944**, P<0.01), security (τb = - 0.806**, P<0.01), land adequacy (τb = - 0.952**, P<0.01), and observation of cultural practices (τb = - 0.952**, P<0.01).

The adequacy of land in the study was found to be decreasing significantly over time (Z = - 4.28, P<0.001). The study revealed that land adequacy had a significant positive correlation with livestock mobility (τb = 0.944**, P<0.01), effectiveness of land management (τb = 0.772**, P<0.01), effectiveness of customary governance systems (τb = 0.910**, P<0.01), land tenure security (τb = 0.620*, P<0.05), and security (τb = 0.754**, P<0.01). To the contrary, the study established that land adequacy had a significant negative correlation with human population (τb = - 0.944**, P<0.01), in-migration (τb = - 0.984**, P<0.01), urban growth (τb = - 0.952**, P<0.01), access to markets (τb = - 0.960**, P<0.01), infrastructure development (τb = - 0.951**, P<0.01), and livestock numbers (τb = - 0.768**, P<0.01). Also, land adequacy had a significant negative correlation with conflicts (τb = - 0.784**, P<0.01), farming activities (τb = - 0.960**, P<0.01), privatization of land (τb = - 0.960**, P<0.01), and establishment of nature conservation reserves (τb = - 0.961**, P<0.01).

The analysis of economic trends was as shown in table 5.

Discussion

The study identified and analyzed various socioecological trends among the pastoralist community in Laikipia County. The human population was found to be increasing over time. This was because people are attracted and migrated to the pastoral area due to the improved access to government services, formal education, and health services. Infrastructural development, improved access to transport and communication services, and information has also attracted people to move to and settle in the area. Goldsmith (2012) observed that access to the internet, mobile telephony, and satellite television are making pastoral areas more attractive to people, including professionals. The growth of urban centers and access to markets has also attracted people to the area. The decline in pastoral mobility and, hence, sedentarization has also caused an increase in population as people are concentrated in one area. Likewise, pastoralists from neighboring drier pastoral areas have been moving and settling in the area in search of pasture, especially during long drought seasons. The reduction in mortality rates, which is partly due to improvements in health services, has also led to an increase in the human population.

Urban centers in the study area were growing as a result of the growth of the human population, decline in pastoral mobility and attraction to spatially fixed-point security and social services that have changed and concentrated the settlement patterns. ODI (2009) observed that population growth and the changes in population distribution in Arid and Semi-arid Lands have led to the emergence and growth of urban areas. Similarly, the improved access to markets and factors that create an enabling environment for business activities in the urban centers such as transport and communication services have also contributed to their growth. The change of

pastoralists from traditional to modern culture and livelihood diversification has led to the adoption of a modern way of life that is urban-oriented. The declining availability of land and other pastoral resources and the reduction in livestock holding per household has also driven the change in livelihoods leading to the adoption of urban-based livelihoods and, hence, the growth of urban areas. In addition, ODI (2009) found that the factors influencing the formation of urban and peri-urban areas in pastoralist areas include conflicts, insecurity, appropriation of land by non-pastoralists, and development activities.

Table 5: Analysis of economic trends

#	*Trend*	*1900s*	*1910s*	*1920s*	*1930s*	*1940s*	*1950s*	*1960s*	*1970s*	*1980s*	*1990s*	*2000s*	*2010s*	*Mann-Kendall (Z) Test*	*Sig*
1	Total number of livestock	2	4	5	5	6	6	6	7	5	8	6	9	3.11	**
2	Number of livestock per household	7	8	8	7	7	6	5	5	4	3	2	2	-3.83	***
3	Livestock disease incidences	10	9	9	9	8	8	8	8	7	5	4	6	-3.41	***
4	Demand for livestock and livestock products	2	2	2	3	3	4	5	6	7	8	9	9	4.17	***
5	Livelihood diversification	1	1	2	2	3	3	4	5	6	7	8	9	4.28	***
6	Honey production	10	9	8	8	7	7	6	5	4	4	3	2	-4.28	***
7	Demand for honey	1	1	2	2	3	4	5	6	7	7	8	9	4.28	***
8	Demand for herb products	3	3	3	4	4	4	5	5	6	7	8	9	4.06	***
9	Demand for wood tree products	2	2	2	3	3	4	5	5	6	7	8	9	4.17	***
10	Ecotourism	0	0	1	1	2	2	3	4	5	6	7	5	3.95	***
11	Sand harvesting	0	0	1	1	2	3	4	5	6	7	8	9	4.34	***
12	Employment opportunities	1	1	1	2	2	3	3	3	3	4	5	5	3.83	***
13	Credit access	1	1	1	1	1	1	2	3	3	4	5	6	3.62	***
14	Farming activities	1	1	1	2	3	4	5	6	7	7	8	9	4.23	***
15	Access to wood fuel	10	10	10	9	9	8	7	7	6	6	5	5	-4.05	***
16	Infrastructure development	1	1	2	2	3	3	3	4	4	5	5	6	4.05	***
17	Access to transport services	1	1	1	2	2	2	3	3	4	4	4	5	3.88	***
18	Access to communication services	1	1	1	1	2	2	2	3	3	4	5	6	3.90	***
19	Access to information e.g. electronic media	1	1	2	2	3	3	4	5	6	7	8	9	4.28	***
20	Access to markets	1	1	1	2	3	4	5	5	6	7	8	9	4.23	***
21	Growth of urban areas	1	1	2	2	3	4	5	5	6	7	8	9	4.28	***
22	Land adequacy	10	9	9	8	7	6	5	4	4	3	3	2	-4.28	***

Food security in the study area was found to be on a downward trend. This was due to the declining number of livestock per household and, hence, the lack of adequate herds to sustain livelihoods in most households. The declining social cohesion has negatively affected social networks and, thus, degraded the mutual mechanisms of reciprocity based on which pastoral communities supported each other during crises such as famine. Also, IPCC (2019) noted that climate change is negatively affecting food security in pastoral systems of Africa's drylands due to direct or indirect effects on crop and livestock production. Moreover, Gelan, Getahun and Beyene (2017) pointed out that pastoralists are facing frequent food security problems due to the scarcity of pastoral resources and ecological stress.

The study, however, found food diversity to be increasing over time. This was due to food insecurity that has caused the affected pastoralists to seek and adopt alternative foods and food sources. The increasing access to markets and thus trade and supply of food products, especially from non-pastoral areas, has also driven the adoption of other food diets. The changing lifestyles have also contributed to the adoption of other food diets. Moreover, greater access to formal education, information, and health services means that people are learning and appreciating the value and health benefits of diverse food diets. According to FAO (2017), urbanization has been accompanied by a transition of dietary patterns and has a great impact on food systems. Besides, Gebremichael and Asfaw (2019) noted that food choices in communities are influenced by market access and the knowledge of nutritious and healthy foods. Pastoral diets are also changing as the effects of climate change and environmental degradation make it increasingly difficult for pastoral households to subsist on a purely pastoral economy due to declining livestock ownership (Krätli and Swift, 2014; Njoka *et al*., 2016).

The observed positive trend in women's empowerment is driven by factors that have exposed pastoral women to the outside world and taught them to be independent. These factors include access to formal education and information, in-migration of people from other areas, and outmigration to other areas. The improved access to government services and, hence, better implementation of policy provisions and initiatives that promote gender equity in the area has also increased women's empowerment. Besides, livelihood diversification has created economic opportunities that enable women to pursue independent livelihoods leading to greater financial independence and space for decision-making. This has been supported by improved access to credit services which enables women to access financial capital. According to Goldsmith (2012), pastoralist women are responding to emerging opportunities and setting up new income-generating activities, particularly around service provision and trade. The increase in community participation in decision-making also translated into greater women empowerment.

The continued decline in social cohesion in the study area is concordant with the Government of Kenya's (2012) observation that pastoralists are caught up in a process of social differentiation whereby the social fabric that held communities together is breaking down. Social cohesion is declining as the observation of cultural practices that acted as points and means for interaction and, thus, contributed to the establishment of the community's social fabric diminishes. The declining trend in moral values also means that the ethics that guided people to coexist have been eroded over time. The declining social cohesion is also caused by factors that cause pastoralists to change their communal lifestyles to become more capitalistic and individualistic including urban growth, access to markets, livelihood diversification, and land privatization. The resultant commodification of pastoral production has enhanced the focus on individual profit as opposed to collective gain and hence the degradation of social cohesion. According to Galvin (2008), the pursuit of livelihood diversification can lead to social fragmentation as individuals pursue disparate goals and, thus, acquire different viewpoints based on their experiences. The commodification of land resources and livestock is fragmenting pastoral communal systems as pastoralists develop a greater preference for individual profit than collective gain (Galvin, 2008; Reid, Fernandez-Gimenez and Galvin, 2014).

The study revealed that income inequality was increasing over time. This agrees with Njoka *et al*. (2016) who observed that the gap between the rich and the poor pastoral communities continues to widen as a few individuals get richer while many pastoral households are trapped in a vicious cycle of poverty. While the group of poor pastoralists has grown bigger, that of well-off pastoralists has remained typically small (FSAU, 2001) as livestock ownership in pastoral areas is increasingly consolidated in the hands of a few wealthy people who are mostly outsiders (De Haan *et al*., 2016). Therefore, some households have been left out or are moving out of pastoralism in the backdrop of the inexistence of viable alternatives as a few individuals increase their production. Similarly, income inequality has increased as the social capital, which enabled mutual sharing in pastoral communities, and, thus, reduced disparities between community members. The unequal accumulation of livestock across domestic groups in the past was offset by collective ties across age sets (Bonte, 1981; Rigby, 1992). Changing land tenure, especially through land privatization and hence unequal accumulation of rangeland resources has also caused income inequalities. Moreover, as pastoralists diversify their livelihoods, income inequalities could result due to unequal access to knowledge, skills, and capital, which cause some households to fair better than others.

The downward trend in security was due to an increase in unethical and criminal activities as moral values decline. The weakening of customary governance systems that were keys to instilling moral values, and law and order in the community has led to an increase in insecurity. Similarly, conflicts in the area have also increased as security has declined. This has been driven by the scarcity of pastoral resources as demand rises and the existing rangeland resources are degraded. Goldsmith (2012) gathered that conflicts in pastoralist areas are caused by several overlapping factors including high population growth rates, environmental degradation, and insecurity. Correspondingly, the weakening of traditional governance systems that are keys in addressing conflict issues in the community has contributed to the increase in conflict incidences. Moreover, climate change and variability, especially the frequent occurrence of droughts in East Africa's arid and semi-arid areas increase communal conflicts over pastoral resources (Raleigh and Kniveton, 2012; USAID, 2012). The intensification of pastoral conflicts in East Africa is also caused by the increased alienation of pastoral land to other uses, and disruptions of pastoral mobility (Few *et al*., 2015).

The customary governance systems and land management have diminished as people get more access to government services that are replacing and weakening the role of traditional governance structures. This is largely explained by the process of the colonial and post-independence governments introducing new land tenure and statutory governance systems in pastoralist areas that disrupted and undermined the traditional governance institutions (Kaye-Zwiebel and King, 2014; Basupi, Quinn and Dougill, 2017). Wynants *et al.* (2019) noted that these coercive policies of land use, privatization, sedentarization, exclusion, and marginalization led to a gradual erosion of indigenous social, political, and economic structures. Furthermore, Kaye-Zwiebel and King (2014) gathered that changing governance systems and new resource management institutions challenge the capacity of communities to effectively manage common pool resources.

