

Distribution of Desert Locust *Schistocerca gregaria* in Rajasthan, India and Establishing an Early Warning System for Locust Control in India

Hameer Jhiknaria (✉ sharmaram23000@gmail.com)

MIT-World Peace University

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Early Warning System for Locust Control in India

by

Hameer Jhiknaria

DISSERTATION

MIT – World Peace University, Pune

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Abstract

Desert Locust is considered to be the most serious pests that cause a devastated damage to the crops and the other agricultural products during their invasions. The Desert Locust is a major threat for food security, livelihoods, environment and economic development in a region. The recent Locust Outbreak caused major damage to standing crops and vegetables in the Central and Western states of India, including Rajasthan, Punjab, Haryana, and Madhya Pradesh, with Rajasthan being the most affected. India had experienced such massive locust invasion after two decades. Establishing an Early Warning System for Locust Control in India is essential to reduce the impact by providing timely and relevant information in a systematic way contributing to increasing in resilience of the country. The distribution of Desert Locusts in Rajasthan, India has been presented from June 2019 to August 2020, along with the key Environmental Factors of Temperature, Rainfall, Soil Moisture and Prevalence of Vegetation significantly affecting Locust Activity. All the datasets used were obtained from Secondary sources. These datasets were obtained from Open Government Data (OGD) Platform. The Maps created in the study show the Distribution of Desert Locusts in Rajasthan, India; along with this the Choropleth map show Average- Temperature, Rainfall, Soil Moisture and Normalized Difference Vegetation Index (NDVI), all at District level. The Early Warning System for Desert Locust Control in India is a key integration of four key elements of: Risk Knowledge, Monitoring and Warning Service, Dissemination and Communication and Response Capability, and four-four sub elements of each key element. Establishing an Early Warning System for Locust Control in India is of paramount importance and a major achievement for the nation itself.

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I am heartily thankful to my supervisors, Prof. Kiran Latpate and Payal Raut Ma'am, whose encouragement, guidance and support from the initial to the final level enabled me to develop a better understanding of the topic and aspects related to it. I wish to express my gratitude to my family and friends for their unlimited help, advices and assistance.

Also, I am grateful to Dr. Preeti Joshi (HOS) and Prof. Dr. Anuradha Parashar for letting me work on this project.

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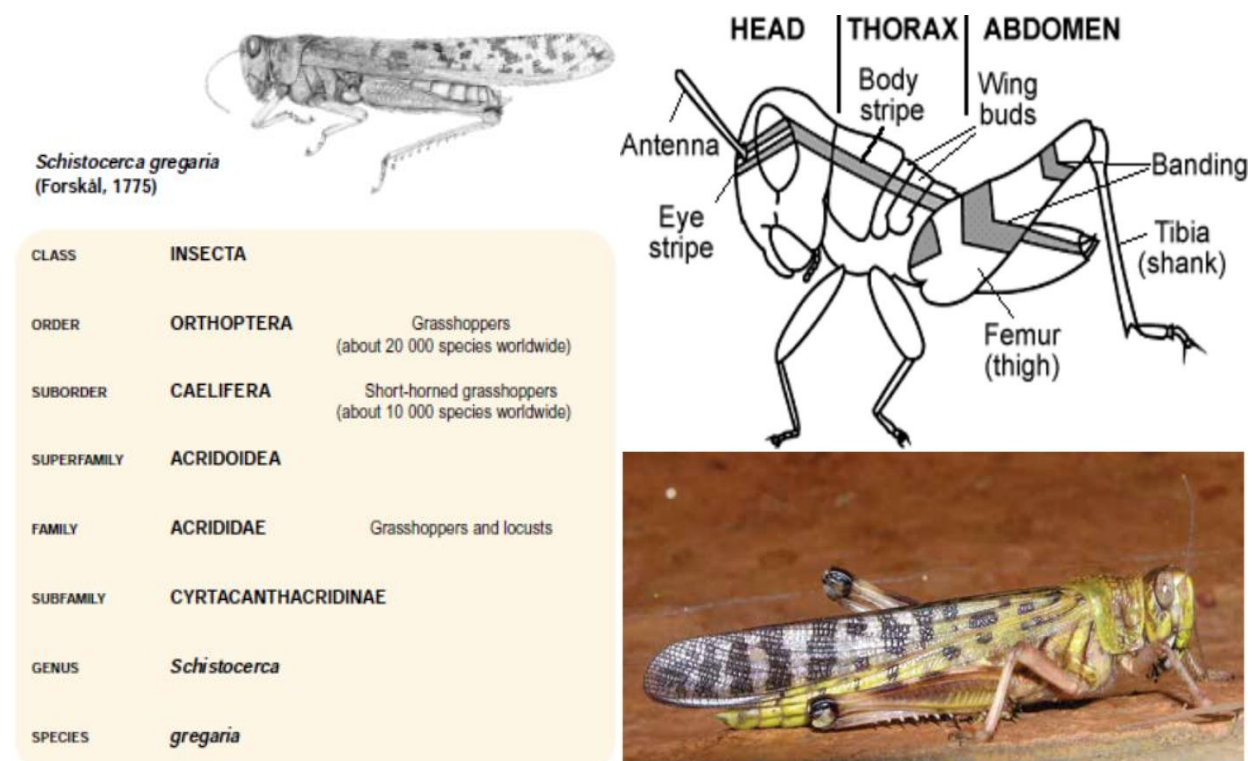
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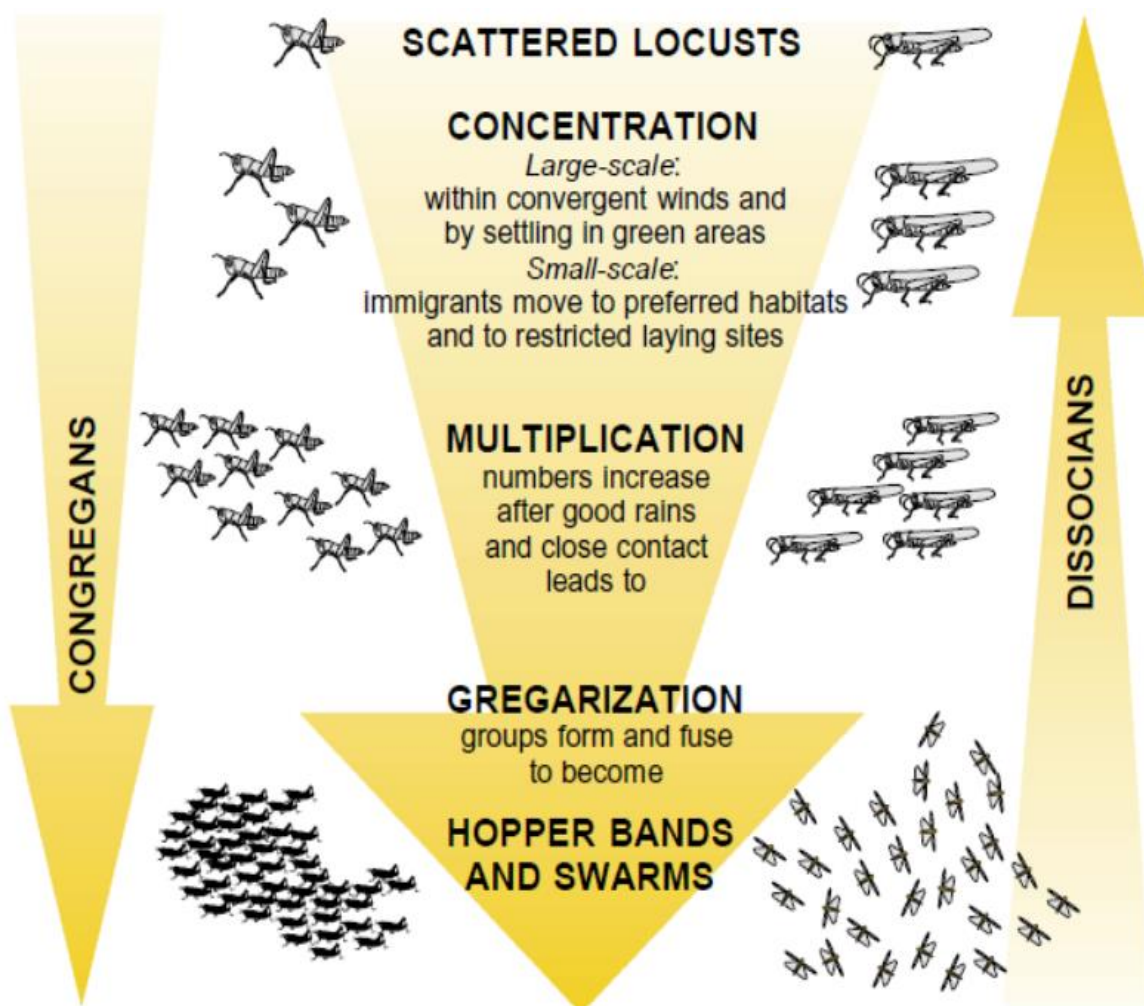
1. Introduction

1.1 Locusts: General Biology and Phase Transformation Processes

The desert locust *Schistocerca gregaria* is one of about a dozen species of short horned grasshoppers (Acridoidea). The Desert Locust is considered to be one of the most dangerous migratory pests in the world. It can travel long distances up to 150 Km/day, due to their ability to travel such long distances they are also called as an International transboundary pest. Desert Locusts have the ability to change their behavior, physiology, color and shape in response to change in locust numbers. At low numbers, locusts behave as single individuals (solitarious phase); at high numbers, they behave as a single mass (gregarious phase). The swarms that form is dense and highly mobile. The generally accepted figure for an average (medium-density) settled swarm is about 50 million locusts/Km sq. whereas the range is 20-150 million/Km sq ^[1].



Desert Locust Biological information. The image was taken from – Symmons, P.M & Cressman, K. Desert Locust Guidelines: Biology and Behaviour (FAO, Rome, 2001)

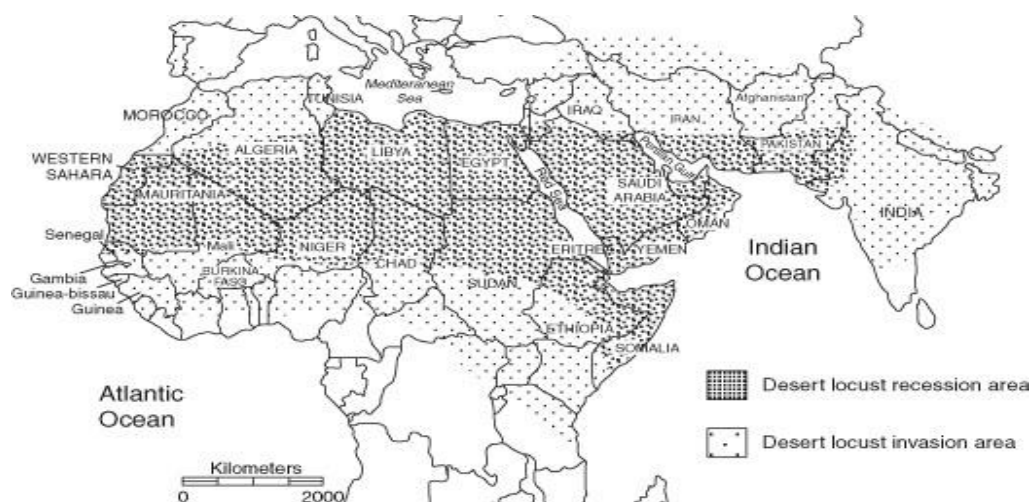


Desert locust phase transformation: concentration, multiplication and gregarization. The image was taken from - Symmons, P.M & Cressman, K. Desert Locust Guidelines: Biology and Behaviour (FAO, Rome, 2001).

As the locusts Swarm, they voraciously feed on nearly all green vegetation (leaves, flowers, bark, stems, fruit and seeds) that comes their way, including key staple crops such as Maize, Wheat, Mustard, Guar, Moong, etc. (<http://www.agriculture.rajasthan.gov.in/>) in turn thereby significantly affecting the livelihoods of small holder farmers and pastoralists. Locusts can cause 80-100% crop losses across affected areas ^[2].

1.2 Locusts Habitat: Global and Indian Setting

In general, the desert locust breeds extensively; during quiet periods in semi -arid and arid deserts extending from West Africa through the Middle East to Southwest Asia, area consisting of about 30 countries; during plagues the pest may spread to larger areas, threatening livelihoods of the population in over 65 countries. During plagues, the desert locust has the potential to damage the livelihood of a tenth of the world's population¹.



Countries lying in invasive and recessive areas of Desert locust. The image was taken from - Alan T. Showler. Desert Locusts *Schistocerca gregaria* forskal (Orthoptera: Acrididae) Plagues.

Agricultural crops and rangeland resources over above 30 million km² in some 55 Third World countries are subject to ravages by the desert locust.

In India, the states of North -Central -Western India, especially Rajasthan, Gujarat, Punjab, Madhya Pradesh, Haryana and Uttar Pradesh are particularly susceptible to desert locust attacks. Until the 1960s, locust outbreaks frequently occurred, except for a few surges in 1978 and 1993, post these years outbreaks were less frequent and occurred, on average, once in a decade.

India has had many plagues, uprising and incursions in the past. In India, there were approximately 12 locust plagues until 1962. No plagues have arisen since then. Similarly, from

1964 to 1997, 13 riots of the locusts have been recorded. In 1998, 2002, 2005, 2007 and 2010 localized small scale reproductivities were also registered and controlled. The condition remained calm from 2010 to early 2019 as there was no news of breeding and swarm formations [3]. In 2019 locusts invaded Rajasthan after a gap of about 26 years. Until February 2020, swarms had damaged crops across 6,70,000 hectares in 12 districts with an estimated loss of about Rs. 1,000 crores, as per Government of Rajasthan-Department of Agriculture (<https://www.outlookindia.com/website/story/india-news-in-pics-locust-attack-in-rajasthan/>).