Moreover, the decline of customary governance systems has been due to cultural erosion as people adopt new ways of life due to the in-migration of new people, access to formal education and information, market access, and urbanization. Besides, the loosening of moral values has led to low respect and recognition of elders and traditional governance structures, especially by the younger generation. The greater incorporation and exposure of pastoral people to western education, national politics, and market economies have resulted in the abandonment of pastoral livelihoods (Thebaud and Batterbury, 2001; Andriansen, 2003). Besides, the erosion of social cohesion and the traditional hierarchical structure within pastoral communities had led to the young generation increasingly feeling much less morally and socially indebted to the older ones (De Haan *et al.*, 2016).

Further, the emerging and accelerating shocks and stresses such as climate change and variability, new land tenure and use regimes, rapid population growth, resource scarcity, insecurity, and conflicts have created new scenarios that disorient, destabilize, and hinder the effectiveness of traditional decision-making structures. These factors also destruct the enabling environment for effective governance. Climate change and variability influence ecosystem dynamics and, thus, exert a major influence on pastoral livelihood strategies and institutions (Galvin *et al.*, 2001). Still, Fratkin (2001) and Catley, Lind and Scoones (2013) construed that population growth, social and economic modernization, and the imposition of statutory land tenure systems have tended to decrease the capacity of customary pastoralist governance and grazing management and restrict the traditional strategies for coping with disturbances such as drought.

The declining adequacy of land was caused by the declining effectiveness of land management mechanisms, which leads to inefficient and unsustainable utilization of the available rangeland resources. Furthermore, the decrease in livestock mobility has meant that pastoralists are mostly confined within their community lands hindering access to alternative grazing lands. This is aggravated by the changing land tenure and land use that have led to the loss of previously pastoral land through privatization and non-pastoral activities such as farming, private ranching, urban growth, infrastructure development, and establishment of wildlife conservation reserves. In addition, there is increasing demand and, hence, pressure on available land due to the growth of the human population and livestock numbers. In Sub-Saharan Africa, competition over land has intensified over the last few decades due to urbanization, agriculture intensification, conservation initiatives, and privatization of communal land through policies that have sought to replace customary communal tenure systems with private liberal property rights (Diao, Magalhaes and Silver, 2019; Kisamba-Mugerwa, Pender and Kato, 2006). This scarcity of land in pastoral areas can be traced back to the colonial and post-colonial times when pastoral communities were systematically excluded from vast areas of land that were repurposed for agriculture, private ranches, conservation areas, and infrastructure development in the name of development (Wynants *et al*., 2019).

The upward trend in climate change and variability was associated with the increase in drought frequency and severity and a decrease in rainfall amounts. A study by Mizutani *et al*. (2005) in Laikipia revealed that annual rainfall values have progressively reduced over time while droughts have become more frequent and

severe. Moreover, several studies have reported a warming trend in the East Africa region during the last six decades consistent with African and global trends (Christy, Norries and McNider, 2009). The deterioration of local climate conditions was caused by environmental degradation including the declining tree cover and the underlying factors. Nagash (2021) concluded that climate change and variability are a direct consequence of rangeland degradation. In line with this, land degradation in the study was found to be increasing. Land degradation was associated with the observed decrease in stream flows, increase in invasive species, and reduction in tree cover. The degradation of the land was due to the increasing pressure on natural resources due to the growth in human population, land inadequacy, restriction of livestock mobility, and an increase in the total number of livestock. Further, Little (2013) deduced that restrictions on livestock mobility and increased human and livestock densities create pressures on rangelands leading to land degradation. The increasing demand for natural resources such as sand, water, herbs, and wood tree products, and demand for livestock and livestock products hence the urge to maximize production have led to unsustainable utilization resulting in land degradation. Hannam (2018) pointed out that rangelands are subject to over-extraction of woody biomass and water resources due to population growth and hence pressure on resources.

Climate change and variability leading to the occurrence of extreme rainfall events and hence soil erosion, and severe droughts that hinder vegetation growth and favor the proliferation of invasive species have also contributed to land degradation. Further, land degradation has been caused by poor land use practices associated with urban growth and the expansion of farming activities. Njoka *et al*. (2016) noted that the upcoming small towns in pastoralist areas are often poorly planned and result in negative social and environmental repercussions. The declining effectiveness of land management and customary governance systems has led to poor land use practices hence causing land degradation. Moreover, the decline in land tenure security translates into declining certainty in ownership and hence declining commitment to sustainably manage land and natural resources. The Government of Kenya (2003) pointed out that environmental degradation in pastoral areas is largely caused by poor land management practices, failure of the community land tenure system, and erosion of the efficacy of the traditional pastoral management system. Further, WISP (2008) gathered that policies that create space for the involvement of customary institutions in decision-making and local enforcement of rules and regulations over resources have been successful in reversing land degradation in pastoral areas.

The availability of pastoral resources including pasture and water was also observed to be declining. This was due to the diminishing effectiveness of customary governance systems and land management that led to unsustainable use and degradation. Further, higher demand and hence the pressure on pastoral resources due to human and livestock population growth, declining livestock mobility, and land inadequacy have led to a decline in the availability of pastoral resources. Population growth, and land use policies that focus on the sedentarization of pastoral communities continue to cause accelerated pressure on natural resources leading to rangeland resources degradation (Meadows and Hoffman, 2003; Western, Groom and Worden, 2009). Similarly, the deteriorating climatic conditions that have led to a reduction in rainfall amounts and an increase in drought frequency and severity have caused the scarcity of pasture and water resources. Ripkey *et al*. (2021) noted that the high sensitivity of

pastoralists to weather conditions that shape both grazing land and water sources makes them more vulnerable to climate variability. Moreover, climate change, including the changing rainfall patterns and severe recurrent droughts, affects ecosystems directly by causing a shortage of forage and water (Thornton *et al*., 2006; Kimaro, Mor and Toribio, 2018).

This increase in demand and pressure on available resources, the deteriorating land management, and governance systems, and the deteriorating climate conditions have also caused a decline in the availability of natural resources such as herbs, wood fuel, and wood tree products in the study area. Few *et al*. (2015) noted that extreme climatic conditions and land degradation have caused the decline of biodiversity in the last decades in East Africa. Similarly, they have caused the observed decline in wildlife and bee abundance and honey production. The decline in wildlife abundance is also caused by declining security which has led to an increase in poaching incidences. It is also due to the increase in conflict incidences which include human-wildlife conflicts and hence result in the killing and displacement of wildlife, especially in community lands. Moreover, changing land tenure and use in pastoral areas through the privatization of land and an increase in farming plots, and the resultant fencing activities have affected wildlife due to a reduction in habitats and animal mobility. According to Ogutu *et al.* (2014), wildlife populations in Africa are declining severely due to climate change, rising population pressures, and policy, economic and sociocultural transformations.

In addition, the study found that market access in the study area is increasing. This increase is due to the improvement in access to government services which means there is an improvement in the necessary support services. Besides, the increase in infrastructure development, better access to transport and commination services, and improved access to information have led to an improvement of the mediums of trade, market facilities, and ease of access to market centers and production areas. Urban growth, human population growth, and an increase in employment opportunities have enhanced the consumer base and hence local demand for merchandise and services which translates to greater market access. According to Thornton (2010), changes in the demand for livestock products have historically been largely driven by human population growth, income growth, and urbanization. Furthermore, market access has increased due to the increasing demand for locally produced products, including livestock and livestock products, herbs, honey, and wood tree products. This concurs with Little (2016) who observed that there has been growth in the national and export markets for rangeland bio-products. Furthermore, Thornton (2010) established that the demand for livestock products will nearly double in Sub-Saharan Africa and South Asia from 200 Kcal per person per day in 2000 to around 400 Kcal per person per day in 2050.

The increasing diversification of pastoralists' livelihoods that was observed in the study area is caused by the declining number of livestock per household which has led to livestock-poor households adopting alternative income-generating activities to survive. Also, the scarcity of land and natural resources due to the increasing population pressure, restricted livestock mobility, and land degradation has necessitated diversification to alternative livelihoods. Diversification is driven by shrinking rangeland resources (Seno and Shaw, 2002; Okello, 2005), declining per

capita livestock wealth, and changing lifestyles (Western and Nightingale, 2003; Homewood, 2009). Pastoralists have also diversified their livelihoods to build their resilience to deteriorating climatic conditions and food insecurity. Asravor (2017) found that a decrease in rainfall led to an increase in livelihood diversification.

Change in local lifestyles due to various underlying factors such as cultural erosion, in-migration, urbanization, access to formal education, and access to information has also driven the observed upward trend in livelihood diversification. Additionally, pull factors such as improved access to markets, urban growth, and the growth experienced in other economic activities such as ecotourism and sand harvesting are attracting people to venture into alternative income-generating activities to leverage the resultant opportunities. Improved access to credits has also led to an increase in livelihood diversification by providing the financial capital for the establishment of business enterprises. Gebru, Ichoku and Phil-Eze (2018) found that a household's choice and adoption of livelihood diversification had a positive relationship with access to credit. Likewise, Little (2016) noted that the availability of non-pastoral livelihood options has always been influenced by the presence or absence of urban centers since towns afford trading opportunities and the chance to engage in the cash economy.

The growth of non-livestock economic activities such as sand harvesting and ecotourism was driven by the improvement of the needed support infrastructure and services such as communication, transport, information, and government services. Moreover, the establishment of nature conservation reserves has driven the growth in ecotourism activities since they constitute the sector's main product. Infrastructure development, increased settlement, and growth of urban centers have led to an increase in the demand for sand and hence increased sand harvesting. The growth of these non-livestock economic activities has also been caused by the reduction in the number of livestock per household and hence the need for livelihood diversification. This is in agreement with Reid, Fernandez-Gimenez and Galvin (2014) who established that the reduction of income from livestock and its failure to satisfy the growing needs of pastoralist families had caused many of them to diversify their livelihoods by engaging in ecotourism and mining activities.

The decline in livestock mobility was due to a change in land tenure and use that led to land fragmentation and reduced the grazing land that is accessible to pastoralists. The changes in land tenure and use include land privatization, encroachment of farming onto pastoral areas, the establishment of nature conservation reserves, and infrastructure development. The reduction of the available rangeland due to land divisions and the influx of small-scale farmers into pastoral areas have caused sedentarization among previously mobile herders in Laikipia (Boles *et al*., 2019). Moreover, Herbert and Birch (2022) noted that livestock mobility has been impeded by competition for land that has been caused by the conversion of rangelands to other uses, an agrarian bias in policymaking, environmental challenges, and population growth. The structures and systems that governed pastoral mobility have also diminished as shown by the negative trend in the effectiveness of customary governance systems, land management, and observation of cultural practices. Additionally, the decline of social cohesion has led to the weakening of mutual sharing mechanisms between communities, yet they were the basis of pastoral mobility.

Rising insecurity and conflicts have reduced the accessibility of vast areas of the remaining pastoral rangelands and thus hindered mobility as pastoralists prefer to live near areas that have security services since they are mainly centralized. Likewise, ODI (2009) pointed out that sedentarization in pastoral areas is taking place due to the alienation of pastoral land, conflicts, and insecurity which have rendered some areas inaccessible and caused a decline in rangeland resources. Pastoralists are also becoming more sedentary as they adopt urban lifestyles, diversify to non-pastoral livelihoods, and align their settlements to the fixed-point provision of social services. Furthermore, sedentarization is taking place due to changes in production and marketing priorities (Herbert and Birch, 2022), the growing trading centers that are becoming an attraction to pastoral drop-outs looking for non-livestock livelihood options, and the provision of social services at fixed locations (Njoka *et al*., 2016). The deteriorating climatic conditions, land degradation, and scarcity of pastoral resources have also caused pastoralists to adopt more sedentary lifestyles as they respond by adopting non-pastoral income-generating activities. According to (FAO, 2001), social, political, and environmental pressures from climate change, population pressure, and land use in East Africa have catalyzed the process of sedentarization.

The study found that the total number of all types of livestock raised in the area is increasing over time. This is due to human population growth and hence the number of livestock owners and livestock owned. The improvements in access to extension and veterinary services have improved livestock husbandry and control of livestock diseases and hence the total number of livestock. According to Thornton (2010), developments in breeding, nutrition, and animal health increase the potential for livestock production. The increasing demand for livestock and livestock products has also caused an increase in livestock numbers as people strive to maximize production to take advantage of the improved market. Besides, Thornton (2010) established that the production response to increasing demand for livestock and livestock products in different livestock systems has been associated with increases in livestock numbers.

Nevertheless, a downward trend was found as appertains to the number of livestock owned per household. Little *et al*. (2001) and Sandford (2006) observed that the growth in human population in pastoral areas eventually outpaced livestock increases leading to a decline in per capita livestock holding beyond the levels needed for subsistence. This was due to the reduced availability of pastoral resources, including pasture and water, and the underlying factors including land degradation, declining climatic conditions, and population growth. Previous studies also revealed that the decline in the number of livestock per household was caused by human population growth and climate shocks (Begzsuren *et al.*, 2004; Randal, 2008).

The increasing inadequacy of pastoral land due to restricted livestock mobility and its alienation and appropriation through the change in land tenure have also reduced the capacity of households to raise adequate livestock herds. Land fragmentation and expansion of crop cultivation into pastoral areas have led to a reduction of available pastoral resources and weakened the sustainability and resilience of pastoral systems (Olson *et al*., 2004; Müller-Mahn, Rettberg and Getachew, 2010). Furthermore, Letai and Lind (2013) established that restricted mobility has heavily impacted herd sizes in the East Africa region. The decline in the number of livestock per household has also been caused by the deterioration of the enabling environment for livestock production

due to rising insecurity, conflicts, and poor governance and land management. The adoption of alternative livelihood activities has also led to the raising of smaller herds as people move out of pastoralism.

Conclusion

The study found that major changes have occurred with the pastoral system from the 1910s to the present. These changes include the increase in the local population, which had a profound effect on the demand, and, hence, sustainability in the use of resources. The social fabric has also changed as local people interact with the outside world and receive formal education, hence, adopting new knowledge systems. The changes in the social status have either been good such as the increase women empowerment or detrimental such as the diminishing of social cohesion and moral values in the community. The erosion of the areas traditional governance systems and cultural values had a major impact not only on the social fabric but also on the governance of natural status and hence the ecological status and resource availability. The decline in the local natural resources base has a negative effect on local economic activities status since, especially since pastoral livelihoods are highly dependent and sensitive to the status of the environment.

The change in the land tenure system as new forms of land governance and management were introduced did not only lead to diminishing of access to land by pastoralists but had a main influence on land use. The observed changes in land use have mainly been detrimental due to misalignment of new forms of use with the local eco-climatic conditions. Changes in land use and resource availability has influenced pastoral management as observed by the declining livestock mobility and increasing sedentarization. The worsening climatic conditions have also had a profound influence on pastoral livelihoods as diminishing rainfall has led to scarcity of pasture and water resources in the backdrop of declining land availability. The evolution of pastoral livelihoods in response to the deteriorating socioecological system is best depicted by the observed positive trend in livelihood diversification as pastoralists attempt to cope and adapt to the *status quo* by adopting new livelihood strategies.

The findings of this study will enrich pastoral development planning and policymaking processes. It can be realized by helping identify the drivers and, thus, causes of the deterioration of various aspects of the pastoral socioecological systems including the observed deterioration of governance, and livelihoods and environmental status, galvanizing the right response action to alleviate the situation. The relationships between the trends will not only explain causality, but the strength of these relationships will help in prioritizing the most effective response actions to use in resolving various challenges. Likewise, the study will also help identify the most effective policy interventions to adaptation and to improve the pastoral socioecological systems.

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Authors' Declarations and Essential Ethical Compliances

Author's Contributions (in accordance with ICMJE criteria for authorship)
This article is 100% contributed by the sole author. S/he conceived and designed the research or analysis, collected the data, contributed to data analysis & interpretation, wrote the article, performed critical revision of the article/paper, edited the article, and supervised and administered the field work.

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Research involving human bodies or organs or tissues (Helsinki Declaration)
The author(s) solemnly declare(s) that this research has not involved any human subject (body or organs) for experimentation. It was not a clinical research. The contexts of human population/participation were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or ethical obligation of Helsinki Declaration does not apply in cases of this study or written work.

Research involving animals (ARRIVE Checklist)
The author(s) solemnly declare(s) that this research has not involved any animal subject (body or organs) for experimentation. The research was not based on laboratory experiment involving any kind animal. The contexts of animals not even indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or ethical obligation of ARRIVE does not apply in cases of this study or written work.

Research on Indigenous Peoples and/or Traditional Knowledge
The author(s) solemnly declare(s) that this research has involved Indigenous Peoples as participants or respondents. Other contexts of Indigenous Peoples or Indigenous Knowledge, if any, are only indirectly covered, if any, through literature review. Therefore, a sample copy of the prior informed consent (PIC) of the respondents and Self-Declaration in this regard are appended.

Research involving Plants
The author(s) solemnly declare(s) that this research has not involved the plants for experiment or field studies. The contexts of plants are only indirectly covered through literature review. Yet, during this research the author(s) obeyed the principles of the Convention on Biological Diversity and the Convention on the Trade in Endangered Species of Wild Fauna and Flora.

(Optional) Research Involving Local Community Participants (Non-Indigenous)
The author(s) solemnly declare(s) that this research has not directly involved any local community participants or respondents belonging to non-Indigenous peoples. Neither this study involved any child in any form directly. The contexts of different humans, people, populations, men/women/children and ethnic people are only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee

or Authority) or prior informed consent (PIC) of the respondents or Self-Declaration in this regard does not apply in cases of this study or written work.

(Optional) PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses)
The author(s) has/have NOT complied with PRISMA standards. It is not relevant in case of this study or written work.

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Author(s) has/have no competing financial, professional, or personal interests from other parties or in publishing this manuscript. There is no conflict of interest with the publisher or the editorial team or the reviewers.

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To see original copy of these declarations signed by Corresponding/First Author (on behalf of other co-authors too), please download associated zip folder [Ethical Declarations] from the published Abstract page accessible through and linked with the DOI: https://doi.org/10.33002/nr2581.6853.060109

SELF-DECLARATION FORM
Research on Indigenous Peoples and/or Traditional Knowledge

The nature and extent of community engagement should be determined jointly by the researcher and the relevant community or collective, taking into account the characteristics and protocols of the community and the nature of the research.

If your research involved/involves the Indigenous Peoples as participants or respondents, you should fill in and upload this Self-Declaration and/or Prior Informed Consent (PIC) from the Indigenous Peoples. [Please read carefully https://grassrootsjournals.org/credibility-compliance.php#Research-Ethics]

1. Conditions of the Research

1.1 Was or will the research (be) conducted on (an) Indigenous land, including reserve, settlement, and land governed under a self-government rule/agreement or?

Yes/No

1.2 Did/does any of the criteria for participation include membership in an Indigenous community, group of communities, or organization, including urban Indigenous populations?

Yes/ No.

1.3 Did/does the research seek inputs from participants (members of the Indigenous community) regarding a community's cultural heritage, artifacts, traditional knowledge, biocultural or biological resources or unique characteristics/practices?

Yes/No

1.4 Did/will Aboriginal identity or membership in an Indigenous community used or be used as a variable for the purposes of analysis?

Yes/No

2. Community Engagement

2.1 If you answered "Yes" to questions 1.1, 1.2, 1.3 or 1.4, have you initiated or do you intend to initiate an engagement process with the Indigenous collective, community or communities for this study?

Yes/No

2.2 If you answered "Yes" to question 2.1, describe the process that you have followed or will follow with respect to community engagement. Include any documentation of

consultations (*i.e., formal research agreement, letter of approval, PIC, email communications, etc.*) and the role or position of those consulted, including their names if appropriate:

The research was based on agreement with the indigenous community. The methodology used was participatory and thus there was consent from individual participants and the leadership to participate

3. No Community Consultation or Engagement

If you answered "No" to question 2.1, briefly describe why community engagement will not be sought and how you can conduct a study that respects Aboriginal/ Indigenous communities and participants in the absence of community engagement.

Name of Principal Researcher: Dr. Caxton Gitonga Kaua
Affiliation of Principal Researcher: Africa Research and Impact Network

Declaration: Submitting this note by email to any journal published by The Grassroots Institute is your confirmation that the information declared above is correct and devoid of any manipulation.

INFORMATION AND CONSENT FORM FROM RESPONDENTS
(Non-Indigenous or Indigenous Respondents)
This form was translated into local language for the respondents

Pastoralists' Socioecological Trends

Principal Researcher: Dr. Caxton Gitonga Kaua
Africa Research and Impact Network, Nairobi, Kenya
Research Supervisor:

A) INFORMATION TO PARTICIPANTS

1. Objectives of the research
This study is aimed to analyze the socioecological trends of pastoral systems with a focus on Laikipia County, Kenya. The study analyzed how pastoral systems have evolved across demographic, social, economic, environmental and economic dimensions.

2. Participation in research
The researcher will ask you several pertinent questions. This interview will be recorded in written form and should last about 50-60 minutes. The location and timing of the interview will be determined by you, depending on your availability and convenience.

3. Risks and disadvantages
There is no particular risk involved in this project. You may, however, refuse to answer any question at any time or even terminate the interview.

4. Advantanges and benefits
You will receive intangible benefits even if you refuse to answer some questions or decide to terminate the interview. You will also contribute to a better understanding of the good causes for pastoralist communities of the Laikipia County.

5. Confidentiality
Personal information you give us will be kept confidential. No information identifying you in any way will be published. In addition, each participant in the research will be assigned a code and only the researcher will know your identity.

6. Right of withdrawal
Your participation in this project is entirely voluntary and you can at any time withdraw from the research on simple verbal notice and without having to justify your decision, without consequence to you. If you decide to opt out of the research, please contact the researcher at the telephone number or email listed below. At your request, all information concerning you can also be destroyed. However, after the outbreak of the publishing process, it is impossible to destroy the analyses and results on the data collected.