1.3. Locusts Impact: Economic and other

The number of people in the world is increasing at about 2,20,000 every day; so that more and more crops must be grown to feed them. No one wants to grow more crops to feed locusts. Desert locusts feed on a very wide range of plants. Four main factors contribute to its status as a major pest: the food intake per individual, the range of food plants and parts eaten, the frequency of occurrence of high-density populations and the mobility of the populations. Because swarms are so mobile there is great variation in the amount of damage caused seasonally, from country to country and from region to region. The greatest crop losses occur when young migrating swarms of immature adults reach cultivated areas. They need to eat at least their own weight (2 -3 g) of fresh vegetation each day, and possibly three times as much [4]. As swarms often contain 50 million individuals per square kilometre, even a moderate sized swarm measuring 10 km² could eat some 1000 tons of fresh green vegetation daily [5]. Locusts can cause much damage because they eat the leaves, flowers, fruits, seeds, bark and growing points and also break down trees because of their weight when they settle in masses, and sometimes even by spoiling plants with their excreta. It has been found that 8% of the damage is caused by hoppers, 69% by immature and maturing gregarious adults and 23% by mature swarms [6].

Using conventional methods to calculate economic losses from desert locust episodes is difficult. The cash value of crops, social value of subsistence farming, adverse effects on pasturage, rangeland, and livestock; costs of food aid, and aid for displaced human populations are challenging to assess. The probability of damage reaching tens of millions of U.S dollars, and numerous economic estimates suggest that agricultural losses are insufficient to justify control, but that was solely based on cash value of some crop systems without considering other factors [7].

Year	Country locusts (in £ sterling)	Value of crops destroyed by(in £ sterling)	1986 value
1926-1934	India	400,000 per year	6 million
1928 and 1929	Kenya	300,000 per year	4.5 million
1953	Somalia (Southern Region)	600,000	
1954-1955	Morocco	4,500,000 in a single season	40 million
1949-1957	FAO estimate for only 12 out of 40 affected countries	1,500,000 per year; in 1955 over 5,000,000	45 million

Example showing, country wise crop losses caused by locust and its value in Euro sterling. The Figure was taken from – Steedman, A. Locust Handbook (3rd edition) (1990)

1.4. Locusts Biology: Behavioral and Morphological changes

Desert locusts are biphasic insects, meaning they can take two entirely different forms. They have the ability to change their behavior, ecology and physiology in response to change in climatic conditions. The impacts of 'climate crises' are directly linked to desert locusts. With increase in temperature, unusual events of rainfall and shifting wind patterns – the maturation rate of locusts have become more rapid leading to more frequent outbreaks and new invasive areas [8].

The behavioral changes in locusts take place rapidly, only taking an hour or so when reared in laboratory. The morphological changes take more time. The full gregarious color takes one crowded generation to develop and shape takes two more. The change in locust color and shape occurs after the behavioral change. Therefore, behavior is the best and most useful characteristic to use in locust control work.

The life cycle of desert locust comprises three stages: egg, hopper, and adult. The time spent in each stage varies considerably depending on weather and related factors. On the average eggs hatch within 10 – 25 days and nymphs fledge in about 24 – 57 days (average = 36 days). Thus, the total life cycle can be completed within 34 – 90 days (average 40 – 50 days), the minimum development period observed so far is about 32 days (about 4.5 weeks), under favourable conditions, fledglings reach sexual maturity within 2 – 4 weeks. In particular within a few weeks, swarming adults, mature, mate and begin to oviposit on soils. Researches have shown that about 20mm of rainfall in a short period is sufficient moisture to allow the eggs to complete their development. Dormant periods of up to 60 days have been recorded in the field by various studies. Suitability for oviposition and subsequent breeding is influenced by factors such as soil type, sand content, soil moisture, surface air temperature, rainfall and prevalence of vegetation.

The speed of egg development varies with the soil temperature, the warmer the soil the faster the eggs develop. Laboratory experiments show that at 24°C hoppers develop at 1.5% per day, but at 38° C this rose to 5%. The length of life of individual adult varies. In field they live between 2.5 and 5 months. Apart from accidental death, the life span depends on how long they take to become sexually mature. The quicker they mature, shorter the total length of life [6].

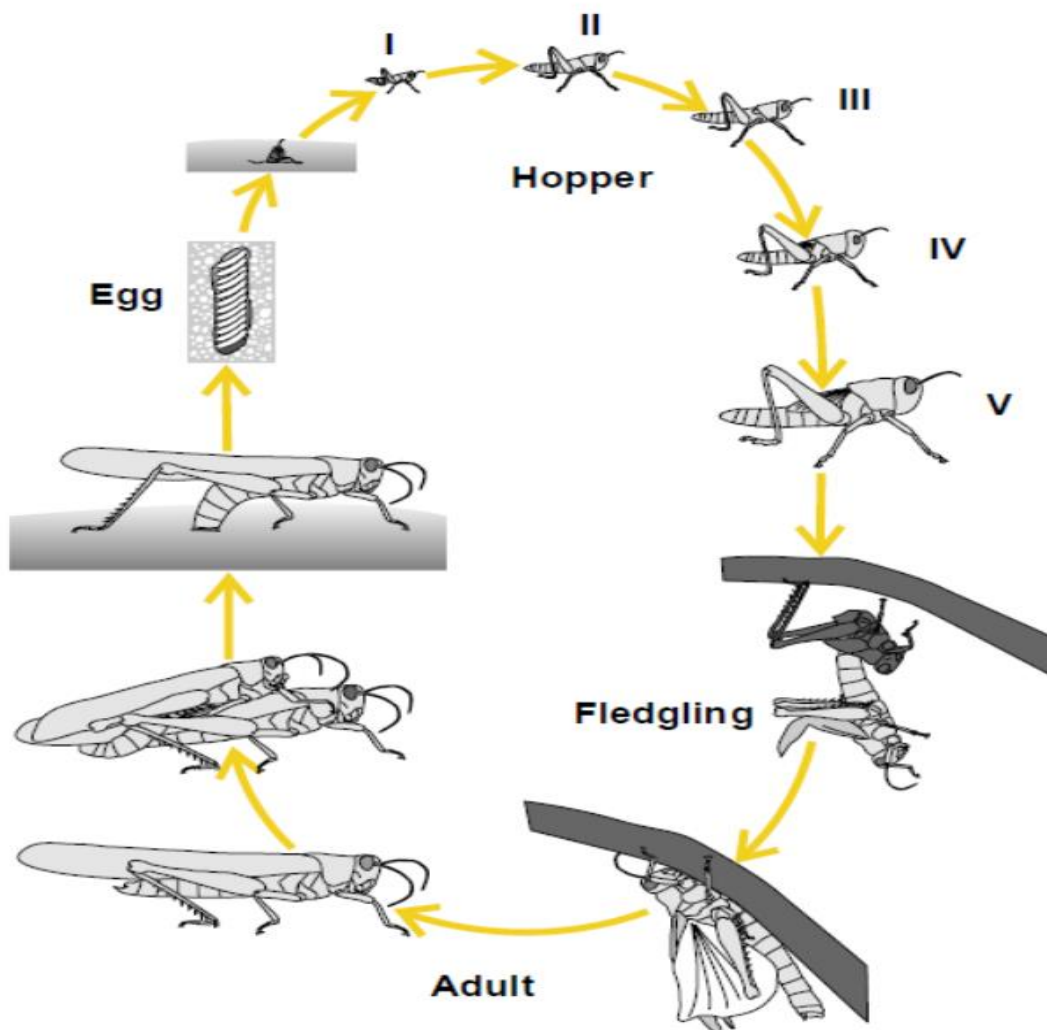


Diagram showing the life cycle of the Desert locust at different stages. The image was taken from - Symmons, P.M & Cressman, K. Desert Locust Guidelines: Biology and Behaviour (FAO, Rome, 2001).

1.5. Locusts Ecology: Factors controlling Population thrive and Migration

Several locusts have very wide ranges of distribution and their swarms may invade vast areas. Others are confined to certain zones which may also be very extensive. The desert locust is the most widely distributed among all species and may invade millions of square miles though not all at the same time. The invasion area contains a great variety of climatic conditions, soil types and vegetation. It extends from India/Pakistan to West Africa through the Middle East. These regions are characterised by seasonal rainfall averaging between 80 and 400 mm annually. Precipitation can be extremely heterogeneous in frequency and intensity, and can differ regionally as well as locally. Moreover, rainfall is the most important requirement for the Desert Locust breeding, because it orients the necessary environmental conditions for the breeding, development and multiplication. A minimum of 25 mm rain was required for the ephemeral food and shelter plants of locust to germinate and for successful breeding, successful breeding being defined as an increase in number from mature parents to filial fledglings because the adults frequently emigrate ^[9]. Rainfall determines whether there is sufficient growth of vegetation to provide adequate food supply for the insect. Rainfall is also found to be influencing the timing of certain developmental milestones in the egg indirectly through soil moisture, the developmental rate of nymphs and sexual maturation of adults through food ^[10]. According to (Abdalla, 2004) ^[11], Desert Locust are attracted to habitats of high vegetation density and compact structure, because they probably need to protect themselves against unfavorable weather conditions and against the attack of the natural enemies, in addition to their need for food. These locusts devour almost all standing crops and plant parts like tree barks, leaves, flowers, fruits, grains and all growing points, leaving behind ruined cropland and barren pastures. While they are not known to

impact forests or natural tree cover, their voracious consumption of most species of crop creates food scarcity for native fauna and other insects.



Desert Locust swarm (Rajasthan, India). Photo Credit: DNA India (images.google.com).

Previous studies on behavior of desert locust have suggested that wind along with temperature and vegetation have a definite role in its migration ^[12]. Movements often take place during periods of particular winds, rather than coinciding with the prevailing wind flow. Locust adults and swarms do not always fly with the prevailing winds but instead wait for specific types of winds to occur. Locust swarms generally move through warm winds. For example, swarms in West Africa frequently move northwards across Sahara Desert in autumn, transported by warm southerlies associated with depressions in the Western Mediterranean. Desert locust migration follows the path of prevailing wind. Adults and swarms leave the summer breeding areas in the interior of Sudan in the autumn and move north-east towards to the Red Sea coast. In order to achieve this, they wait for the prevailing north-easterly winds to be interrupted by south-westerly

winds, which may be warmer and more humid. In order for swarms to migrate from the interior of Arabia to central Sudan at the beginning of summer, locusts in the Red Sea area can fly only on the rare days with cross-sea upper-level winds, and even then, the swarms appear to select a particular height at which to fly.

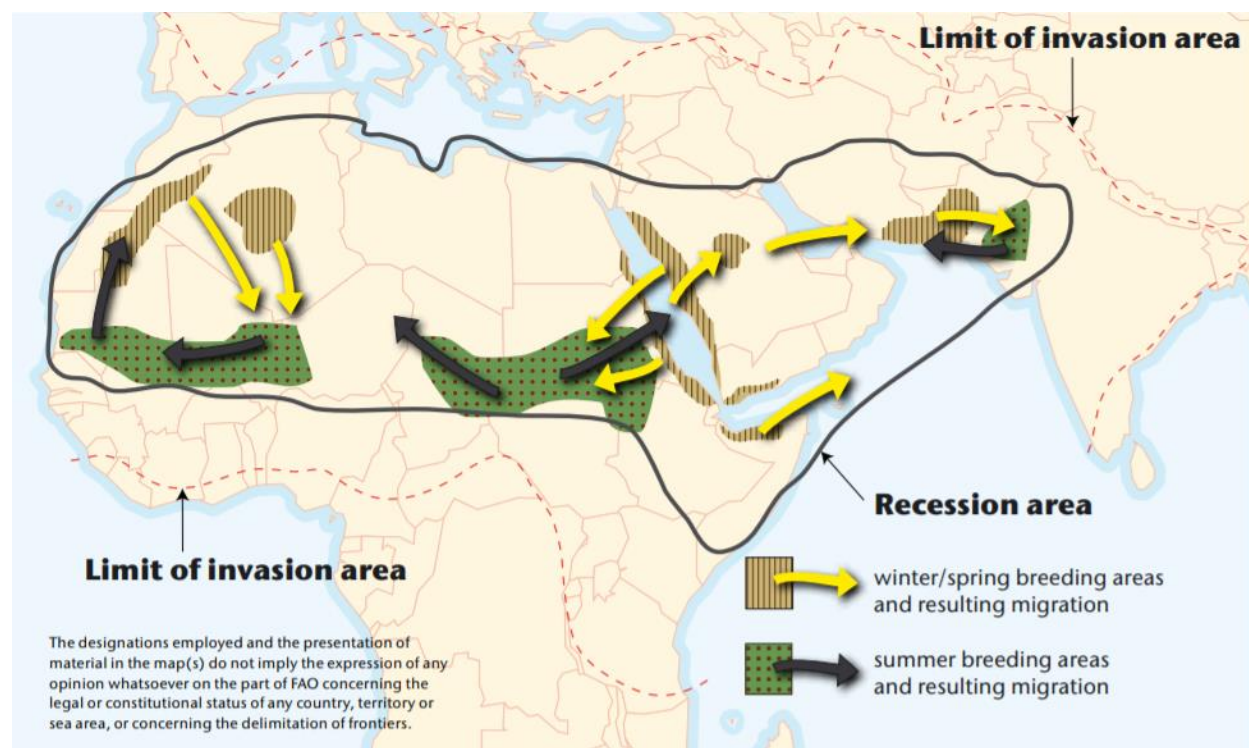


Figure showing the breeding zones of Desert Locust along with their seasonal movements. The limits of invasion areas and recession areas are also shown in the figure. The image was taken from – Cressman, K. & Stefanski, R. Weather and Desert Locust. World Meteorological Organization (WMO). Food and Agricultural Organization (FAO) of United Nations (UN) (2016).

In India, desert locusts arrive through the neighboring country of Pakistan. The winds of the western disturbances that move from the Mediterranean High to the Himalayan low play a major role in its migrations. India has only one locust breeding season (i.e.) Summer Breeding Season (July to October). One of the reasons for the recent locust outbreak (2019-20) was because of the

alteration of wind patterns as a resultant of three cyclones in Arabian Sea.