B) CONSENT

Declaration of the participant

- ⇨ I understand that I can take some time to think before agreeing or not to participate in the research.
- ⇨ I can ask the research team questions and ask for satisfactory answers.
- ⇨ I understand that by participating in this research project, I do not relinquish any of my rights, including my right to terminate the interview at any time.
- ⇨ I have read this information and consent form and agree to participate in the research project.
- ⇨ I agree that the interviews be recorded in written form by the researcher: Yes ( ) No ( )

Signature of the participant : _____ Date : _____10 Dec 2022_____

Surname : _____ First name : _____

Researcher engagement

I explained to the participant the conditions for participation in the research project. I answered to the best of my knowledge the questions asked and I made sure of the participant's understanding. I, along with the research team, agree to abide by what was agreed to in this information and consent form.

Signature of the researcher : Date : 10 Dec 2022

Surname: *Kaua* First name: *Caxton*

- ⇨ Should you have any questions regarding this study, or to withdraw from the research, please contact Mr. Caxton GitongaKaua or by e-mail at caxtonk2008@gmail.com
- ⇨ If you have any concerns about your rights or about the responsibilities of researchers concerning your participation in this project, you can contact the Director, Research and Impact Network, Nairobi, Kenya, Tel: +254746130873 Email: info@arin-africa.org

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M – 00333y | Analytical Article

Adverse Effects: Thirteen Homeowners Near A Blasting Quarry Bought Out By Quarry Owner

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Abstract

In Ontario, a blasting quarry operation, once established, is allowed to effectively operate indefinitely, as a licence to permit aggregate extraction has no expiry date. Once established, the prospect of terminating a quarry operator's licence is virtually non-existent, regardless of the nature or number of site plan and quarry violations or adverse impacts (e.g., flyrock, noise, toxic fumes, fugitive dust, vibrations, drain or damage domestic wells), all due to a lack of effective government oversight (e.g., government staff shortage exacerbated by allowing self-reporting of the aggregate industry). Before a blasting or non-blasting quarry operation is permitted, the owner of the quarry should be compelled to purchase potentially impacted properties, provided that in doing so the environmental impact is reduced to a "trivial" level and the surrounding community is not destabilized. Otherwise, once a quarry is operational, the only remedy available to the municipality and impacted property owners is to launch a civil action at considerable time and expense, a process that can drag on for years with no guarantee of success. Sometimes, a quarry operator will voluntarily commit to purchase adversely impacted properties, but sometimes the acquisitions are undertaken surreptitiously, and require the property owner to sign a non-disclosure agreement. This case study pertains to a number of adversely effected homeowners whose homes were bought out by the owners of the Acton Quarry in Halton Hills, Ontario. They concealed their true identity through the use of numbered companies and one with the delightful sounding name (Snowfarm Ltd.) when purchasing the houses and in the process destabilized the community.

Keywords

Blasting; Quarry; Adverse effects; Environmental impact; Extraction

Introduction

Blasting quarry operations are notorious for their adverse effects on the environment and its inhabitants, both human and non-human, and their negative impacts increase with the scale, intensity and duration of operations. The adverse effects become even more pronounced when municipalities or planning boards allow aggregate extraction to occur near sensitive lands (e.g., wetlands,

aquifers, floodplains, etc.) or populated areas where people live, work or play (e.g., settlement areas, rural clusters, parks, heavily travelled public roads, etc.), or in areas that are planned or slated for future population growth or heavy public use.

While the case study presented in this paper pertains to the Acton Quarry[1] in Halton Hills, Ontario, the *adverse effects* that the neighbouring homeowners had to continually endure before being bought out primarily by numbered companies to conceal the identity of the quarry owner, the negative quality of life and disruption to use and enjoyment of property, ultimately leading to a loss in homeowner equity (i.e., property value), is common to all homeowners residing near blasting quarry operations everywhere. The Acton Quarry was established in the early 1800s, and the quarry operation in its most recent expansion has grown from 222.3 hectares (549 acres) to 287.9 hectares (711 acres). Aggregate extraction at the Acton Quarry was put on hold during the 2019-2020 period.[2] Acton Quarry was selected for analysis, and as the scale, intensity and duration of blasting quarry operations increase so does the duration of *adverse effects*, some of which are permanent and irreversible. *Adverse Effects* have the same definition in both the Ontario Environmental Protection Act (EPA) and the 2020 Provincial Policy Statement (PPS), with the later specifically addressing land use planning policies in Ontario.

Properties Acquired by the Quarry Owner

A search of rural residential property sales over a number of years (1991-2010) near the Acton Quarry in Halton Hills, a quarry blasting below the water table, now operated by Dufferin Aggregates through a series of changes in corporate ownership, uncovered acquisitions of fourteen (14) rural residential properties on Third Line, including one vacant building lot, by owners of the Acton Quarry. None of the 13 residences and one vacant building lot were purchased in the open market, as evidenced by the absence of any "for sale" MLS listings corresponding to the date each property was purchased by the then owner of Acton Quarry. In 8 of the acquisitions, the quarry operator's true identity was concealed through the use of numbered companies, and one company with the delightful name "Snowfarm Ltd." The 14 transactions are summarized as follows in table 1.

Aerial views and other data sources reveal that ultimately 9 homes of the 13 improved properties on Third Line bought out by Acton Quarry have been demolished: 1 dwelling (2010-2015), 2 dwellings (2015-2017), and 6 dwellings (2017-2019). According to the scaling function provided by the Toronto Real Estate Board (TREB), at the time each homeowner of the 14 properties (13 rural residences and one vacant building lot) was bought out by the then corporate owner of the Acton Quarry, the closest distance from the quarry pit to each of the three Sub-Groups of sales (shown on the attached aerial sketch – Appendix A) was approximately:

- Sub-Group (7 sales) - 750 feet - (229 metres) - from quarry pit

[1] See the destruction of the terrain and stagnant water ponds at the Acton Quarry on the August 5, 2014 YouTube video, https://www.youtube.com/watch?v=nJd6j2K2754.
[2] 2021 State of Aggregate Resources, Halton Region, https://www.halton.ca/getmedia/a23b652e-2bfd-4883-8dd9-66886e18ac84/Attachment__1_LPS67-21_State_of_Aggregate_Resources_in_Halton_Region.aspx.

- Sub-Group (5 sales) - 2,100 feet - (640 metres) - from quarry pit
- Sub-Group (2 sales) - 4,950 feet - (1,509 metres) - from quarry pit

Table 1: Transaction of Properties

Address		*PIN*	*Lot Dimensions*	*Lot Area (sf)*	*Sale Date*	*Sale Price (in CA$)*	*Vendor*	*Purchaser*	*Demolished*
11759	Third Line	25017-0077	160' x 400'	63,647	8-Jan-10	468,000	Watson	Snowfarm Limited	
11749	Third Line	25017-0078	160' x 400'	63,712	8-Jan-10	495,000	McEachern	Holcim (Canada) Inc.	
11998	Third Line	25017-0005	100' x 200'	19,913	29-Dec-06	410,000	Harris, Oliver	St. Lawrence Cement Inc.	
11992	Third Line	25017-0006	122' x 200'	24,305	29-Jan-07	656,500	Locke	St. Lawrence Cement Inc.	
11988	Third Line	25017-0007	100' x 200'	19,913	28-Dec-00	232,000	MacNeil	Blue Circle Canada Inc.	2010-2015
11978	Third Line	25017-0008	125' x 200'	24,897	28-Dec-00	224,000	Bradbury	Blue Circle Canada Inc.	2015-2017
11970	Third Line	25017-0009	125' x 200'	24,897	28-Mar-91	359,000	Vander Eyken	St. Lawrence Cement Inc.	2015-2017
12723	Third Line	25005-0030	203' x 226'	38,600	27-Mar-08	683,333	French	764296 Ontario Ltd.	2017-2019
	Third Line	25005-0029	125' x 242'	31,980	23-Oct-08	300,000	Coxe	747752 Ontario Ltd.	
12759	Third Line	25005-0028	125' x 269'	35,359	27-Mar-08	683,333	Henderson	764296 Ontario Ltd.	2017-2019
12763	Third Line	25005-0027	125' x 296'	38,729	27-Mar-08	683,333	Pettipher	747752 Ontario Ltd.	2017-2019
12765	Third Line	25005-0026	125' x 323'	42,108	27-Mar-08	658,133	Hotham, Osborne	764296 Ontario Ltd.	2017-2019
12771	Third Line	25005-0025+	157' x 364'	51,473	27-Mar-08	683,333	Kirkwood	747752 Ontario Ltd.	2017-2019
12775	Third Line	25005-0138	425' x irreg	159,618	27-Mar-08	733,333	Coxe, et al.	764296 Ontario Ltd.	2017-2019

Market Value

Typically, an appraisal would be commissioned for each residential property, accompanied by instructions from the quarry owner to the appraiser to ignore the impact of the quarry operation on the market value, with each property owner required to sign a confidentiality agreement as a condition of sale. Implicit in the concept of *Market Value*, defined as follows, is that the purchaser is well-informed or well-advised. However, the vendor will virtually always be more knowledgeable than the prospective purchaser.

> "The most probable price, as of a specified date, in cash, or in terms equivalent to cash, or in other precisely revealed terms, for which the specified property rights should sell after reasonable exposure in a competitive market under all conditions requisite to a fair sale, with the buyer and seller each acting prudently, knowledgeably, and for self-interest, and assuming that neither is under undue duress." *(Appraisal Institute, 2020).*

It is an unrealistic expectation of the aggregate industry that a typical homebuyer contemplating acquisition of a property in proximity to a blasting quarry operation could possibly have an awareness and understanding of all the adverse effects, both short- and long-term, their family would have to endure for the entire life of the quarry operation, which, in Ontario, can remain operational indefinitely.

Ongoing Adverse Effects

The Russell family, one of the numerous families victimized by the Acton Quarry operation, described the adverse effects endured while residing near the Acton Quarry for approximately 10 years during testimony (Witness Statement) at an OMB hearing (LPAT PL170688), which commenced May 21, 2019, involving another quarry,

blasting below the water table, proposed some 1,500 metres from their present residence in Guelph Eramosa. The description is narrated below:

- *My family and I lived on Third Line Acton, south of 22nd Sideroad from [November 25,] 1988 to 1999 [December 30, 1998]. When we moved into the house, the Acton Quarry was an established operation that was bounded on the south side by 22nd Sideroad which meant that our house was about 1,100 m from the quarry…. However, the quarry did expand south of 22nd Sideroad a few years after…. which brought with it several new challenges but the key ones that I am addressing here are the property damage and consequential property devaluation.*
- *[B]lasting shockwaves were very evident at the house. One could feel the whole structure move as the shockwave passed. I vividly recall the first time I personally experienced the blasting shortly after moving in. I was on vacation (and so at home at the regular daily noon hour blasting) and sitting on the garage floor working on my car. For an instant, as the shockwave passed, I felt weightless, almost as though I left the ground!*
- *[T]his blasting was daily at the time, and so my wife and three pre-school children experienced that same shockwave effect every day.*
- *My house eventually started to display significant symptoms that I would believe were a direct result of the repeated mechanical shocks [from everyday blasting]. At first they were relatively minor such as cracks in window frames and some cracks in the drywall. Eventually, the symptoms became more serious.*
- *Following the expansion of the quarry south of 22nd Sideroad, cracks started to propagate across the concrete floor of the garage and basement. The house then developed a crack through both of the masonry walls on the south wall of the structure (this was the largest section of the structure above ground). This grew…[to] be a ½" crack that extended diagonally both on the interior structural masonry as well as the exterior cosmetic masonry. The two cracks propagated at 90 degrees to each other suggesting that they were not just due to simple subsidence (note that the house had been there for approximately 20 years already so the foundation would reasonably be considered as very stable).*
- *Inaccessibility to 22nd Sideroad due to the 3rd Line being closed by quarry workers due to the risk of rocks [i.e.,* flyrock[3] *landing on the 3rd Line road during the blasting.*
- *The congestion caused by trucks lining up for the opening of the quarry in the early morning. These stationary, large vehicles caused safety issues due to road constrictions and visibility issues for other motorists.*

When the Russell family discussed the damage to their home, which they attributed to repeated detonations of explosives at the quarry, with representatives of the Acton Quarry, the quarry operator denied any liability, stating that

[3] "Flyrock" is the ultimate adverse effect, and is defined by the National Institute for Occupational Safety and Health (NIOSH) as "any debris that lands outside the designated blasting area. It can vary in mass from marble-sized to car-sized and can be incredibly dangerous and potentially fatal." Wherever there is blasting of rock, flyrock can occur, and be propelled distances exceeding 1,000 metres. No matter how well a blast is executed the consequences of flyrock are unpredictable.

> "There was no proof that the cracks were related to the blasting as I had not had the foresight to have my house monitored with accelerometers and recorders [which provide less than reliable measures of damage when a property is exposed to repeat blasting]."

In *Darney v. Dragon Products Company, LLC, Dist. Court*, D. Maine (2011)[4], the court referenced studies undertaken by the Bureau of Mines, which conclusively demonstrated that blasting has the potential to damage property and poses a danger to nearby residences, as noted in the court's findings:

> *"The Court has little difficulty agreeing with the Darneys that blasting poses a high degree of risk of some harm to both persons and property. Even defense expert Mr. McKown specifically stated on direct that "Yes, I believe that the handling of explosives is inherently dangerous" (Tr. Vol. IV at 856). Indeed, the Bureau of Mines (BOM) conducted extensive studies on blasting done near residential structures, which demonstrated quite conclusively that blasting has the potential to cause damage to buildings from fly rock, ground vibration, and airblast. Similarly, given the extensive best practices recommended by the BOM by those engaging in quarrying activities, and the rigor with which the State of Maine oversees such activities, the Court has little difficulty that any such resulting harm has the potential to be great. In short, in applying these first two factors, the Court agrees with the Dyer Court that "blasting is inherently dangerous." Dyer, 984 A.2d at 216 (citing Maravell, 914 A.2d at 714)." [emphasis added]*

And, yet, despite Acton Quarry's refusal to acknowledge the possibility of property damage from blasting, inexplicably, in December 2000, only two years after the Russell family had sold their home to Angela MacNeil in December 1998, the then quarry owner (Blue Circle Canada Ltd.) acquired the property, along with the abutting home at 11978 Third Line, both of which were subsequently demolished by the owner of Acton Quarry.

A representative of Dufferin Aggregates, when asked at a December 10, 2012 public meeting by a resident whether an inventory of any issues with houses near the quarry had been recorded when Dufferin Aggregates acquired Acton Quarry in November 2001, responded as follows:

> *"The public is repeating concerns that existed over 10 years ago and many homeowners in the area bought homes when they knew a quarry was present. He believes those complaining should show proof that cracks in foundation happened due to recent Acton Quarry operations. He explained it is likely the cracks occurred well before Dufferin Aggregates came into the town p. 5]."*

This offensive reverse onus on homeowners residing near quarries blasting below the water table to prove damages to their residences is a classic tactic of quarry owners. Repeated blasting, coupled with dewatering,[5] is known to cause environmental and

[4] *Darney v. Dragon Products Company, LLC*, Dist. Court, D. Maine 2011, https://scholar.google.ca/scholar_case?case=18045799007160645928&q=fly-rock&hl=en&as_sdt=2006.

[5] 6th Annual Georgia Environmental Conference, Savannah, Georgia, August 25, 2011, Limestone Conditions With Pit Dewatering, USGS Open-File Report OF-010484, Worst-Case: 1) WATER TABLE

structural damage, and compromise the health, safety and welfare of nearby residents, pets, livestock and wildlife. Blasting is an ultra-hazardous activity held to strict liability. All of the homes surrounding Acton Quarry were built at different times, using different building materials, presumably, in compliance with the building code prevailing at the time each home was built. Accordingly, there is no uniform intensity of blasting that each residence can withstand. The homeowners are not under any legal obligation to ensure that their homes are constructed to a (fortress) standard that would withstand the impacts of repeated blasting using powerful explosives.

By ignoring residents' complaints of property damage, the only effective remedy available against a quarry owner is costly litigation, which may be dragged out by the quarry operator for years, with an uncertain outcome, even with the benefit of strict liability and a favourable "more probable than not" burden of proof. This is one more reason why the precautionary principle should be applied, and an abundance of caution exercised, when a municipality considers the locational characteristics of an application for a new quarry blasting below the water table, or expansion of an existing quarry blasting below the water table.

Destabilization of Community and Unwitting Home Purchasers

Any semblance of community life along Third Line near the Acton Quarry has all but been obliterated, as only a few homes remain standing. The few remaining homes on Third Line near the Acton Quarry are not readily marketable or mortgageable on typical terms and conditions, and homeowner insurance may be difficult or costly to obtain, especially if previous damages have been claimed, leaving Acton Quarry as the only viable buyer. Of course, there is always the possibility of selling one of the few remaining homes on Third Line to an unsuspecting purchaser with no knowledge or comprehension of the *adverse effects* associated with residing near a quarry blasting below the water table.

Buying a home with an awareness of a quarry nearby does not imbue the typical purchaser with an understanding of all the potential *adverse effects* of a quarry blasting below the water table.[6] Many questions would need to be answered:

- Was the purchaser informed of how long the quarry would remain operational (Ontario aggregate licenses have no expiry date)?
- Was the purchaser informed of the potential adverse effects of living near the quarry by the realtor (or was the realtor as uninformed as the purchaser) before purchasing the property?
- Was the purchaser aware of how often blasting would occur at the quarry and

lowered by quarry dewatering. 2) SPRING no longer receives groundwater discharge. 3) WETLANDS dried up & destroyed. 4) CAVITIES & PIPES form in the soil where groundwater support is lost. 5) SUBSIDENCE of the land occurs. 6) COLLAPSE SINKHOLE after soil falls into an underlying cavity. 7) STREAM dries up. 8) RIPARIAN WOODLANDS destroyed. Slide 22, https://citizensagainstmining.org/wp-content/uploads/2017/04/Quarry-Effects-by-Leggette-Brashears-and-Graham.pdf.

[6] Labelling a quarry operation as in "interim" land use is extremely misleading, as a quarry can theoretically remain operational in perpetuity, and where aggregate extraction occurs below the water table, there is no prospect of rehabilitating the excavated pit to a productive economic use.

the average number of detonations per blast, and that blasting is an ultra-hazardous activity?

- Was the purchaser aware that operations at the quarry, including blasting, could interfere with use of outdoor amenity space by family, relatives, guests, pets, livestock and wildlife?
- Was the purchaser giving implied consent to the quarry operator to compromise the health, safety and welfare of their family, relatives, guests, pets, livestock or wildlife?
- Was the purchaser advised of the health risks of exposure to silica dust,[7] a by-product of quarry operations, to their family, relatives, guests, pets, livestock or wildlife?
- Was the purchaser advised of the dangers of *flyrock*, an inevitable by-product of blasting rock, and considered the ultimate adverse effect (most people have never heard of *flyrock*, a closely guarded dirty little secret of the aggregate industry and its explosives engineers)?
- Was the purchaser advised by the realtor to make any offer conditional on obtaining a satisfactory building condition report from a structural engineer?
- Was the purchaser advised by the realtor to make any offer conditional on obtaining a satisfactory environmental audit?
- Was the purchaser advised by the realtor to make any offer conditional on obtaining a satisfactory well water pumping test? (CMHC requires a water flow of ≥ 3 gallons per minute for 2 hours and a government tested well sample)

Considering the significant amount of time (steep learning curve) and cost to be incurred by a prospective homeowner to properly and adequately address the concerns identified in the acquisition of a property near a quarry blasting below the water table, and discounting the asking price accordingly, the potential pool of buyers becomes virtually non-existent. When access to important information is asymmetrical, resting solely in the possession of_the vendor (property owner or agent), a prospective homeowner is rendered incapable of making an informed decision, and overpays.

> *"Uninformed buyers overpay, particularly when purchasing complex assets whose values are difficult to accurately quantify (Carlin et al., 2013). Uncertainty over value creates market environments that allow asymmetric information price effects to persist (Kelly and Ljungqvist, 2012)….Home buying is an area where the ability of households to gather and effectively use market information can have profound effects on housing decisions, through both the choice of mortgage product and the purchase transaction itself [p.1]"* (van der Vlist and Turnball, 2015).

[7] "Crystalline silica has been classified as a human lung carcinogen, and can cause serious lung disease and lung cancer. It only takes a very small amount of respirable silica dust to create a health hazard. One of the dangerous effects of silica exposure is a disease called silicosis, which can be contracted after just a few months of high exposure. Silicosis occurs when silica dust enters the lungs and causes the formation of scar tissue, reducing the lungs' ability to take in oxygen. There is no cure for silicosis, and cases can be disabling or even fatal." https://www.concentra.com/resource-center/articles/what-is-silica-and-why-is-it-dangerous/.

Adverse Effects and Diminution in Property Values

According to the Provincial Policy Statement, 2020 (p. 39),[8] *adverse effects*, as similarly defined in the *Environmental Protection Act*, mean one or more of:

a) impairment of the quality of the natural environment for any use that can be made of it;
b) injury or damage to property or to plant or animal life;
c) harm or material discomfort to any person;
d) an adverse effect on the health of any person;
e) impairment of the safety of any person;
f) rendering any property or plant or animal life unfit for human use;
g) loss of enjoyment of normal use of property; and
h) interference with [the] normal conduct of business.

Flyrock meets the Ontario EPA definition of contaminant, and the *adverse effects* of *flyrock* are not trivial. In *Castonguay Blasting Ltd. v. Ontario (Environment)*, 3 SCR 323, 2013 SCC 52 (CanLII), the Supreme Court held that "the flyrock could easily have seriously injured or killed someone." The residents of the community near the Acton Quarry have been exposed to a number of potential short- and long-term (permanent and irreversible) *adverse effects* including *flyrock*, and there is a diminished sense of community as most of the homeowners along Third Line have been bought out by the Acton Quarry owner.

According to a search of public records, Dufferin Aggregates (owner of the Acton Quarry since November 2001) subsequently bought out 11 nearby homeowners, and, in 8 of those acquisitions, Dufferin Aggregates concealed its identity through the use of numbered companies, including one named "Snowfarm Limited."

Diminution in Property Value

As to the diminution in the value of the Russell family home while they retained ownership, the Russell family had this to say:

- *When we sold our house [on December 30, 1998, for $209,000], we realized an 11% appreciation in the [acquisition] price [of $189,000 paid on November 25, 1988] in nominal dollars [which amounts to an [insignificant] average annual rate of increase of 1.04758% over a period of 10.10 years.]*
- *During the time [10.10 years] that we lived there, the consumer price index moved up by 35%....When adjusted for inflation, our property declined in real value by 24% despite all our significant upgrades to the property and the fact that the presence of the quarry would have already been factored into the price we paid initially [but the expansion of the Acton Quarry brought the Russell family home closer to the quarry].*
- *In reality, the loss [in property value] was probably much worse if the performance was to be compared to an appropriate housing index given that Acton was a growing community at the time [the property was sold on*

[8] Provincial Policy Statement, 2020, Under the *Planning Act*, https://files.ontario.ca/mmah-provincial-policy-statement-2020-accessible-final-en-2020-02-14.pdf.