(<https://www.indiatoday.in/news-analysis/story/locusts-in-india-global-swarming-explained>)

1.6. Locusts and Environmental Factors: Bioclimatic and Edaphic

All the different phases in the life cycle of a locust require certain ideal conditions for it to develop. Bioclimatic (Temperature and Rainfall) and Edaphic (Soil Moisture and Sand Content) along with Wind patterns and prevalence of Vegetation are the most critical variables for Desert Locust breeding locations.

The time needed for the Desert Locust to transition from one stage to other is highly dependent on weather patterns. Meteorological data are important for both assessing the current locust situation and forecasting its development. Information on meteorological and ecological parameters such as rainfall, soil moisture, soil and air temperatures, surface and boundary winds, synoptic-scale patterns and the convective state of the atmosphere are needed to understand and forecast swarm movement and the various developmental stages. These stages include egg-laying, egg development, hopper development, molting, hardening of the wings, adult maturity, rate of movement of hopper bands and adult swarms, and transition from the solitarious phase to the gregarious phase.

	Data	Actual	Forecast	Use	Stage
Rainfall	Total	Daily Dekadal Monthly	+1 day +10 day +30 day Seasonal	Breeding Migration	Outbreaks Plagues Recessions
Temperature	Min/max	Daily Dekadal Monthly	+1 day +10 day +30 day Seasonal	Maturation Migration	Upsurges Plagues Outbreaks

Figure showing useful meteorological information in detection/prediction of outbreaks, upsurges and plagues and in planning control operations during different stages of Desert Locust development. The image was clipped from – Cressman, K. & Stefanski, R. Weather and Desert Locust. World Meteorological Organization (WMO). Food and Agricultural Organization (FAO) of United Nations (UN) (2016).

Rainfall data can be used to identify which areas may become suitable for breeding or where green vegetation and locusts may be present. Locust development either directly or indirectly (edible Vegetation) require rainfall to mature from Eggs to Hoppers and from Hoppers to Adults. Temperature data can be used for estimating the development rate of eggs and hoppers, as well as indicating whether it is warm enough for adults to take off and fly. Temperature plays a pivotal role in life of Locusts. Egg development in female Locusts depend on temperature. Hopper development is also a function of temperature, the hopper development period decreases with increasing daily temperature (from 24°C to 32°C). Adults and Swarms take off at a certain, specified temperature range ^[13].

Soil Moisture is a very good indicator of reproduction potential over an area, since female desert locusts are known to prefer warmer and more open sites for initiating probing and digging activity for oviposition ^[14]. Locust eggs develop and hatch successfully when there is enough moisture in the soil, whereas insufficient moisture may stop egg development and dry them out ^[15]. The amount of water availability in soil acts as a catalyst for other factors. In comparison to rainfall, SM allows to focus on areas where reproduction might happen ^[16].

Searching behavior is an active movement by which insects seek resources. Vegetation provides the main resource and structural element, especially in the habitat of Phytophagous insects.

Movement of Locusts can be directed by the abiotic environment, such as orientation relative to a wind current, but can also be highly affected by biotic factors like resource distribution ^[17].

Locust behaviour differs in response to the type of vegetation present. In a habitat where vegetation is evenly distributed, locusts frequently move in and out of the area. In areas with non – uniform vegetation, locusts spend very little time on the ground and most of the time in the vegetation in habitats consisting of large, dense low plants ^[1].

1.7. Locusts: Population Dynamics

The total distribution area of the Desert Locusts extends over some 29 million km/sq. of Africa, the Middle East and south-west Asia, but more than half of this area is infested only by migrating swarms ^[18].

Individual locusts are not a threat to humans and vegetation. Only after gregarization and the formation of bands and swarms are locusts a serious threat to food security of the human population. Both the Hopper bands and Adult swarms can cause significant damage in the invaded areas. One tonne of locusts (a very small part of an average swarm) eats as much food in one day as about 10 elephants or 2500 people.

An outbreak or contemporaneous outbreaks that are not controlled can evolve into an upsurge.

An upsurge generally affects and occurs after several successive seasons of breeding and further hopper band and adult- swarm formation takes place. Although outbreaks are common, only a few leads to upsurges. Similarly, few upsurges lead to plagues ^[13].

The attack of the desert locust used to occur earlier in a phases of plague cycles (a period of more than two consecutive years of wide-spread breeding, swarm production and thereby damaging of crops is called a plague period) followed by a period of 1-8 years of very little locust activity called as the recession period again to be followed by another spell of plague.

Plagues occur as a result of rapid increase in numbers of recession populations in several successive seasonal breeding areas from several generations. While no two upsurges or plagues are similar, most seem to follow the same general pattern ^[19].

Natural enemies affect the population dynamics of the desert locust by reducing numbers of viable eggs, hoppers and adults. Locusts are attacked in their outbreak and recession area by various types of natural enemies. The wasp *Scelio* sp. and the flies *Stomorhina lunata* and *Systoechus somali* and the beetle *Trox procerus* are important parasites and predators of the desert locust eggs. The fish fly *Blaesoxipha filipjevi*, the flesh fly *Symmictus costasus* and the protozoan *Nosema locusta* are parasites of adult locust ^[20].

India witnessed several locust plague and locust upsurges and incursions during last two centuries.

(A)

Locust plagues observed during following years	
1812-1821	1900-1907
1843-1844	1912-1920
1863-1867	1926-1930
1869-1873	1940-1946
1876-1881	1949-1955
1889-1891	1959-1962

(B)

Year	No. of swarms incursion
1964	004
1968	167
1970	002
1973	006
1974	006
1975	019
1976	002
1978	020
1983	026
1986	003
1989	015
1993	172
1997	004
2019	276
2020	103

Tables showing (A), Years of Locust plague period in India (B), Years of Locust upsurges in India. The image was taken from – (<http://ppqs.gov.in/divisions/locust-control-research/locust-plagues-and-upsurges>).

1.8. Locusts: Control Strategies

All countries affected by desert locust generally adopt a preventive control strategy for the management of desert locust in order to reduce the frequency, duration and intensity of plagues.

1.8.1 Chemical Control

Man has faced plagues of desert locust for more than a thousand years with mostly unsuccessful control effort. In the past, only mechanical methods which included herding, collecting crushing or burning the hoppers were used. They also included harrowing and tilling ^[19]. After the Second World War, synthetic insecticides have become the sole solution, in particular the long-lasting chlorinated hydrocarbons. They were effective and relatively inexpensive. Dieldrin, Gamma BHC, Chlordane and Heptachlor were the most commonly used chemicals for desert locust control for more than 30 years ^[21]. Aerial application of doses of these insecticides are used in form of fine droplets (ULV) were used to control Desert Locust swarms effectively. After few decades of extensive use of these organochlorine pesticides many drawbacks were identified, such as contamination of the environment and toxicity to non – target organisms (predators, parasites and pollinators) harmful residues in food, pest resistance and bio accumulation in the food chain. New synthetic pesticides with shorter periods of persistence, namely organophosphates, carbamates, and pyrethroids appeared more suitable, but with these, blanket coverage applications were necessary, thus causing negative impacts on the environment and increased the cost of control ^[22].



1.8.2 Biological Control

The fungus *Metarhizium anisopliae* is one of the pathogens currently used in the control of the desert locust. This fungus can be formulated and applied by ULV equipment. The *Metarhizium* strains used are environmentally safe and have been registered in many countries ^[23]. Although Semi chemicals have been successfully used in the field for the management of some pests, they are not generally considered to be sufficiently reliable in their action when used alone. They are efficient when used as part of integrated control strategies ^[24].

Many of these biocontrol approaches are applicable to locust and grasshopper control but their potential has been underestimated in the past because of the emphasis on chemical control. The use of entomopathogens as control agents is referred to as microbial control; when the entomopathogenic microbe is mass-produced, formulated and applied ^[25].

1.8.3 Traditional–Cultural Control

Often, individual farmers do nothing when faced with locusts or grasshoppers. But they also developed a variety of cultural and physical controls before the availability of chemical ones. Physical and cultural control methods continue to be practiced, alone or in combination with chemical control, especially against small infestations in crops or hopper bands near croplands. For example, some farmers combine the use of pesticides with fire, burning roosting locusts at night. The farmers dug trenches and herded hopper bands into deep trenches and buried them. Most traditional controls have been replaced by the use of chemical insecticides. Some methods which are used for control of the desert locust adult and hopper populations by the farmers are as follows ^[26]:

1. Beating or trampling on the hoppers
2. Digging up egg pods or plowing fields infested with egg pods

3. Scattering straw over roosting sites and then burning it
4. Lighting fires or making noise to prevent swarms from settling in crops
5. Driving hoppers into trenches and burning, drowning, or crushing them
6. Use of flame throwers

1.8.4 Integrated Pest Management

Integrated pest management (IPM) combines the use of chemical, biological and cultural practices to subdue pest incursion. It involves:

- (i) Proper knowledge regarding the pest with respect to life cycle and growing areas.
- (ii) Escaping the pest attack by properly selecting the plant varieties, site of plantations, understanding the mechanism of host-pest interactions with proper farm management.
- (iii) Crop monitoring and establishing pest prediction models.
- (iv) Applying control measures.
- (v) Proper evaluation and planning.

Many national and intergovernmental bodies have firmly decided that the future officially endorsed paradigm for crop protection will be Integrated Pest Management. For Example, European Union ^[27].

Application of insecticides and pesticides in the form of spray, dust, etc. has been followed by the farmers for quite a long time to deal with insect pests. Organophosphate chemical and/or Malathion 96, Chlorpyrifos, Endosulfan, Methyl Parathion, etc. treatment to vast stretches of agricultural land is till date the chief practice followed by the Indian farmers. However, the huge volume of insecticides that would be required to eradicate locust swarm will turn this into a futile effort. Moreover, these pesticides and insecticides are in most cases non-specific, meaning that they can target any unwanted insect species, causing loss to insect diversity ^[28].

1.8.5 Preventive Desert Locust Control in Indian Perspective

Plagues of the desert locust develop within a larger recession area that extends from Mauritania and southern Morocco eastwards through Arabia to Rajasthan in India.

In the 1940s and 1950s, first ground, and then aerial, spraying techniques were introduced and the persistent organo-chlorines BHC (benzene hexachloride) and dieldrin became the insecticides of choice. The BHC was first used for desert locust control in India in 1949 and it became a popular desert locust killer. Spraying of aldrin insecticide against desert locust control by air was conducted in 1951. Due to shortage of water in the desert Exhaust Nozzle Sprayer was invented in which exhaust gases from the vehicle were used for atomizing the pesticide in fine droplets which was carried by the wind onto the target. In the 1960s, dieldrin was most often used against Desert Locust hopper bands and BHC against adult swarms. Initially, dieldrin and the other persistent pesticides seemed to be a major technological advance. Dieldrin, for example, remains toxic for 30 to 40 days on vegetation and longer in soil, despite rain or sun. Hopper bands were controlled by spraying swathes of vegetation with dieldrin, forming barriers in front of marching bands.

The type of insecticides used in desert locust control programs has shifted markedly away from the persistent organo-chlorines such as dieldrin, BHC, aldrin, and lindane to organophosphates. The insecticides most commonly used now a day's for controlling desert locusts in India are fenitrothion and malathion. These organophosphates are principally contact insecticides with short residual action (2 to 3 days).

The biopesticide developed from entomopathogenic fungus *Metarhizium anisopliae* used for desert locust particularly hopper control in Africa and Australia has not been used in India for locust control. Currently desert locust infestations are sprayed with Ultra Low Volume (ULV)

formulations of contact pesticides by using microULVA, ULVAmast and by Micronair AU 8115 sprayers on ground. The ULV spray technique is designed to spray overlapping swaths of small droplets of a concentrated pesticide formulation on to locusts at very low dose rates. The pesticide can be directly sprayed on bands with hand held sprayers if the infestations are small. Larger infestations are sprayed with vehicle mounted sprayers ^[26].

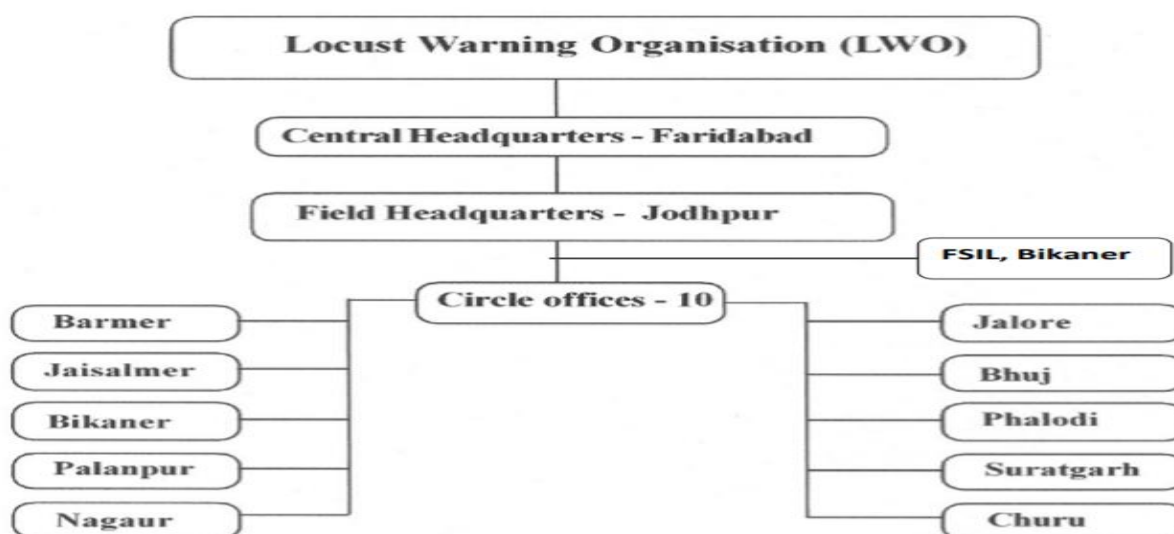
According to, The Contingency Plan for Desert Locust Invasions, Outbreaks, and Upsurges by The Government of India- Ministry of Agriculture & Farmers Welfare- (Department of Agriculture, Cooperation and Farmers Welfare)- Directorate of Plant Protection, Quarantine & Storage, Faridabad (2019). The current preventive control strategy for the management of desert Locust consists of regular surveys and contingency plans to allow early and effective response before the situation becomes out of control.