December 30, 1998].

- *The direct and indirect influences of the quarry operations led to a further deterioration to the neighbourhood such that my old property [11988 Third Line] today is now gone following a series of degradations that ultimately led to the house being no longer fit for habitation….In fact, 6 [now 9] of the 13 houses along the road where we lived are…no longer there or are uninhabitable.*

The diminution in property values is always a major concern expressed by municipalities and residents living near existing pits and quarries, or living near proposed pits or quarries, a sentiment conveyed by the Town of Caledon in a January 22, 2014 submission to the Standing Committee on General Government Report on the Review of the Aggregate Resources Act.[9]

Reduction in Value of Neighbouring Properties

An issue which is raised by the public at all municipal meetings for aggregate operations is the impact on the value and rnarketability of neighbouring properties. At one of Caledon's public meetings for an aggregate pit, a resident provided evidence confirming that the Province of Ontario's Municipal Property Assessment Corporation (MPAC) has recognized the impact on property value by providing a 10% reduction in assessment to a landowner due to proximity of the property to an aggregate pit.

> "The Town of Caledon undertook a study which included property value impact to support its position with respect to a quarry application. However, no detailed economic studies have been done. The Province should undertake a comprehensive study on the impact of new aggregate pits on neighbouring property values. This study by the Province should form part of the criteria for the ARA licence and Planning Act approval." [p. 7]

At a 2015 Town Board public meeting of the Town of Nassau, New York,[10] evidence was presented by Hite and Robinson (2015) relating to the impact of a proposed quarry blasting below the water table, on the value of nearby residential properties:

- 12 residential parcels within 500 feet (152 metres) of the proposed quarry;
- 22 residential parcels at 1,000 feet (305 metres);
- 26 residential parcels at ¼ mile (402 metres); and
- 291 residential parcels within 1 mile (1,609 meters).

At 2.6 people per household (pph), that equates to 756 people (291 × 2.6 pph) or about 15% of the Town's population, lives within 1 mile (1,609 metres) of the proposed quarry [p. 80]. The results of Hite and Robinson's (2015) study are summarized as follows:

> "That analysis of property value impacts (The Impact of Hard Rock and Gravel Mines on House Prices in Upstate New York) applied a scientific model (Hedonic Price Model) to analyze the effect of mining operations on house

[9] https://www.peelregion.ca/council/agendas/pdf/rc-20140213/communication-ma-b3.pdf.
[10] Resolution of the Town Board of the Town of Nassau Decision on the Troy Sand & Gravel Special Use Permit Application Resolution No. 17, September 1, 2015.

> values. This study used a large dataset on housing sales in areas surrounding three industrial stone mines and one sand/gravel mine in Columbia, Saratoga, and Renssealer counties…. Hite's study concludes that mine operations are a disamenity that would have a negative impact on property values ranging from a 7.5% to 36% discount. Related to these discounts, she concludes (page 12) that 'These discounts are statistically significant at the 99+% level; such a high degree of significance leads us to conclude that, without a doubt, the quarry that Troy Sand & Gravel Co., Inc., proposes to develop and operate in the Town of Nassau, Rensselaer County, New York, will have a deleterious financial effect on existing homeowners' [p. 72]." [bold added]

Had residents of the Town of Nassau been aware or made aware of the proposed blasting quarry, they would have bought property elsewhere, and if the quarry were to be established the homeowners contend they would have difficulty selling their homes or be unable to sell their homes or develop additional residences. On March 19, 2009, Dufferin Aggregates submitted Official Plan and Zoning By-law Amendment Applications to the Town of Halton Hills[11] to permit expansion of the Acton Quarry by 124.4 hectares (307.4 acres) with an extraction area of 99 hectares (244.6 acres), subsequently revised in June 2012 to 90.6 hectares (223.9 acres) and 66.5 hectares (164.3 acres), respectively.

Dufferin Aggregates retained Golder Associates Ltd. (Golder) to prepare a Blasting Impact Assessment report (November 2008), a copy of which was obtained from the internet. The report does not include an assessment of the risk of *flyrock*, let alone even mention the word *flyrock*. As noted below in a study undertaken by the Mine Health and Safety Council, South Africa (Milestone 5, p. 31), and a blaster-training manual (Module 8) prepared on behalf of the U.S. Department of the Interior's Office of Surface Mining, the impact of flyrock on the environment and its inhabitants can lead to destruction of property, injury or death:

> *"Human response is generally extreme. Apart from any consideration of damage, it is the only blasting-related hazard that can cause serious injury and death. It is the ultimate adverse effect of blasting and must be avoided at all costs.*[12]*Flyrock is debris ejected from the blast site that is traveling through the air or along the ground. Flyrock is the single most dangerous adverse effect that can cause property damage and injury or death. A rock that lands harmlessly in a field may not appear to be a large issue. However, mowing and tilling become hazardous when rock is struck by farm equipment. Rock through timber stands mar trees and potentially impacts the market value."*[13]

Accordingly, without acknowledging *flyrock*, the statement at p. 16 of the Blasting Impact Assessment (Blast Design) report, that *"the proposed operation will not result in unacceptable impacts on surrounding receptors,"* is not credible. That "*receptors*"

[11] Town of Halton Hills, Report PDS-2014-0028, May 30, 2014.
[12] Mine Health and Safety Council, South Africa, https://mhsc.org.za/sites/default/files/public/research_documents/SIM140901%20Final%20Report.pdf.
[13] "Controlling the Adverse Effects of Blasting," OSMRE, https://www.osmre.gov/sites/default/files/inline-files/Module8.pdf.

are not defined makes the Blast Impact Assessment report even less credible. At p. 3, Golder states that

> *"[t]his report…evaluates the long term impact of the blasting operations on surrounding structures," concluding that repeated blasting "would not [have] any noticeable cumulative effect,"*[9] *[despite years of complaints to the contrary based on the historical operation of the quarry]*

Equally disturbing is that the Joint Agency Review Team (JART) in its March 2013 report failed to raise concerns about *flyrock*, a health and safety issue ignored in the Blast Impact Assessment undertaken by Golder in connection with Dufferin Aggregates' March 2009 application to expand operations at the Acton Quarry. However, JART may not have possessed awareness or comprehended the potential dangers of "flyrock," nor that repeated blasting, even if undertaken within regulatory limits, would cause damage to nearby residential properties.

Inconceivably, the Golder report does not even provide the definition of *adverse effect*, as defined in the Ontario EPA (and PPS), the statutory (legal) benchmark for identifying and analyzing *adverse effects* that are an inevitable consequence of the Acton Quarry expansion. It is a little known fact that the impetus for environmental protection of the Niagara Escarpment, which is impacted by the Acton Quarry, came as a protest against the damage caused by *flyrock*, as explained by Murray Stephen of the Halton Region Conservation Authority in the January 1991 issue of *The Journal* (Milton Historical Society):[14]

> "The impetus for the conservation authority in this area came not from the need for flood control but as a protest against "flyrock" from industrial blasting at Mount Nemo [p. 4]."

All potential adverse effects, including flyrock, from a quarry blasting below the water table must be borne by the proponent/applicant, and confined to the site of the private profit-seeking quarry operator.[15] It is repugnant for a quarry operator to attempt to impose adverse effects on innocent third-party property owners living nearby and have the health, safety and welfare of their families, relatives, guests and pets compromised, and their standard of living lowered without permission and compensation.[16]

In denying Troy Sand & Gravel's application to permit quarry blasting below the water table, the Town of Nassau concluded with the following reasons, highlighting, in particular, the egregious and presumed use of neighbouring properties as an off-site "dumping" ground for adverse effects (e.g., fugitive dust, air pollution, noise, vibration, flyrock) and sterilizing the properties from future development or

[14] The Journal, Milton Historical Society, January 1, 1991, http://miltonhistoricalsociety.ca/documents/journal_archive/1991.pdf.
[15] In *Norma Moore et al. v. Smith Construction Company, a Division of the Miller Group Inc.*, OSCJ [Nov 2011], the Superior Court agreed with the defendants that a quarry owner "is a private, for-profit company and should be required to pay the full cost of its operations without forcing the plaintiffs [homeowners] to effectively subsidize its business through the free use of their properties [para. 70]."
[16] Resolution of the Town Board of the Town of Nassau Decision on the Troy Sand & Gravel Special Use Permit Application, Resolution 17, September 1, 2015.

redevelopment, without concern for the health and safety, quality of life, and financial well-being of the property owners.

> "Use of private lands surrounding the proposed quarry in order to buffer impacts is unacceptable. The Lead Agency's Findings Statement used the location of the homes located around the mine [quarry] property as receptors for judging impacts, such as fugitive dust and air pollution, noise, and vibration from blasting. In many cases, the Lead Agency relied upon the spaces and distances between the nearest houses and the property boundary of the mine [quarry] as a buffer area for off- site impacts of the mine [quarry]. For example, noise or vibration impacts migrating out from beyond the property line of the mine [quarry] were expected to dissipate on the properties of surrounding land owners, but prior to reaching the location of existing homes on the properties. The same conclusion was reached about dust and air pollution that would migrate beyond the mine [quarry] property boundary. In that event, according to the Lead Agency, dust and pollutants were expected to dissipate and settle upon the land of those property owners, but before those pollutants reached existing homes. Town Board members had a visceral reaction to the idea of the Applicant using neighboring private properties to buffer mine [quarry] impacts. This was essentially letting the Applicant using those properties to dispose of various forms of impacts or pollution without either their permission or compensating them. But the potential damage is still larger than that. The Town Board is aware that there are home-based businesses in the lands surrounding the mine [quarry] site that depend on the rural character and the existing peace and quiet as part of their businesses. Hence, the use of these properties as buffer areas for noise, dust and vibration, the impacts of the mine [quarry] will likely damage the local rural economy which is fragile as it is without additional stress factors. Still further, by relying on the location of existing homes only (receptors), the DEC's analysis on this point also rested on the unsupportable assumption that no new homes would be located closer to the mine in the next 100 years or so. This is improbable. The use of neighboring properties as buffer area for off-site impacts, and to deposit settling dust which migrates off-site, is unacceptable. The Applicant should have been required by the Lead Agency to mitigate these impacts before they reach the mine [quarry] property line." [pp. 100-101]

As documented in the March 2013 JART report,[17] which reviewed the proponent-driven studies submitted by Dufferin Aggregates in support of its application to permit expansion of the Acton Quarry, there have been numerous complaints from nearby residents about well-water quantify and quality:

> "Private well-related concerns have been raised by some local residents since the mid-1990s and were again re-iterated at the September 26, 2012 public meeting at Halton Region and in correspondence with the Agencies regarding the proposed expansion. The comments ranged from general concern with the potential impacts of the proposed expansion on private water supplies to specific concerns that historical impacts on private wells are related to the existing quarry."

[17] JART REPORT, March 2013.

> "Specific private well-related concerns have mainly been clustered around the homes to the east of the Dufferin-owned lands along Fourth Line. Between 17 Sideroad and the rail line to the north, private wells are typically bedrock wells drilled into the Cabot Head and Queenston Shale formations, with some using the Reynales or Whirlpool formations as a source of water. In general, well-related complaints have been attributed to the relatively poor capacity of the shale bedrock formations to provide sufficient capacity to be used as a reliable source of water, particularly under drought conditions. Water quality-related issues have generally been related to the operation of the private wells resulting in excessive drawdown during dry periods and resulting in degradation of the shale bedrock when exposed to air causing sediments in well water [p. 41]."

According to a January 26, 2010 article in the Independent Free Press,[18] the Lister family, who reside on a farm on Fourth Line 1,800 metres from the existing quarry and 1,850 metres from the extraction limit of the quarry extension (expansion),[19] complained that

> "their farm has been experiencing water shortage problems since 2005 when the quarry stopped pumping water into the southern pond. At that time she said their water supply changed. Over the past two years she said they have had to have water delivered every two days, which Dufferin [Aggregates] has paid for."

Other complaints relating to well issues and water quality and quantity by nearby residents are described as follows:

> Dufferin responded to one complaint received in regards to the Acton Quarry (ARA 5492) in 2012 relating to "cloudy water". Although their investigation did not determine the exact cause of "cloudy water", Dufferin installed a water storage tank and filtration system to prevent similar issues in the future [p. 5].[20]
>
> I've lived on the Fourth Line for approximately 13 years…Eight years ago [c.2004] we lost all our water, our well collapsed and its 200-foot well is full of 100 feet of sand[21] [Steve Hepman September 27, 2012]
>
> This is a 1,500 gallon [plastic] water tank that the quarry has installed for us because several weeks ago on a Thursday we ran out of water. What came out of our taps was sand and sludge. We were told not to drink the water from the well because it could be contaminated. Now that has an impact on all of us. As you can see we have three children here. Three young people that need water.[22] [Pat Bonozew, Fourth Line Resident, December 3, 2012]

According to a representative of Dufferin Aggregates addressing residents at a December 10, 2012 public meeting,[23] Acton Quarry confines monitoring of ground water impacts caused by dewatering the quarry pit to a radius of 200 metres, which appears to be an inadequate cone of influence given that water quantity and quality

[18] "Dufferin [Aggregates] seeking to expand quarry," https://www.theifp.ca/life/dufferin-seeking-to-expand-acton-quarry/article_35aa83e7-b9f4-55e1-8a3b-f9b3cf82bc6e.html?
[19] Dufferin Aggregates, OMB Case No. 15-137, August 26, 2016, para. 113.
[20] Report No. – LP(6-15-State of Aggregate Resources within Halton Region, September 2, 2015.
[21] https://www.youtube.com/watch?v=oQOdpZuSrik.
[22] https://www.youtube.com/watch?v=1FsyvMFVokg.
[23] Dufferin Aggregates Acton Quarry Community Panel (CAP) Meeting Minutes, https://dufferinaggregates.com/wp-content/uploads/2020/06/Meeting-Minutes-20.pdf.

complaints have been received from residents residing far beyond the 200-metre radius arbitrarily chosen by Acton Quarry.

> "Dufferin Aggregates does not measure impact on the ground water outside 200 metres around the quarry boundary [p. 4]."

Maintaining the water allocation between the Credit River and Sixteen Mile Creek watersheds requires perpetual (i.e., forever) pumping (dewatering) at the Acton Quarry,[24] and, in the event of mechanical failure (all pumps eventually fail), the environmental consequences could be catastrophic. According to the March 2013 JART report,

> "The [JART] peer review team reiterates that perpetual pumping will be required to maintain the present allocation of flow between the Sixteen Mile Creek and Credit River watersheds. Without permanent active management, all surface and groundwater flows towards the existing quarry, and the proposed extension would be directed to the Credit River watershed. As part of the on-going agreement negotiations CVC and Conservation Halton have agreed that an allocation strategy for discharge between the Credit River and Sixteen Mile Creek will be required. This allocation is proposed to become a requirement of the long term agreements relating to the project [p. 39]."

According to the Town of Halton Hills, third-party aggregate haulers at the Acton Quarry repeatedly circumvent the designated haul route, and

> "In 2018, the records identified 50 violations of improper use of Maple Avenue….Dufferin Aggregates provided a one-time contribution of $15,000 to the Town to hire an additional two students to monitor the haul route [p. 2]."[25]
>
> "The Town's survey results identified an average of 11 violations of 37 trips travelled by haul trucks on Maple Avenue that accessed Acton Quarry between July 25, 2017 and July 30, 2019. The Maple Avenue violation rate of 30 percent (%) is due to the private haulers accessing Acton Quarry [p. 2]."

The one-time token payment of $15,000 by Acton Quarry to the Town of Halton Hills to hire two students to monitor the haul route does nothing to stop truckers hauling aggregate from circumventing indefinitely the designated haul route, thereby exposing residents to fugitive dust, noise, increased traffic and potential motor vehicle accidents, problems which will continue to adversely affect the health and safety of residents unabated while Acton Quarry remains operational.

As reported by Acton Up News on October 22, 2022, the Acton Quarry operation continues to disrupt the quality of life of area residents and the use and enjoyment of their properties with no relief in sight:[26]

> *"The residents who live close to the Acton Dufferin Quarry are simply fed up with the Dump truck driver's lack of respect for the residents and the law. Also,*

[24] JART Report March 2013.
[25] Dufferin Truck Monitoring Station Update, August 13, 2019. https://pub-haltonhills.escribemeetings.com/filestream.ashx?DocumentId=6946.
[26] Residents 'Fed Up' with Local Quarry, *Acton Up News*, October 22, 2022, https://www.actonup.ca/news/residents-fed-up-with-local-quarry.

> *the hours that the Quarry is permitted to run are not posted online or available for residents to find. Why is the Quarry permitted to run 5:45 am - 11:30 pm Monday through Saturday? The quarry has no regard for the residents who must hear their loud machinery working late into the night. Do the residents know that there are supposed to be meetings held by the Quarry for the community? We are supposed to be involved and yet nothing has been arranged since 2018….*
>
> *The quarry's governing body, Ministry of Northern Development, Mines, Natural Resources and Forestry (NDMNRF), refuses to listen to the residents' complaints. I have been in contact for 6 months to which nothing has changed. Others and I have been complaining to the Mayor, Halton Police, our MPP, Ward 2 Councillors, and the Halton Traffic Coordinator to which no one seems to be making any significant changes. Dump trucks are spilling their loads, speeding, passing motorists who are already driving above the posted speed limits, driving on roads at times that they are not permitted, and the list continues. Limehouse has a small bridge over the train tracks and the dump trucks are constantly driving over it regardless of the signs posted "Maximum 10 tons" and a large sign of a "no trucks" symbol."*

In a promotional Case Study of the Acton Quarry posted on the internet,[27] Orica Mining Services (Orica), the blasting contractor, cites testimonials received from Acton Quarry applauding the benefits of less downtime and more productivity (enhanced profitability) from larger blasts at the Acton Quarry, while externalizing costs on unwitting and innocent third-party homeowners, and ignoring to mention the adverse effects that blasting (detonation of explosives) has, and continues to have on the environment and neighbouring residents. No neighbouring residents are cited as being thankful for the larger blasts at the Acton Quarry. Of course, Orica's Case Study fails to mention the consequences (adverse effects) to the residents living nearby that the increase in blasting power (more detonations of explosives with each blast) causes problems such as intense and alarming ground vibrations, airblast and flyrock, and greater structural damage in response to the vibrations from each blast.

> "The larger the blast, the less downtime and more productivity for the quarry. We went from single row blasts to 3 rows. The digging is good and we have less oversize. It's working out. And we're significantly below compliance even with the larger blasts."
>
> "We can shoot more pounds per delay, we can expand the pattern, so we save on drill costs, we save on not having to deck as much, and we get better fragmentation because of the accurate timing we can put in." [Assistant Director of Operations Acton Quarry]
>
> "Before we were shooting every day and we had to shut down the operation for 45-60 min. in peak production time. Now if we can shoot once a week or every 5 days and it's a big plus for us." [Quarry Manager Acton Quarry]

[27] Case Study – Reducing Community Impact while increasing Productivity with Larger Blast Sizes, Acton Quarry, Canada. https://www.oricaminingservices.com/uploads/Fragmentation/quarries/100034_Case%20Study_Reducing%20Community%20Impact%20while%20Increasing%20Productivity%20with%20Carer%20Blast%20Sizes_Acton%20Quarry_English.pdf.

Orica is the same blasting contractor responsible for the May 4, 2007 blast at the Pattersonville quarry that launched flyrock debris 526 feet (160 metres) onto New York State Thruway I-90, striking two vehicles and a charter bus, and injuring two people, one of whom was a teenage passenger on the charter bus that was penetrated by a 100-pound (45.36-kilogram) boulder:[28]

> "On May 4, 2007, the shot was laid out by Orica and drilled by Archibald Drilling. Flyrock from the blast traveled approximately 526 feet onto the New York State Thruway, I-90, striking three separate vehicles. A charter bus traveling west was struck by a rock measuring approximately 16- inches by 12-inches and weighing approximately 100 pounds. The flyrock passed through the roof of the bus and struck a teenage passenger. A passenger car traveling east was struck in the driver's side windshield, striking the operator in the abdomen. A third vehicle received a broken windshield and dents to the hood."

With Acton Quarry buying out homeowners as far away as approximately 1,509 metres from its quarry blasting below the water table speaks to the far-reaching significant and sometimes catastrophic adverse effects that quarries have on the environment and neighbouring communities, including the health, safety and welfare of their residents, pets and livestock, and their quality of life.

Demolition of the homes on Third Line, accompanied by the loss in market value of the remaining homes in the community surrounding the Acton Quarry, has eroded the municipality's tax base, a loss that will continue for as long as the blasting quarry remains operational.

Erosion of Municipal Property Tax Base

In 2017, the Ontario Aggregate industry launched an industry-wide assessment appeal that resulted in the reclassification of aggregate pits from *industrial* to *Class 5 farm land*,[29] retroactive to 2009 (Frisque, 2017), shifting the realty tax burden without compensation to homeowners (for the life of the quarry operation) and causing a substantial hardship on municipalities such as Halton Hills, with a number of Licensed Aggregate Sites and a small 2016 population base of approximately 61,200 residents.

The Town of Caledon was the lead municipality in the scheduled assessment appeals before the Assessment Review Board. MPAC had applied an industrial land rate of $75,000 per acre to 846 acres of extraction lands in the Town of Caledon, while the appellants argued for agricultural land rates of $8,000 to $12,000 per acre. The details of the settlement reached in the Aggregate Property Assessment Appeals are contained in a November 17, 2020 memorandum addressed to Members of Caledon Council.[30]

[28] MSHA Contest Proceeding, May 26, 2010, https://www.msha.gov/data-reports/fatality-reports/2010/fatality-8-may-26-2010/final-report.
[29] Canada Land Inventory System Soil Classification defines *Class 5* as "Soils have very severe limitations that restrict their capability to producing perennial forage crops, and improvement practices are feasible."
[30] November 17, 2020 Memorandum, https://pub-caledon.escribemeetings.com/filestream.ashx?DocumentId=11838.