LWO-Locust Warning Organization (comprising of all field units) undertakes regular surveys in the scheduled desert area of Rajasthan and Gujarat to monitor the presence of desert locust and ecological conditions. During the survey, an assessment is made to determine, if the locust numbers have crossed the economic threshold level (ETL) which is 10,000 adults/ha. and 5-6 hoppers/bush that may require control. These surveys are done regularly during the entire year, but most importantly from May to November when desert locust activity is considered at its peak due to congenial breeding conditions. Whenever and wherever the population of desert locust is found exceeding the economical threshold level, immediate control measures are pressed into operation.

All the 11 Locust Circle Offices (LCO) are self-sufficient, in normal locust situation, in term of manpower, vehicles, control equipment, and personal protective equipment. Each Circle Office has control potential for treating about 300-hectare areas per day. In case of emergency, pesticide

from storage site can be mobilized to the control sites within 6–10 hours. Malathion 96% ULV is used in Desert Locust control in India. The total requirement of heavy and light vehicles is assessed based on severity of locust infestation and invasion. Each of the 11 Circle Offices are equipped with wireless sets for quick transmission of information pertaining to locust operations and logistics within locust field units and to the Field HQ Jodhpur. At present no aviation agency is available in India for controlling desert locust. Provision of fund for plan expenditure is always kept in the annual budget of Locust Scheme in which the amount varies from year to year based on requirements as assessed by various field units, Headquarters, Faridabad and DAC&FW. Apart from Ministry of Agriculture and Farmers Welfare, Department of Agriculture, Cooperation and Farmers Welfare, other ministries such as Ministry of Home, Ministry of Defense, Ministry of External Affairs, Ministry of Civil Aviation, Ministry of Communication, State departments and other relevant stakeholders are to be involved for their role and responsibilities during the locust control/locust emergency.

(http://164.100.161.213/sites/default/files/contingency_plan_0.pdf)



Setup diagram showing Locust Warning Organization (LWO). Taken from The Contingency Plan for Desert Locust Invasions, Outbreaks, and Upsurges- Govt. of India

1.9. Locusts: Impacts of Climate Crisis

Climate change experts predict more extreme weather, including droughts, floods and cyclones. Whereas locust numbers decrease during droughts, locust outbreaks often follow floods and cyclones. Local increases in rainfall can favor breeding conditions for locusts and determine the size of feeding areas, leading to changes in plague development. Recently, In June 2020, the United Nations- Food and Agriculture Organization (FAO) issued a threat level warning to countries across East Africa and southwest Asia: Desert locusts (*Schistocerca gregaria*) are swarming. A severe outbreak that started in 2019 had spread across the Horn of Africa and the Middle East before moving on to western Asia. The outbreak in 2020 spread from Kenya to Pakistan and India, and was worst in the past 30 years and may be the most economically destructive since the 1960s.(<https://eos.org/articles/record-locust-swarms-hint-at-whats-to-come-with-climate-change>). The example may be a precursor for other outbreaks and upsurges in unexpected locations, possibly linked to a changing climate.

Climate change experts also predict that temperatures will continue to rise. Temperature governs the speed of locust development and swarm movement. Thus, increased temperatures associated with climate change can potentially shorten both the long maturation and incubation periods during the spring and allow an extra generation of breeding to occur in North-West Africa, the Arabian Peninsula and South-West Asia. This could increase the number of locust generations in a year in these regions and amplify overall plague risk. Changes in El Niño and La Niña events due to climate change could affect breeding. The effects of climate change on winds are less certain. Any changes in wind speed, direction and circulation flows are expected to affect Desert Locust migration and could allow adults and swarms to reach new areas at different times of the year ^[13].

1.10. Early Warning System for Desert Locusts

The number and severity of disasters is rising as the climate undergoes changes, and as the world's population continues to increase. This trend is exacerbated by populations clustering in vulnerable areas, by the degradation of the environment, and by the expansion of areas at risk due to climate crisis. Disasters threaten especially the segment of the population which is more vulnerable, largely because they are both highly sensitive to hazards and have limited capacities to cope with the resulting impacts. Disasters threaten the food security of the poorest people, and if measures are not taken to mitigate disaster risks and impacts, hazards may cause or create circumstances promoting economic downturns and civil disorder in areas already impacted by disease, poverty, conflict, and the displacement of people ^[29].

The term 'early warning' is used in many fields to describe the provision of information on an emerging dangerous circumstance where that information can enable action in advance to reduce the risks involved. Early warning systems exist for natural geophysical and biological hazards, complex socio-political emergencies, industrial hazards, personal health risks and many other related hazards.

An Early Warning System (EWS) can be defined as a set of capacities needed to generate and disseminate timely and meaningful warning information of the possible extreme events or disasters (e.g., floods, drought, fire, earthquake and tsunamis) that threatens people's lives. The purpose of this information is to enable individuals, communities and organizations threatened to prepare and act appropriately and in sufficient time to reduce the possibility of harm, loss or risk (https://nidm.gov.in/easindia2014/err/pdf/themes_issue/technology/early_warnings.pdf).

The benefit of Early Warning System has been proven on several occasions in recent years. In Bangladesh, for example, the use of modern Early Warning System helped limit casualties from

Cyclone Sidir in 2007 to 3000 (only 1%) of the 300,000 casualties caused by equally strong Cyclone Bhola in 1970, despite a population that has grown rapidly in the interim.

The value of Early Warning System can also be measured in monetary terms using cost-benefit ratios, which can manifest gains of up to 500:1, depending on the hazard type and on the overall response capabilities of the communities [30].

Early warning is a strategy adopted by many societies to reduce the impacts of disasters. Early Warning System are often based on interconnections between visual observations, past experience, and co-operation to mitigate losses from upcoming hazards. Early warning strategies are the set of measures taken to increase resilience that is not subsumed within risk-reducing initiatives. If correctly implemented, Early Warning System can help to reduce losses of lives and property, and to minimise environmental damage. All this coheres in a favourable cost benefit ratio while also increasing safety.

For an early warning system to be effective, the inclusion and interaction between four key elements is vital: risk knowledge, monitoring and warning services, dissemination and communication, and response capability.

Graph 1. Key elements of EARLY WARNING SYSTEM



Diagram showing the four components of Early Warning System. The diagram was taken from -
Brazzola, N and Helander, S. Five Approaches to build Early Warning Systems. UNDP (2018)

Early warning is the integration of four main elements:

1. **Risk Knowledge:** Risk assessment provides essential information to set priorities for mitigation and prevention strategies and designing early warning systems.
2. **Monitoring and Predicting:** Systems with monitoring and predicting capabilities provide timely estimates of the potential risk faced by communities, economies and the environment.
3. **Disseminating Information:** Communication systems are needed for delivering warning messages to the potentially affected locations to alert local and regional governmental agencies. The messages need to be reliable, synthetic and simple to be understood by authorities and public.
4. **Response:** Coordination, good governance and appropriate action plans are a key point in effective early warning. Likewise, public awareness and education are critical aspects of disaster mitigation.

A global early warning and preventive control system against desert locust has been in place for more than half a century, representing the world's oldest migratory pest warning system. Some two dozen frontline countries have created dedicated national locust centres within their government, consisting of well-trained specialized survey and control teams. To find insect infestations, these teams rely on their own knowledge as well as on information from nomads. This knowledge is combined with up-to-date satellite imagery indicating rainfall and green vegetation, allowing the teams to identify potential breeding sites and growing locust infestations. The teams record their observations on a rugged handheld tablet, which transmits the data in real time via satellite to their national locust centre. This information is then passed on

to the Desert Locust Information Service (DLIS), based at the headquarters of the Food and Agriculture Organisation (FAO) of the United Nations in Rome, Italy.

The early warning system for desert locust is based on more than 75 years of collaboration. New advances in technologies have led to a paradigm shift in locust early warning from that of collecting information for interpreting and forecasting breeding and migration to predicting habitat development and the development of outbreaks, upsurges, and plagues. In the past three decades, the system has shifted from camels to four-wheel drive vehicles, from telex to e-mail, from map reading to GPS, from narratives to handheld data loggers, from manual plotting to GIS, and from weather station reports to satellite-based rainfall estimates and greenness maps. The current early warning system consists of a variety of integrated elements that all must function smoothly and reliably in order to provide accurate and timely information and alerts on a regular basis to a large international audience.

In the past decade, a new challenge is facing the locust early warning system. Political unrest and instability, national border disputes and sensitivities, kidnappings, mines, and conflict have led to insecurity in many parts of the recession area. The success of the early warning system for desert locust depends on a well-organized and funded National Locust Control Centre-NLCC in every locust-affected country that can monitor field conditions and respond to locust infestations ^[31].

The successful prevention of desert locust plagues relies on regular monitoring in the desert, early warning, and timely response. While the early warning and preventive control system to manage Locust plagues are well-established and functions on a daily basis to protect valuable food supplies and livelihoods, it is not perfect. Currently, there are three primary limitations that impact this system: the huge and remote desert areas that must be searched for locust

infestations; increasing political insecurity, inaccessibility and dangers within these areas; and the safe use of pesticides during control operations [32].

FAO Desert Locust Information Service (DLIS) relies on field data collected by national teams associated with the NLCs during locust survey and control operations (Figure 1). Data, including observations of vegetation, soil, and locust populations, is recorded in a handheld, touch-screen data logger (eLocust2) that is connected to the GPS satellite system so that each survey and control location can be geo-referenced. The data logger is also connected to the International Maritime Satellite Organisation (Inmarsat) satellite system, which allows data to be transmitted in real time to the NLC in each country.

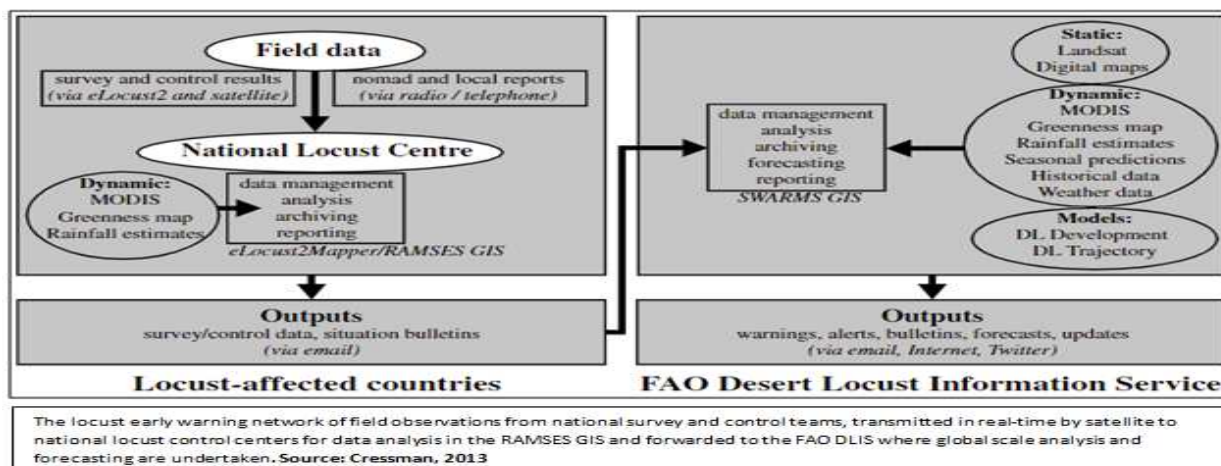


Figure showing locust early warning network. The figure was taken from –

(http://www.fao.org/ag/locusts/common/ecg/190/en/1209_IRI_FAOCASESTUDYDLIS.pdf)

In order to establish an efficient and meaningful Early Warning System, leveraging of the most advanced tools of humanity are needed. Space technology and its applications provide solutions that institutions can rely on. This can be efficiently used to respond to Locust induced issues as well as to increase resilience to future iterations. Technological developments continue to

advance in a number of areas related to locust early warning such as telecommunications, data management, remote sensing, computing and meteorology.

Locust outbreaks can develop suddenly and unexpectedly in remote inaccessible areas or in the absence of regular surveys and incomplete data. Recent developments in satellite techniques to monitor rainfall and vegetation has made it easier to detect potential areas of significant Locust activity that may require survey and control ^[13].

About 90% of anthropogenic heat is absorbed by the oceans, and the western part of the Indian Ocean is the fastest-warming in the tropical Ocean system, with a summer average increase of 1.2 °C. This warming has increased the frequency and intensity of extreme climate events in neighbouring regions. In 2019, a record-breaking eight tropical cyclones developed over the Indian Ocean and made landfall over different locations in Asia and East Africa. Moreover, from October to December 2019, the Indian Ocean Dipole (IOD) experienced one of its strongest positive phases, causing one of the wettest rainy seasons.

Such events are likely to increase in the future; in a 1.5 °C warmer climate, extreme positive Indian Ocean Dipoles are expected to occur twice as often. The increased cyclone frequency and more extreme climate variability could increase the likelihood of pest outbreaks and spread. This adds compromised food security to the consequences of the storms themselves.

The recent locust outbreaks and the role of Indian Ocean warming show that the impact of climate change is not merely the consequences of changes in mean temperature, but also of increases in extreme and unprecedented events. Such extremes are exacerbated further in a butterfly effect by non-climate factors such as political instability, armed conflicts, poor governance, weak early warning systems and limited financial resources, hurting the most vulnerable communities ^[33].

In this context of a changing climate, increased climate variability and the vulnerability of the socio-economic activities to these factors, it is crucial for our Government to put in place a Self-Developed Early Warning System for Locust Control. Such a system should include robust surveillance and forecasting methods, dissemination channels and response mechanisms to avert the potential impacts of extreme events.

India has an impressive array of achievements in the development of space technology for various applications. The remote sensing applications using Indian Remote Sensing Satellite-IRS have proliferated into almost every facet of national development. The data is now used regularly for agricultural crop acreage and yield estimation, drought monitoring and assessment, flood mapping, land use and land cover mapping, wasteland management, water resources management, ocean/marine resources survey and management, mineral prospecting, forest resources survey and management, etc. Meaningful use of this data can be done by integrating this information in our Early Warning System under detection, monitoring, analysis and forecasting.

Prevention of biological invasions is much less expensive than post entry control ^[34]. Therefore, to reduce the environmental degradation, ecological destruction, habitat loss and the socio-economic losses caused by uncontrolled desert locust invasions, it is extremely essential to have knowledge of Potential grounds of locust activity. Based on this knowledge, timely and meaningful warning information will be generated and disseminated for response (conservation, planning and forecasting) and decision making. Development and Implementation of a sound Early Warning System for Locust Control in India is need of the hour.

2. Aim & Objectives

A search of information related to Desert Locusts in India, specifically Rajasthan was carried out through Google Scholar and Web of Science. Relevant literature found was largely theoretical, comprising works addressing the information about Locust (Biology, Incursions and Economic losses) and the Government's actions to combat them. The recent invasion (2020) was highly addressed in most of the articles/papers. The unavailability of good, qualitative and practical works on such an important issue at State and National levels was the main inspiration that drove this work forward.

2.1. Research Aim: -

The aim of this paper is: - To develop an Early Warning System for Locust Control in India using Open Government Data (OGD) and showing the distribution of Desert Locust *Schistocerca gregaria* in Rajasthan, India from 1st June 2019 to 31st August 2020 and addressing the reasons behind distribution.

2.2. Research Objectives: -

The objectives of this paper are as follows: -

- Developing a tool that enables to monitor and control locust invasions effectively.
- Showing the relationship between known Desert Locust presence sites with critical Bio-climatic (Temperature, Rainfall and Vegetation) and Edaphic (Soil Moisture content) factors.
- Establishing a practical Early Warning System involving key elements and sub elements in each key element.
- Lay foundation for the scope and development of Early Warning System for Locust Control in India.

3. Study Area & Selection

3.1. Choice of Study Area

India frequently battles Desert Locust onslaughts. The recent Locust outbreak (2019, 2020) caused more damage in the Central and Western states of India, including Rajasthan, Punjab, Haryana and Madhya Pradesh, with Rajasthan being the most affected^[35]. The first encounter with the Locust swarm was reported in Jaisalmer, Rajasthan (Indo-Pak border region) in the second week of April 2020 (<https://indianexpress.com/article/explained/explained-locust-agriculture-crops-india-lockdown-6400755/>). The state of Rajasthan, India acts as the forefront for nearly all Locust invasions in India.

As per The Commissioner of Agricultural Department, till 28th May 2020, 20 districts out of the total 33 districts in the state (Rajasthan, India) had been affected due to the 2020 Locust attack (<https://economictimes.indiatimes.com/news/politics-and-nation/locust-attack-about-90000-hectares-hit-in-20-rajasthan-districts/articleshow/>).

The area for the study is confined to the state of Rajasthan (3,42,239 sq. Km).

3.2. Introduction of Study Area

The state of Rajasthan is located in the northwestern part of India. It is the largest state covering an area of 3,42,239 square kilometers, bounded by 23°30'North and 30°11'North latitude and 69°East and 78°East longitude. The state shares its west and northwestern boundary with Pakistan which is about 1070 km. Gujarat and part of Madhya Pradesh on its south, rest of Madhya Pradesh and Uttar Pradesh on its east and Punjab and Haryana on its north and northeast. This state has a type of rhomboid shape and stretches lengthwise 869 km from west to east and 826 km from north to south. The tropic of Cancer passes through its southern tip in the

Banswara district. This state is practically free from maritime to influence. Orographic features and absence of maritime influence affect the climate of the state to a large extent.

TOPOGRAPHY: - The distinguishing feature of the state is the Aravalli range, the strong barrier which divides the plains of Marwar (lying between 24°37' and 27°42' North Latitudes and 70°05' and 75°22' East Longitude) from the high table land of Mewar (lying between 23°49' and 25°28' North Latitude and 73°01' and 74°49' East Longitude). The range which commences at the 'Ridge' at Delhi, comes into prominence near the town of Ajmer, where it appears in a succession of parallel hills. The highest point, on which is perched the fort of Taragarh, rises immediately above the city of Ajmer to a height of about 870 meters above sea level between 395 and 425 meters above the valley at its base. The 'Nagpahar' or serpent hill, 5 km west of Ajmer city, attains a slightly lower elevation. About 16 km from Ajmer, the hills disappear for a short distance but in the neighborhood of Beawar form a compact double range which approach each other southward and finally meet near Todgarh, from where a succession of hills and valleys extends to the farthest extremity of the Merwara. Thence the range gradually becomes bolder and more precipitous, till it finally terminates in the southeast corner of the Sirohi district near Mount Abu.

The plateau on which the town of Ajmer stands, marks the highest point in plains of India and from the hills, which surround the land slopes away on every side range of hills between Ajmer and Nasirabad marks the dividing watershed of the Indian sub-continent.

The entire portion of West Rajasthan formerly known as Marwar (lying 24°37' and 27°42' North Latitude and 70°05' and 75°22' East Longitude) is sterile, sandy inhospitable but improves gradually from a mere desert in the far west and north comparatively fertile and habitable lands in the northeast, east and southeast in neighborhood of the Aravalli hills. The 'great desert',

forming the whole of the West Rajasthan - Sind frontier, extends from the edge of the Rann of Kutch beyond Luni river northward and between it and what has been called the "little desert on the east is a zone of absolutely barren country, consisting of a rocky land cut off by limestone ridges, which to some extent protect it from the desert sands. These places are covered with sand hills, shaped generally in long straight ridges, which seldom meet but run-in parallel lines. Some of these ridges may be 3 kilometers long ^[36].

The only important river in west Rajasthan is the Luni or salt river (the Lonavari or Lavanavari) which rises in the hills southwest of Ajmer city and was first known as Sagarmati. After passing Govindgarh in the Ajmer district, it is joined by the Sarasvati which has its source in the sacred lake of Puskar, and from this point it is called the Luni. After a course of about 320 km generally west to southwest it is finally lost in the marshy ground at the head of the Rann of Kutch. It receives the drainage brought by the mountain torrents down the western slopes of the Aravalli hills between Ajmer and Abu. It has several tributaries, the chief being the Lilri, the Raipur Luni, the Guhiya, the Bundi, the Sukri and the Jawai on the left bank and the Jojri on the right, but none of them is perennial.

The other principal rivers are the Chambal and its tributary, the Banas. The Chambal (the Charmwati) rises in Central India some 14 km southwest of the cantonment of Mhow and after flowing generally north for 315 km, enters Mewar in the extreme east near the old fort of Chaurasgarh. From Bahinsrorgarh the Chambal flows northeast for some 10 km and the rest of its course lies in or along the borders of the Bundi, Kota, Jaipur, Dholpur and Gwalior districts. It eventually falls into the Jamuna 40 km southwest of Etawah in Uttar Pradesh.

The Banas (the 'hope of the forest') rises in the Aravalli, about 65 kms northwest of Udaipur and flows southward until it reaches Gogunda plateau, when it turns to the east and cutting through

the outlying ridges of the Aravalli, burst into open country. Its subsequent course lies in or along the borders of Udaipur, Ajmer, Jaipur, Bundi, Tonk districts and it eventually falls into the Chambal. Its total length is about 480 km.

The river Banganga originates from the low hills of Bairath (Jaipur district) flows eastward entering Sawai Madhopur and Bharatpur districts. The river Gambhiri which originates from Karoli hills in Sawai Madhopur district passes through the parts of Bharatpur district and joins the river Jamuna. The river Mahi also originates from the Mhow ranges at Madhya Pradesh. It enters Rajasthan state near Khandu Village (Banswara district).

The Indian state of Rajasthan is divided into 33 districts for administrative purposes.

Ajmer, Alwar, Banswara, Baran, Barmer, Bharatpur, Bhilwara, Bikaner, Bundi, Chittorgarh, Churu, Dausa, Dholpur, Dungarpur, Hanumangarh, Jaipur, Jaisalmer, Jalore, Jhalawar, Jhunjhunu, Jodhpur, Karauli, Kota, Nagaur, Pali, Pratapgarh, Rajsamand, Sawai Madhopur, Sikar, Sirohi, Sri Ganganagar, Tonk, and Udaipur.

AGRICULTURE: - The state occupies 10 percent of the total geographical area of the country, but the vast geographical area commands only 1 percent of the total water resources in the country. Agriculture is mainly rain fed but it is inadequate and aberrant. Focus of cropping pattern in rain fed areas is to meet the food requirement of the people and fodder requirement of the animals. The crops are grown under high risk. In normal years, farmers face price falls due to glut in the market while drought years have yield risk due to total or partial failure of crops. Out of the total geographical area in the State, even 50 percent is not cultivable and within cultivable land, soil fertility varies considerably across districts. The wide differences in land productivity indicate the variation in soil health across districts in the State. A relatively large average size of holdings of 3.07 hectare of land is again a manifestation of the less fertile land and soil structure

in most of the arid and semi-arid zones in the state. Small and marginal farmers in the state constituted more than 58.40 percent share in total area. On the other hand, farmers with holding size of 10 hectares but held 33.33 percent of the total area.

Rajasthan being geographically the largest state in the country has a varied topography where Soils differ in quality depending on the organic matter present in them, their physical structure, local climatic variation, the crop rotation cycle that is followed, availability of moisture etc. Soils of the state have low microbial activities and poor soil organic carbon due to which more than 75% soils of the state are not in good health. Deficiencies of Nitrogen, Phosphorous, Sulphur, Zinc and Iron are quite common. Different soil types are found in the different districts of Rajasthan. Based on the type of the soil found in different districts in Rajasthan, broadly the soils can be classified under 14 categories. The least fertile desert soil is found in Sri Ganganagar, Churu, Jhunjhunu, Bikaner, Jaisalmer, Nagaur, Barmer, part of Jodhpur and Sikar. The productivity in those districts for all varieties of crops is much on a lower side than other districts in the State.

WATER RESOURCE MANAGEMENT: -

RAINFALL PATTERN: Rajasthan is known for its aberrant and uncertain nature of rainfall. As more than 60 percent of the gross sown area in the state falls under arid or semi-arid zones in the state, agriculture in the state continues to be largely rain fed.

1. The department is promoting use of short duration varieties of crops suitable for rain fed areas. Diversification of crops from more to less water requiring crops, is also encouraged. Water efficient cropping systems like, millet-Gram, millet-mustard, Fallow-Taramira, soybean- coriander etc. are popular among farmers.
2. Cultivation of wheat and Barley requiring high water are put in lesser area.

3. Farmers are motivated for deep summer ploughing for control of insect, pest and diseases.
4. Use of organic manures before rains to conserve water in soil is popular.
5. Seed treatment, timely sowing, balanced use of fertilizers promoted.
6. Water saving structures encouraged like construction of farm pond, diggies, jal hoj etc. and also subsidized to farmers.
7. Contingency crop plans prepared and popularized among farmers to reduce risks.

GROUND WATER: Rajasthan is a deficit state with respect to groundwater as well as available irrigation water. It contains about 11 percent of total land resource of the country but the availability of the total water resource of the country is hardly 1 percent. Maximum utilization/exploitation of these water resources has resulted in the irrigation of 32 percent of the area in the state.

For optimum utilization of available water, water storage structures like construction of farm ponds, water storage tanks, construction of diggies and pipeline are being promoted under various schemes : (a) diggi-cum-sprinkler are very beneficial in canal commands areas, where canal closure and breakage and under supply of water is a common phenomenon, (b) water storage tanks become vital in well and tube well irrigated area where water is drawn from 300-600 feet depth and electricity is in short supply or available during nights, in such cases water storage tanks acts as reservoir for storage of water from wells/tubes wells which ensures as-and-when-irrigation in required quantities, (c) rain water harvesting structures particularly the farm ponds are useful in runoff water collection during rainy season which is used for life saving irrigation during Kharif when there is long dry spell or normal irrigation in Rabi season.

MAJOR CROPS: - The diversity of land, soil and climate in Rajasthan makes the state a distinctly different one in India. In two major seasons, viz., Kharif and Rabi, cultivation in the state under normal conditions of rainfall grow mostly cereals, oil seeds and pulses. However, prospects of a normal crop year is often marred by intermittent drought as the probability of every other year turning out to be a drought year has been estimated as high as 0.5. Moreover, Rajasthan accounts for 70 percent of the total arid and semi-arid zone in India and these arid zones are concentrated mostly in the western part of the state. A notable difference between Kharif and Rabi crops is that Bajra is the major crop in Kharif while Wheat takes on other crops in area during Rabi season.

ANIMAL HUSBANDRY: - In Rajasthan Animal Husbandry is not merely a subsidiary to Agriculture but it is a major economic activity specially in arid and semi-arid areas, thus providing the much-needed insurance against prominently occurring scarcity conditions. Parallel to crop production Animal Husbandry is the most important activity in Rajasthan. Income from livestock accounts for 30 to 50% of the rural household's income, with wide variation in region to region. The state supports 5.5% of India's human population and about 11% of the country's livestock population. Because of the limited water resources, most of the agriculture production is rain-fed & as such, the livestock sector assumes more importance.