> "For the 2009 – 2012 assessment cycle, aggregate/gravel pit property owners, supported by the Ontario Stone, Sand and Gravel Association (OSSGA) filed assessment appeals across the province. These appeals then carried forward to the 2013-2016 assessment cycle as they remained unresolved by the close of 2012. The property assessments of fourteen of the twenty-five gravel pits in the Town of Caledon were appealed, with two of these appeals going back to 2006. The initial valuation proposal put forth by the OSSGA was $8,000 to $12,000 per acre. Aggregate properties in Caledon were assessed at $75,000 to $101,000 an acre for 2009-2012 and $60,000 to $92,000 an acre for 2013-2016….
> For the current property assessment years between 2017 and 2020, gravel pit assessments are now based on class 5 farm land rates and cap out at $15,000 per acre. That represents a significant hit to all affected municipalities and their taxpayers."

According to the Town of Caledon,[31] the Town's portion of the annual revenue tax loss stemming from the reclassification of gravel pits to farmland (class 5) is estimated at $270,000, which, over an assumed average operational life of 40 years, without taking into account inflation, the burden of which will fall on the shoulders of the residents of Caledon, in the form of higher property taxes. Similar concerns are expressed by the Town of Halton Hills:

> "According to Wendy O'Donnell, Manager Halton Hills, in addition to annual revenue losses – which have already been accounted for – town staff determined the settlement for Halton Hills pits alone would cost municipal taxpayers in Halton Region a total of $2,010,750.56 in back taxes to be refunded….
> The hit just for Halton Hills taxpayers based on seven listed pits in the report clocks in at $671,442.26 – all to be paid back to the pits in question for past taxes no longer applicable based on the settlement.
> The MPAC assessment settlement, which was explained to Halton Hills council in a presentation by MPAC reps at its May 9 meeting, drew understandable consternation from the mayor and all councilors present….
> "We have nine (gravel pits and quarries)…" said the mayor [Rick Bonnette], adding the tax revenue gained by allowing aggregate pits following this decision is becoming so small as to call into question the value of even allowing new ones.
> A number of other councilors echoed those same concerns, pointing out the environmental impact of aggregate extraction and cost of road maintenance to accommodate the heavy trucks needed to transport the extracted materials.
> According to Somerville, the one-time hit of $670K and the loss of annual tax revenue is going to hit property taxes for local residences and business, who will be required to make up the shortfall.
> "I don't think it's right, but I think we're stuck with it," added Councillor Jane Fogal."

[31] May 13, 2013, Town of Caledon letter regarding Assessment Appeals of Gravel Pit Properties.

Building and Sustaining Healthy Communities

According to the 2020 Provincial Policy Statement, under Part V: Policies (1.0 Building Strong Healthy Communities), there is a statutory obligation on the part of all municipalities in Ontario to protect the environment, build sustainable communities, and protect the health, safety and welfare of their residents by avoiding land use conflicts:

> *"Ontario is a vast province with urban, rural, and northern communities with diversity in population, economic activities, pace of growth, service levels and physical and natural conditions. Ontario's long-term prosperity, environmental health and social well-being depend on wisely managing change and promoting efficient land use and development patterns. Efficient land use and development patterns support sustainability by promoting strong, liveable, healthy and resilient communities, protecting the environment and public health and safety, and facilitating economic growth."*

Precautionary Principle

Aggregate extraction, in particular a quarry operation that detonates explosives below the water table, is one of the most toxic, noxious and destructive industrial activities that has both short- and long-term impacts on the environment, some of which are permanent and irreversible, without any prospect of rehabilitation to an economic use. Most, if not all, proponent-driven studies prepared at a point in time, under static environmental conditions, in support of aggregate extraction fail or cannot possibly quantify with any degree of certainty the adverse effects on the environment and its inhabitants, human and non-human, given the dynamic nature of aggregate extraction, coupled with the fact that in Ontario an aggregate licence or permit issued under the Aggregate Resources Act has no expiry date.

Accordingly, every application (proponent) seeking land use amendments (Official Plan/Master Plan and Rezoning) to permit aggregate extraction should be accompanied by an all-encompassing Environmental Assessment (EA), and if there is uncertainty as to the extent of the environmental impacts or there is the potential for land use conflicts, both now and in the future, that cannot be avoided or reduced to a "trivial" level, the municipality should deny the application. Doing so not only preserves ecological integrity, but ensures that a municipality can achieve its long-term land use planning objectives in an orderly fashion, and preserve and enhance property values (homeowner equity), which is vital for the financial well-being of a municipality's property tax base.

Conclusion

In this case study of the Acton Quarry it has been shown that it is virtually impossible to mitigate the *adverse effects* of aggregate extraction operations to a "trivial" level, and as the scale, intensity and duration of quarry operations increase so do the magnitude and number of *adverse effects*, many of which are permanent and irreversible. How a quarry blasting below the water table that causes numerous *adverse effects*, leading to the destabilization of a community, can possibly be

consistent with the Province's policy objective of *building strong healthy communities* remains a mystery. As implausible, ironic and arrogant as it seems, in 2014, Dufferin Aggregates "earned the prestigious Environmental Achievement and Community Relations Award," from the Ontario Stone, Sand & Gravel Association (SOSGA), a self-serving lobby group of the aggregate industry.

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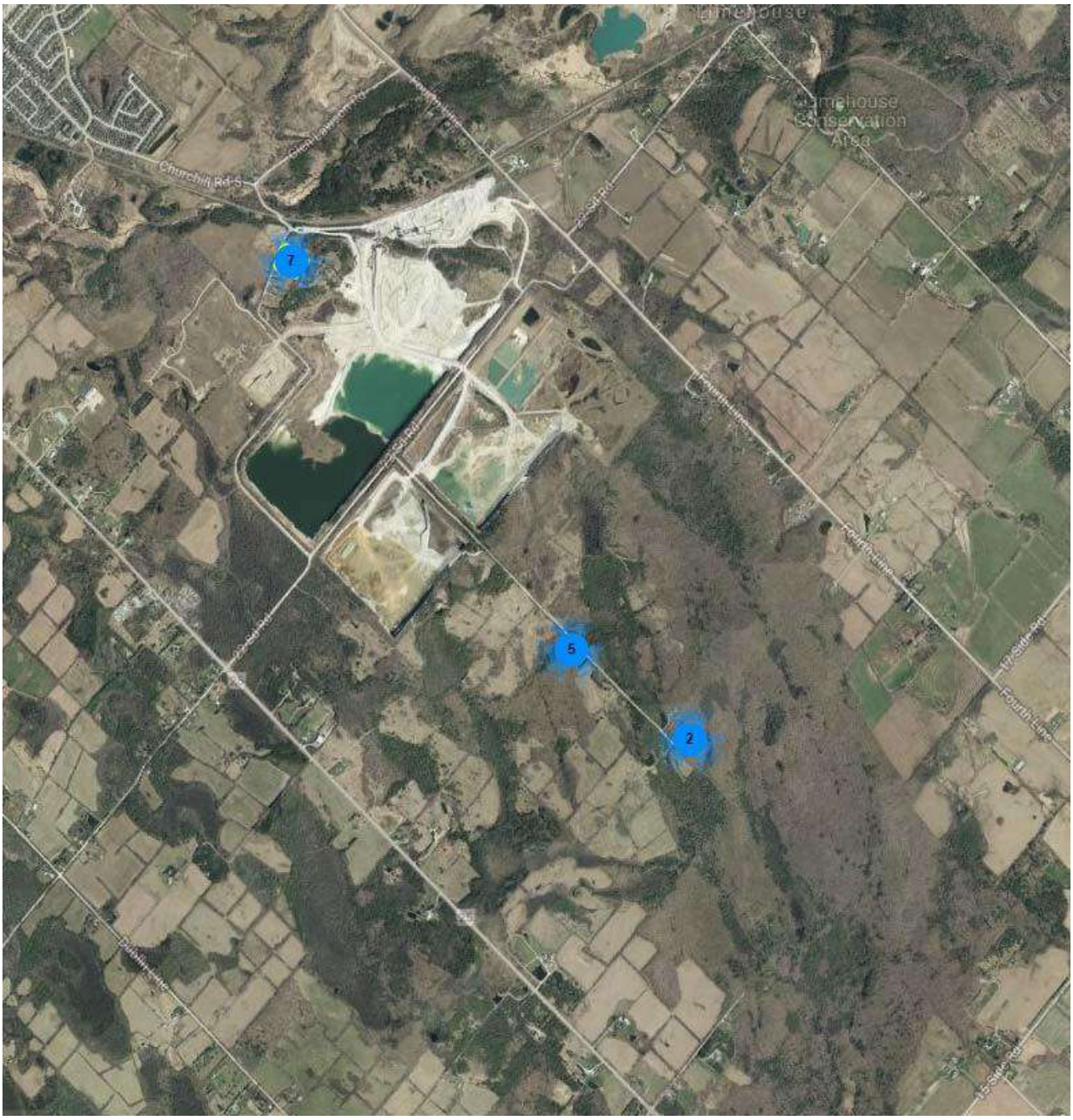
Appendix A: Maps



TREB (Map Date: Spring 2019)

Sub-Group (2 Properties – 11749-11759 Third Line

Sub-Group (5 Properties – 11970-11998 Third Line

Sub-Group (5 Properties – 11970-11998 Third Line

Author's Declarations and Essential Ethical Compliances

Author's Contributions (in accordance with ICMJE criteria for authorship)
This article is 100% contributed by the sole author. S/he conceived and designed the research or analysis, collected the data, contributed to data analysis & interpretation, wrote the article, performed critical revision of the article/paper, edited the article, and supervised and administered the field work.

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Research involving human bodies or organs or tissues (Helsinki Declaration)
The author(s) solemnly declare(s) that this research has not involved any human subject (body or organs) for experimentation. It was not a clinical research. The contexts of human population/participation were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or ethical obligation of Helsinki Declaration does not apply in cases of this study or written work.

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The author(s) solemnly declare(s) that this research has not involved any Indigenous Peoples as participants or respondents. The contexts of Indigenous Peoples or Indigenous Knowledge, if any, are only indirectly covered, if any, through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or prior informed consent (PIC) of the respondents or Self-Declaration in this regard does not apply in cases of this study or written work.

Research involving Plants
The author(s) solemnly declare(s) that this research has not involved the plants for experiment or field studies. The contexts of plants are only indirectly covered through literature review. Yet, during this research the author(s) obeyed the principles of the Convention on Biological Diversity and the Convention on the Trade in Endangered Species of Wild Fauna and Flora.

(Optional) Research Involving Local Community Participants (Non-Indigenous)
The author(s) solemnly declare(s) that this research has not directly involved any local community participants or respondents belonging to non-Indigenous peoples. Neither this study involved any child in any form directly. The contexts of different humans,

people, populations, men/women/children and ethnic people are only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or prior informed consent (PIC) of the respondents or Self-Declaration in this regard does not apply in cases of this study or written work.

(Optional) PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses)
The author(s) has/have NOT complied with PRISMA standards. It is not relevant in case of this study or written work.

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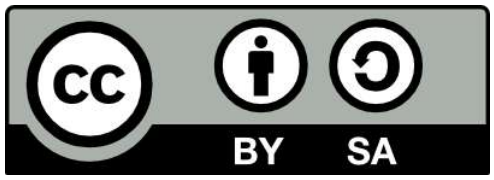

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