Livestock rearing is the major component of arid agriculture. Animal husbandry enhances the economic viability & sustainability of farming systems particularly in rain fed areas. In arid western region, livestock farming essentially works as an insulating factor against vagaries of drought and famines, & provides a kind of stability and sustenance livelihood to the rural poor. In Rajasthan, income from livestock averages 22.5 per cent of the total household income, whereas in arid region the contribution of livestock sector is even more than 50 per cent of the

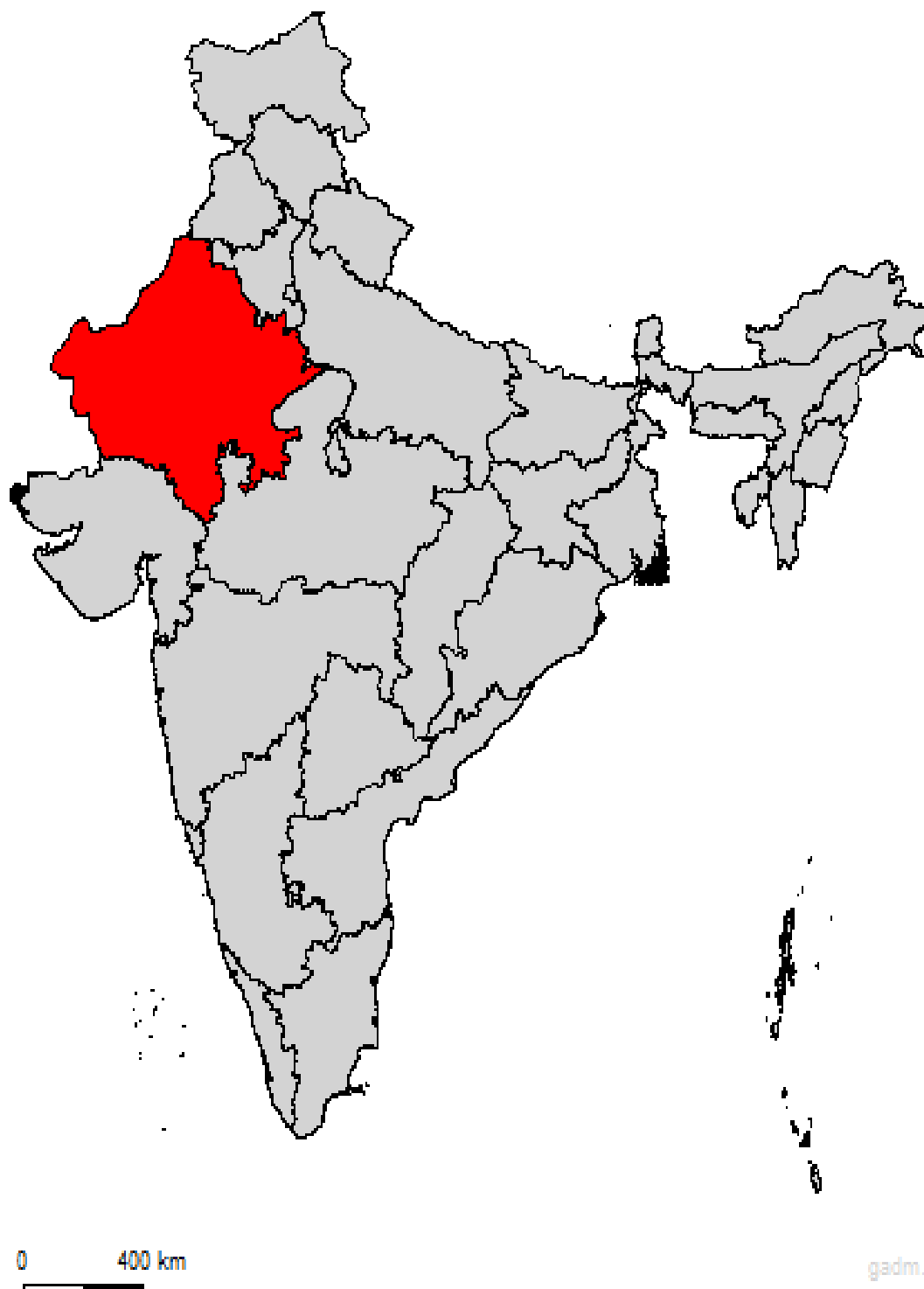
total household income. In Rajasthan animal husbandry is major economic activity contributing about 11 percent of the State's net Gross Domestic Product ^[37].



Administrative Map of India with 29 states, union territories, major cities, and disputed areas.

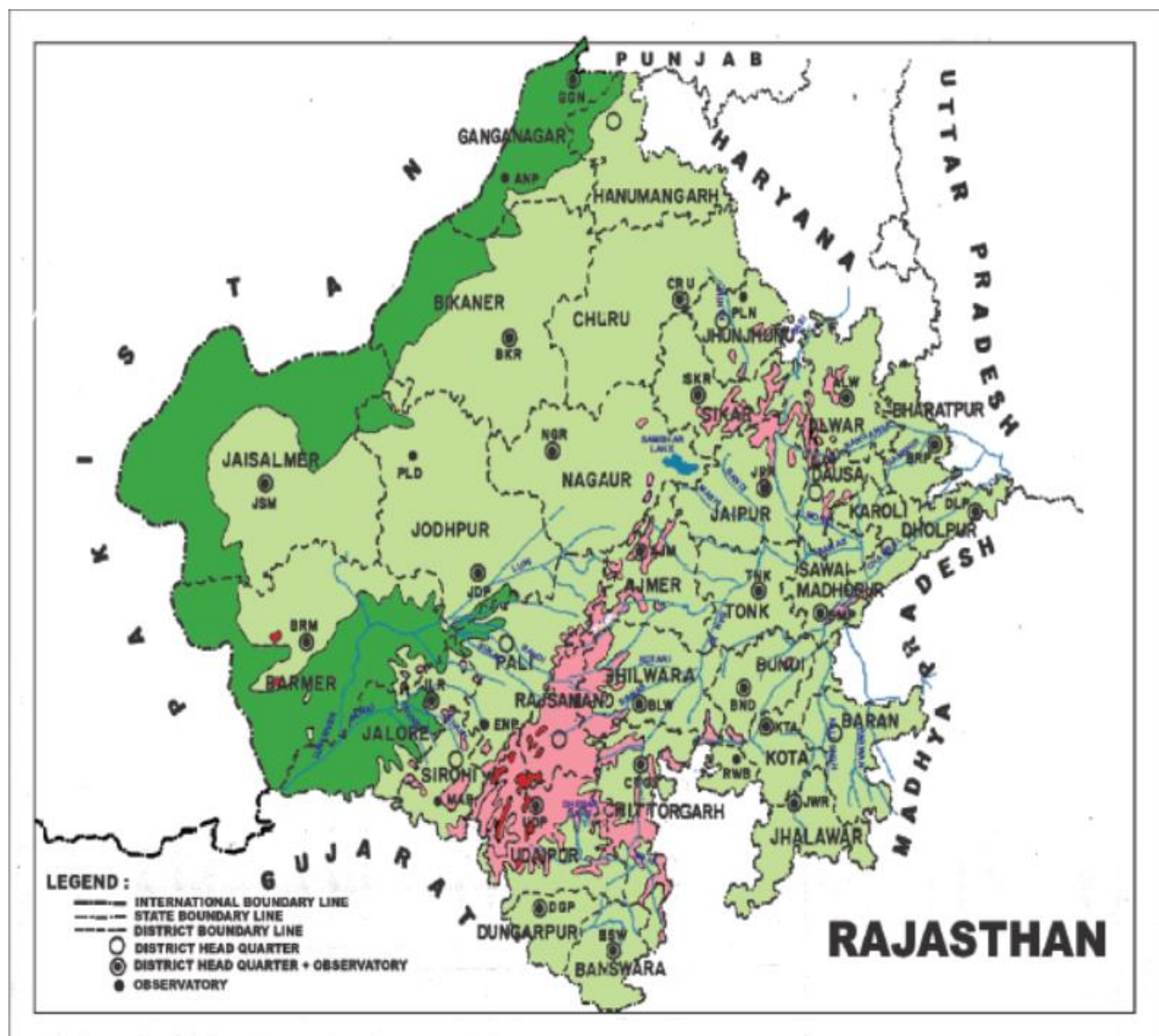
The map shows India and neighbouring countries with international borders, India's 29 states, the national capital New Delhi, state boundaries, union territories, state capitals, disputed areas, and major cities. The study area perimeter is shown using colour Red. Map Source: -

(<https://www.nationsonline.org/oneworld/map/India-Administrative-map.htm>)



Location Map showing the study area (Red colour). This map was downloaded from: -

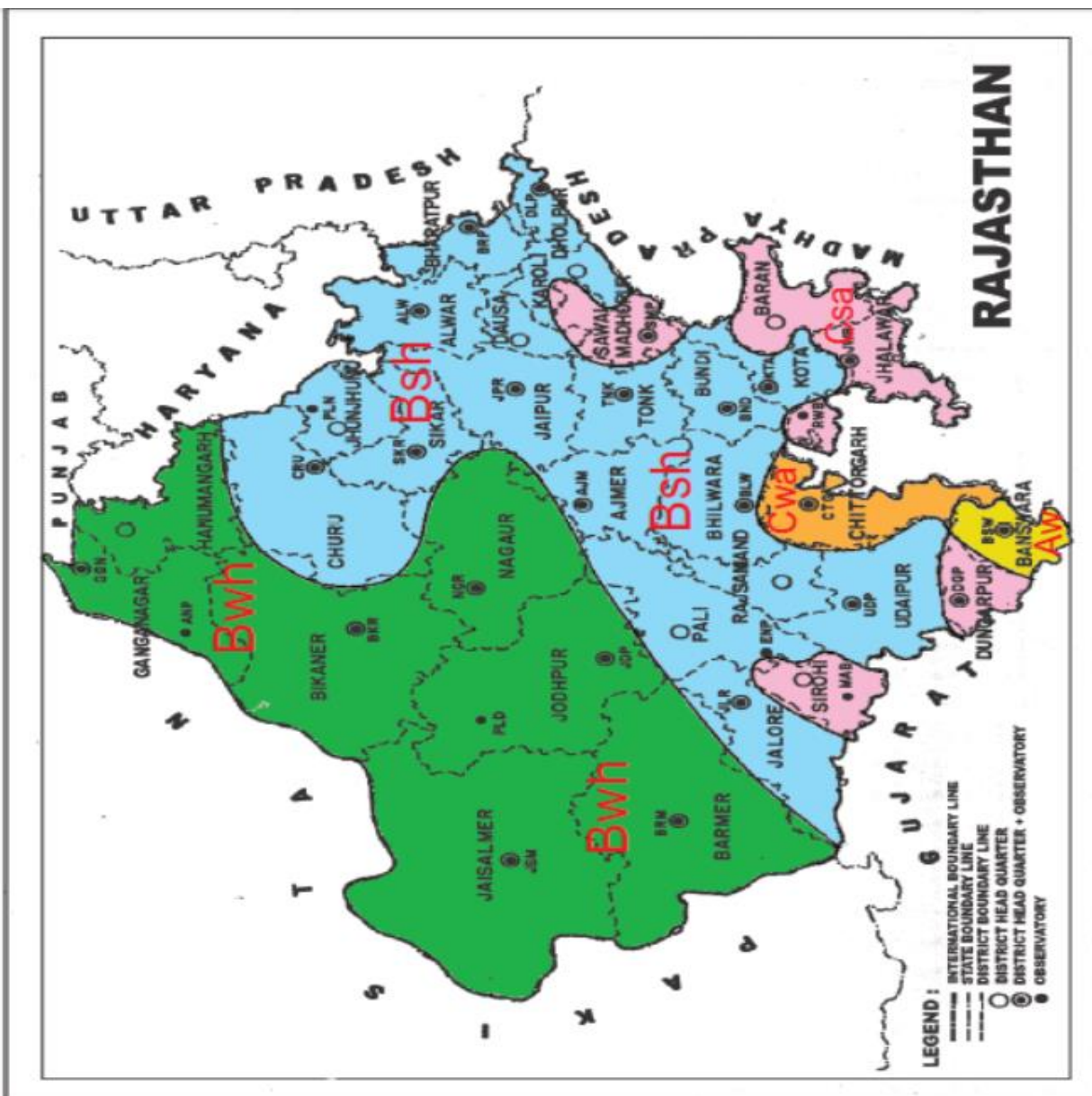
(<https://gadm.org/maps/IND/rajasthan.html>)



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4. The spellings of names in this map, have been taken from various sources.

Map showing Physical Features of Rajasthan State. This map was taken from – Government of India. Ministry of Earth Sciences. India Meteorological Department. Climate of Rajasthan.

Climatological Summaries of State Series – No. 16.



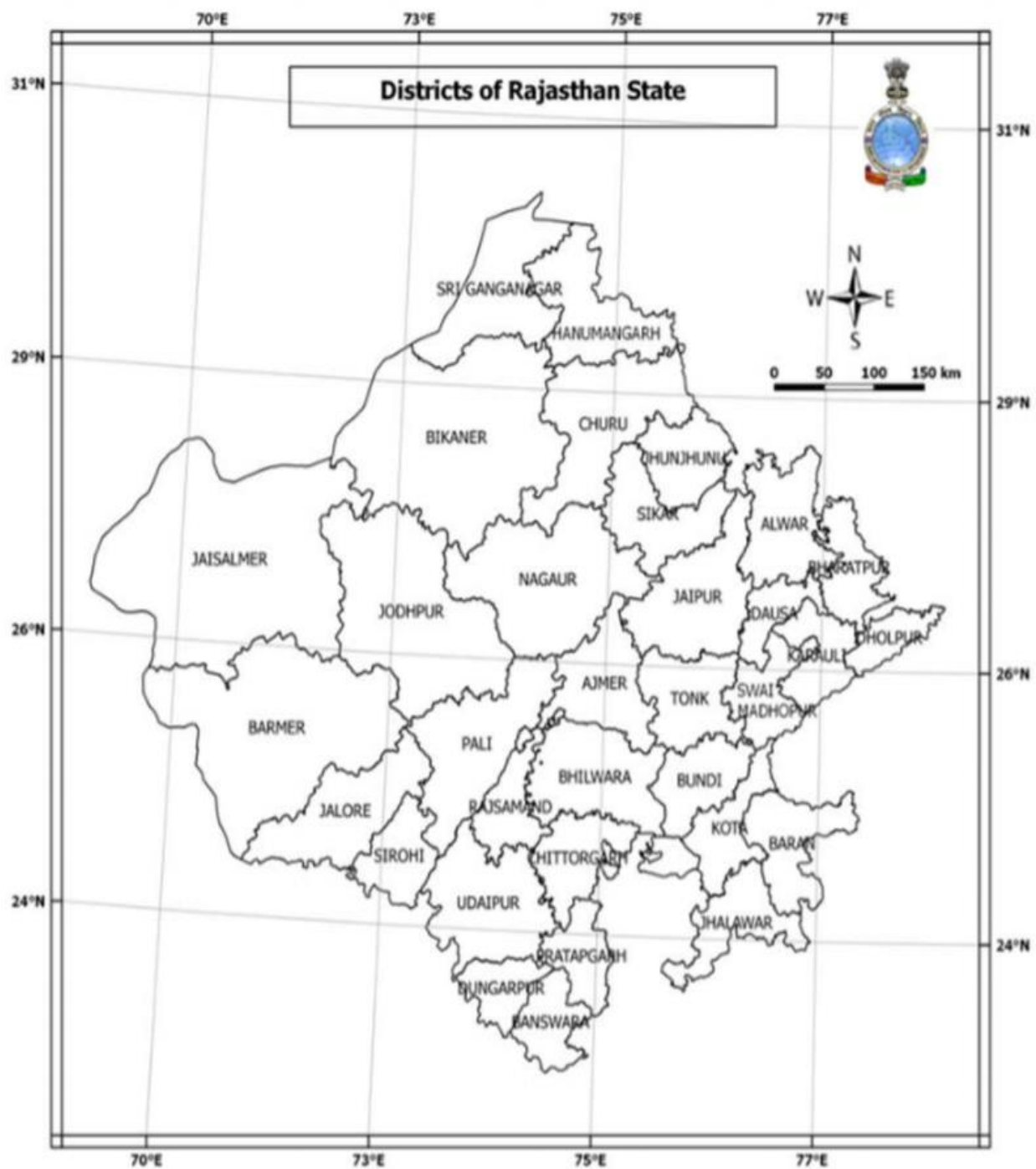
Bwh		Tropical Desert, arid, hot	Bsh		Tropical Steppe, semi arid, hot	Csa		Mild winter, dry & hot summer
			Cwa		Sub tropical monsoon with mild & dry winter, hot summer	Aw		Tropical savanna hot, seasonally dry (winter)

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Climatic Classification of Rajasthan State. This map was taken from – Government of India.

Ministry of Earth Sciences. India Meteorological Department. Climate of Rajasthan.

Climatological Summaries of State Series – No. 16.



Location Map of Districts of Rajasthan, India. This map was taken from – Guhathakurta P., Surendran D., Menon P., Prasad A.K., Sangwan N. and Advani S.C. Observed Rainfall Variability and Changes over Rajasthan State. Climate Research and Services. Indian Meteorological Department. Ministry of Earth Science. Pune. (2020).

4. Methodology

All datasets used were obtained from secondary sources; no survey for ground scouting was conducted. The study, therefore, aligns with the concept promoted by the Open Science Movement, that is encouraging the reuse of data for further discovery and advisory^[38]. The secondary datasets were all obtained from Open Government Data Platform (<https://data.gov.in/>). The underlying philosophy of Open Government Data is of making data freely available to everyone, without limiting restrictions. The Open Government Data Platform seeks to ensure dissemination of information held by public authorities like Ministries, Departments and other agencies. Therefore, users are encouraged to tap datasets from this portal and other governmental website for securing information about various dimensions^[39].

4.1 Data Collection, Compilation and Conversion

4.1.1 Desert Locust Occurrence Sites

The information related to Desert Locust occurrence sites was sought through Google and Web of Science. The keywords used for the search comprised the following: Desert Locust occurrence sites in India from 2019 to 2020 and known Desert Locust occurrence sites in India. The focus was given to obtain the data with respect to study area (Rajasthan, India) and temporal scale i.e., from 01st-June-2019 to 31st-August-2020 (15 months). Government of India – Ministry of Agriculture & Farmers Welfare – Department of Agriculture, Cooperation & Farmers Welfare – Directorate of Plant Protection, Quarantine & Storage – Locust Warning Organization, produces and issues the Desert Locust Situation Bulletin at fortnightly intervals (15 days – 2 weeks). The bulletins are available in English and Hindi language. The bulletin provides regional summary of the Locust situation along with Weather events and Ecology of potential significance of Locust development. The bulletin also provides information related to Food and Agriculture

Organization (FAO) Update on Locust situation in Africa and South Asia. The bulletin provides with additional forecast information about likely development of Locust activities in India (<http://ppqs.gov.in/divisions/locust-control-research/locust-bulletin>). With respect to our temporal scale Desert Locust Situation Bulletins were selected from Volume 71, Number 11 (Period – 01-15 June, 2019) to same Volume, Number 16 (Period – 16-31 August, 2020). The bulletin includes maps showing Desert Locust – Presence sites and Absence sites along with the Control Operations area (if taken). Presence data are usually simpler to obtain while confirming the absence of an organism involves extensive and much detailed work of identifying and plotting ^[40]. Individual Locust situation maps were clipped from each locust bulletin lying within the temporal scale, the maps were then added in QGIS 3.16.2 – QGIS Geographic Information System – Open-Source Geospatial Foundation Project (<https://qgis.org/en/site/>) and the use of Raster Georeferencer tool was done using the Coordinate Reference System – ESRI:104199 GCS – WGS 1984 Major Auxiliary Sphere (datum for the WGS 1984 Web Mercator Auxiliary Sphere coordinate system). A total of 1484 presence sites were recorded with respect to time scale and the study area. These sites were noted along with their Place Name, Month-Year, Longitude(X) and Latitude(Y) in using Microsoft Corporation, Microsoft Excel. The Excel sheet containing the Locust Presence sites was then saved as in .csv (comma separated value) format which allowed the data to be saved in a table structured format. The converted file was then added as a layer under Add Delimited Text Layer in QGIS 3.16.2, the layer was overlaid on a Shapefile containing the District-wise Administrative division of the study area (Rajasthan, India). Hence, giving the final output of the Desert Locust Presence Records Map with respect to the Temporal Scale (01st June 2019 to 31st August 2020) and the Study Area (Rajasthan, India).

4.1.2 Bioclimatic and Edaphic Factors

According to Cressman, K. & Stefanski, R. ^[13] Temperature, Rainfall and Soil Moisture along with Wind and Prevalence of Vegetation are the most critical environmental factors concerning Desert Locusts. Among the many variables; Temperature (General), Rainfall (2019, 2020), Soil Moisture (2019, 2020) and Normalized Difference Vegetation Index (NDVI) Indices (2019, 2020) data was sourced from different Open Government Data Platforms to prepare District wise Choropleth Maps. Please Note for the above factors, an average of three months (June, July, August) for each factor was calculated and mapped. These three months correspond to the Desert Locust invasion activities in Rajasthan, India. Rationally, the environmental factors used are of identical Month-Year timeline with the Desert Locust Occurrence records, except for the factor of Temperature.

Temperature: - Rajasthan is one of the warmest regions in India, with an average daily high temperature of 33 degrees centigrade. It is yearlong warm and hot. A general temperature data was sourced from different platforms; mainly the data was extracted from: Government of India – Ministry of Earth Sciences – India Meteorological Department produced Climate of Rajasthan, Climatological Summaries of State Series – No. 16. The data was then cross-referred with Dainik Bhaskar – E-paper. The newspaper publishes daily Maximum, Minimum and Average Temperature on the upper right-hand corner of their newspaper. Historical Archives of the newspaper were studied using the newspaper’s subscription available easily on the internet. Daily district wise temperature records were analysed and cross-referred from the previous data with respect to the study’s Temporal Scale. An average of temperature data of three months (June, July, August) was calculated to get the district wise total average map used to produce the final map. A single map showing General Temperature was prepared for the Temperature factor.

Rainfall: - Rajasthan is one of the driest states of India; droughts, dry spells and erratic rainfalls are a common feature of the regional climate. Data for the factor of Rainfall was extracted from: Government of Rajasthan – Water Resources Department produced Monsoon Report 2019 and Monsoon Report 2020. This report discusses about spatial and temporal variability of the rainfall, important features of rainfall and tank gauge, peculiarities of the pattern, onset, advancement and withdrawal of the monsoon during the season. Over all, this report provides useful and authentic information about the southwest monsoon season for operational forecasters, researchers and other users. Valuable information for the production and presentation of this report is provided by Indian Meteorological Department (IMD) & Government of Rajasthan - Revenue Department. District wise averages of the three months (June, July, August) were sourced to calculate the total average for 2019 and 2020. This data was used to prepare final maps showing Average Rainfall in Rajasthan for 2019 and 2020 (in mm). Two maps were prepared for the Rainfall factor.

Soil Moisture: - The data for the factor of Soil Moisture was calculated from: Government of India – Ministry of Agriculture & Farmers Welfare – Department of Agriculture, Cooperation & Farmers Welfare – Mahalnobis National Crop Forecast System; under Projects – National Agricultural Drought Assessment and Monitoring System (NADAMS). NADAMS project, developed by National Remote Sensing Centre, provides near real-time information on prevalence, severity level and persistence of agricultural drought at state/ district/sub-district level. Data on the level of district using soil moisture model is provided on the portal. The data is provided in terms of Percent Available Soil Moisture (PASM %) derived using Soil Moisture Balance Model. The Soil-Water-Balance (SWB) model has been developed to allow estimates of potential recharge to be made quickly and easily. The code calculates components of the water

balance at a daily timestep by means of a modified version of the Thornthwaite-Mather soil-moisture-balance approach^[41]. The daily Percent Available Soil Moisture (PASM %) was converted to average monthly Soil Moisture for the months of June, July and August and the year of 2019 and 2020. This data was further used to calculate total average for each of the district. The data was used to prepare final maps showing Average Soil Moisture in Rajasthan for 2019 and 2020 (in Inches of water per Foot). Two maps were prepared for the indicator of Soil Moisture.

Prevalence of Vegetation: - Rajasthan is a unique State which shows great variation from one area to another and is noticeable in respect of Vegetation. The data for the factor of Prevalence of Vegetation was taken from the same source as that of the factor of Soil Moisture i.e. Government of India – Ministry of Agriculture & Farmers Welfare – Department of Agriculture, Cooperation & Farmers Welfare – Mahalanobis National Crop Forecast System; under Projects – National Agricultural Drought Assessment and Monitoring System (NADAMS). Data on the level of district is provided in Normalized Difference Vegetation Index (NDVI) format, using Moderate Resolution Imaging Spectroradiometer imaging sensor - Terra is a multi-national NASA scientific research satellite in a Sun-synchronous orbit around the Earth (MODIS-TERRA). The Normalized Difference Vegetation Index (NDVI) works as follows: Normalized Difference Vegetation Index (NDVI) is a measure of the state of plant health based on how the plant reflects light at certain frequencies. Calculations of NDVI for a given pixel always result in a number that ranges from minus one (-1) to plus one (+1); however, no green leaves give a value close to zero. A zero means no vegetation and close to +1 (0.8 - 0.9) indicates the highest possible density of green leaves. The monthly data for June, July and August was collected and used to calculate District wise averages of 2019 and 2020. The data was used to prepare final maps showing

Average Normalized Difference Vegetation Index (NDVI) for 2019 and 2020. Two maps were prepared for the factor of Prevalence of Vegetation.

4.2 Assumptions & Processing of Data

The study assumed that all the Desert Locust Occurrence Site(s) Records were obtained from a larger area, within the country with reference to the temporal scale and the study area. The Desert Locust Occurrence Sites follow Standard Operating Procedures (SOP) for Desert Locust Ground Survey defined by Food and Agriculture Organization (FAO) of United Nations (UN) (http://ppqs.gov.in/sites/default/files/sop-_desert_locust_survey.pdf). Although many of the Desert Locust affected countries are directed to use the Food and Agriculture Organization (FAO) - Standard Operating Procedures (SOP) for Desert Locust ground surveys, the accuracy of sample size, data quality, manipulation and misrepresentation of data may take place while data handling. Similarly, the sources used in the collection of Bioclimatic and Edaphic factors notify in the Disclaimer section: The Respective Department is not responsible for any errors and omissions; and the contents published within the report have been checked and authenticity assured within the limitations of human errors. Data gathering for the Bioclimatic factor of Temperature was a long laborious process, a general district wise temperature data was selected, cross-referred and refined with regionally popular Newspaper data showing daily Temperature data indices.

Processing of data was done using pen and paper, for calculations use of calculator was preferred to ensure accuracy in data representation. Statistical calculations were done using Social Science Statistics Calculator available online on the Internet (<https://www.socscistatistics.com/tests/>).

Although, the results were checked twice, the possibility of human error still remains present. Rest assured, no hardware and software errors were encountered during any part of the study.

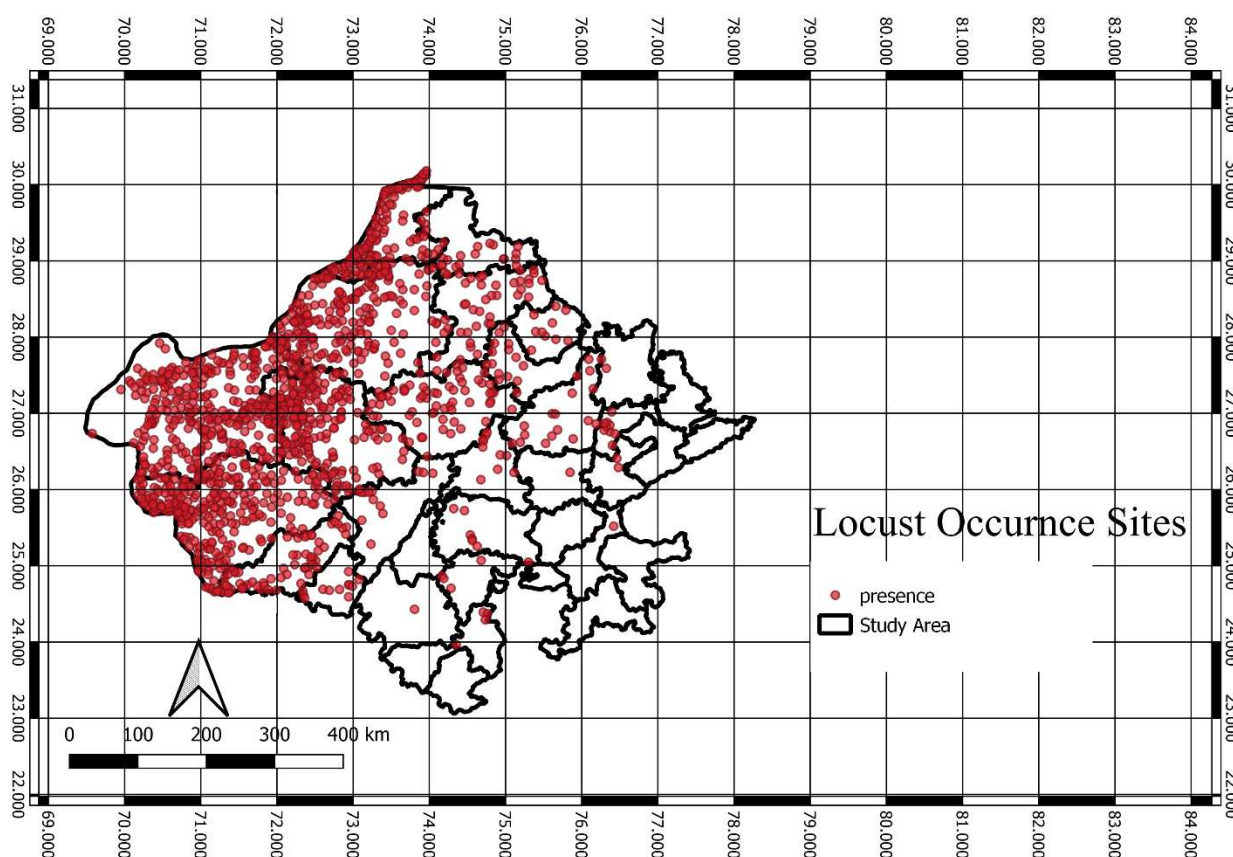
5. Results

This chapter covers the presentation and general description of the obtained results, which were an outcome of processing and analyzing of the datasets mentioned in the methodology chapter.

5.1 Distribution of Desert Locust Occurrence Sites

In total, 1484 Desert Locust Occurrence Sites were recorded to be used with respect to the Study Area (Rajasthan, India) over the Temporal scale from 1st June 2019 to 31st August 2020. Out of the total 1484 Desert Locust Occurrence Sites, 9 sites were removed as these sites were mapped outside of the Study Area. The map was prepared using QGIS 3.16.2 software.

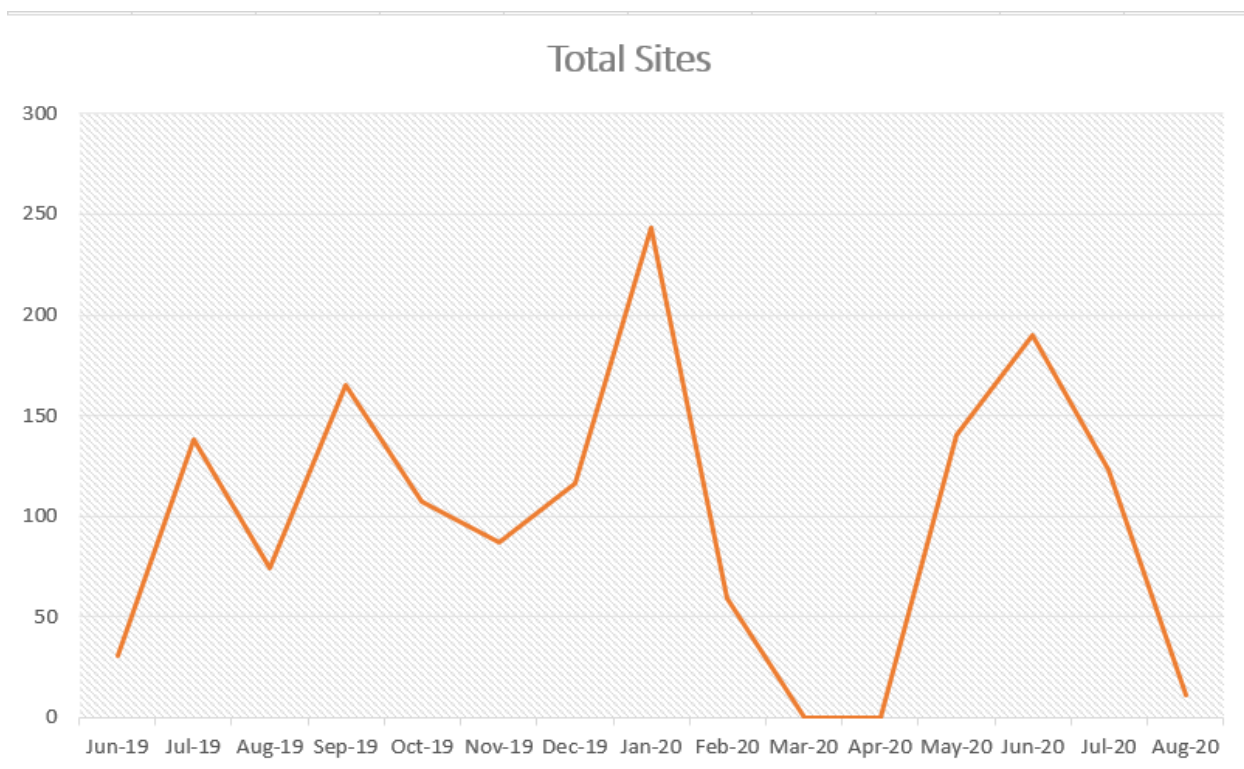
Map 5-1 displays the Desert Locust Occurrence Sites.



Map 5-1. 1475 Desert Locust Occurrence Sites digitized using QGIS 3.16.2. Desert Locust Presence sites are shown using red circles on a District level Administrative map of Study Area.

The vast majority of Desert Locust presence sites are located in western part of the State, comprising the districts of: Jaisalmer, Bikaner, Sri Ganganagar, Barmer, Jodhpur, Hanumangarh, Jalore, Nagaur and Churu. The districts along the International Border Boundary of India-Pakistan face the Desert Locust invasions at first in the whole country. These districts include: Barmer, Jaisalmer, Bikaner and Sri Ganganagar. Rajasthan shares a 1,408 Km long International Border with Pakistan. The Desert Locust Presence sites decrease gradually from West to East, being completely absent in the extreme Eastern and Sothern districts of, Eastern: Bharatpur, Dholpur, Karauli, Baran, Jhalawar and Bundi; Sothern: Banswara and Dungarpur. No Locusts were observed in Rajsamand district.

A line graph was prepared showing Total Desert Locust Presence Sites over the months considered in the Temporal Scale (June 2019 to August 2020), a total of 15 months along with Total Presence Sites is presented below.



Total Desert Locust Presence Sites are shown on y-axis and Months with Year over x-axis.

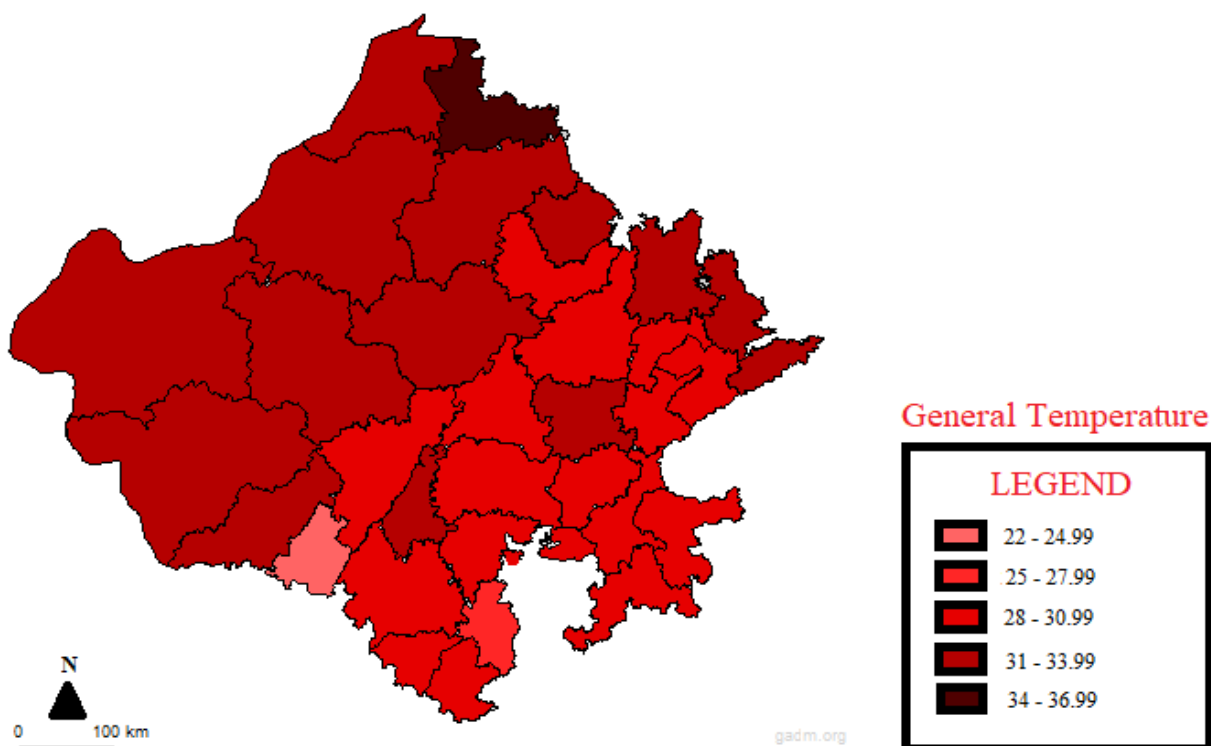
5.2 Environmental Factors

Among Environmental Factors, Choropleth maps were prepared for: Average General Temperature, Average Rainfall for the year 2019 and 2020, Average Soil Moisture for the year 2019 and 2020, and Average Normalized Difference Vegetation Index for the year 2019 and 2020.

5.2.1 Average Temperature (in Degree Celsius - °C)

Temperature is the highest contributing factor in predicting habitat susceptibility for the breeding regions of Desert Locust. In a study of Prediction of breeding region for the Desert Locust in East Africa, the temperature variable accounted for 70.2% contribution among other significant variables ^[42].

Map 5-2 displays the General Average Temperature of the state at district level, calculated for the months of June, July, August.



Map 5-2. General Average Temperature Choropleth Map. Unit: °C

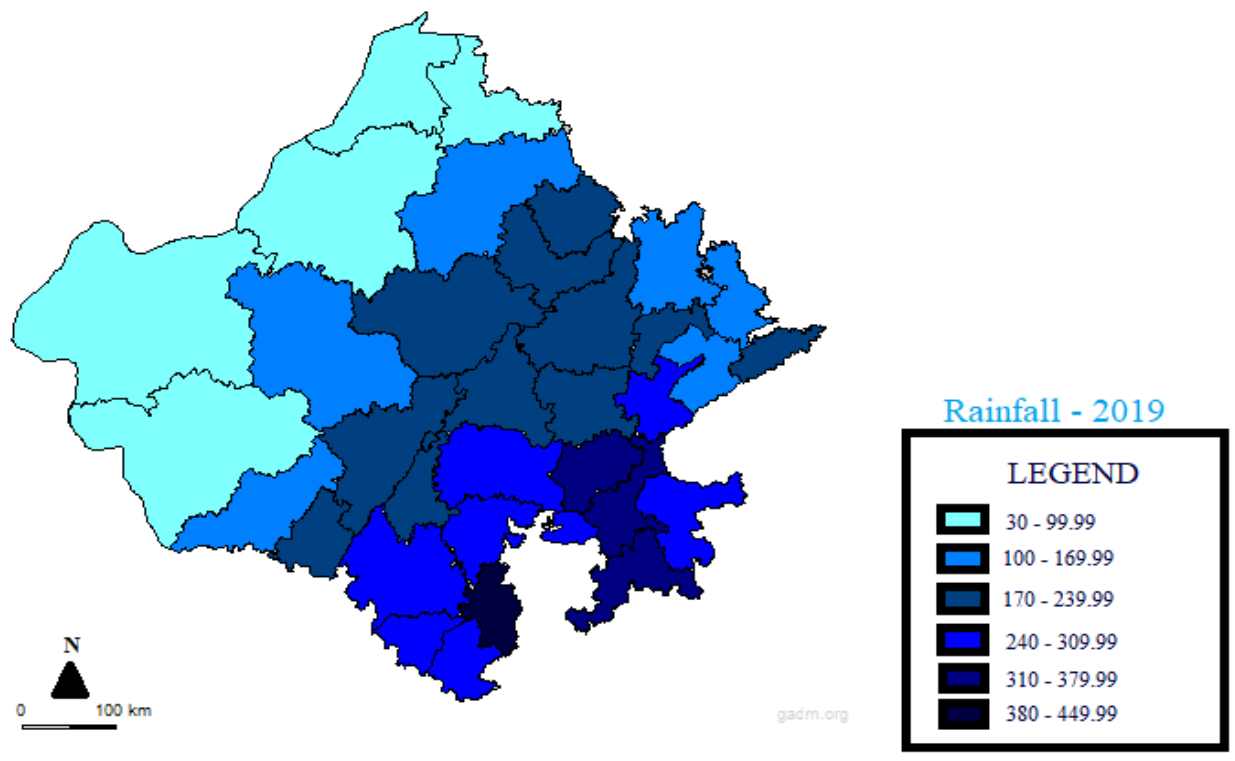
The temperature rises from West to East. The data was selected for the months of June, July and August. These months correspond with the seasons of Summer and Monsoon in the State.

District recording the highest average Temperature was Hanumangarh, with average temperature lying in the range of 34°C – 36°C; whereas lowest average Temperature was recorded at Sirohi district, lying in the range of 22°C – 24°C. Possible reason for the lowest average Temperature recording at Sirohi District could be that the Weather Monitoring Station is located at Mount Abu, perched at an altitude of 4000 feet above sea level.

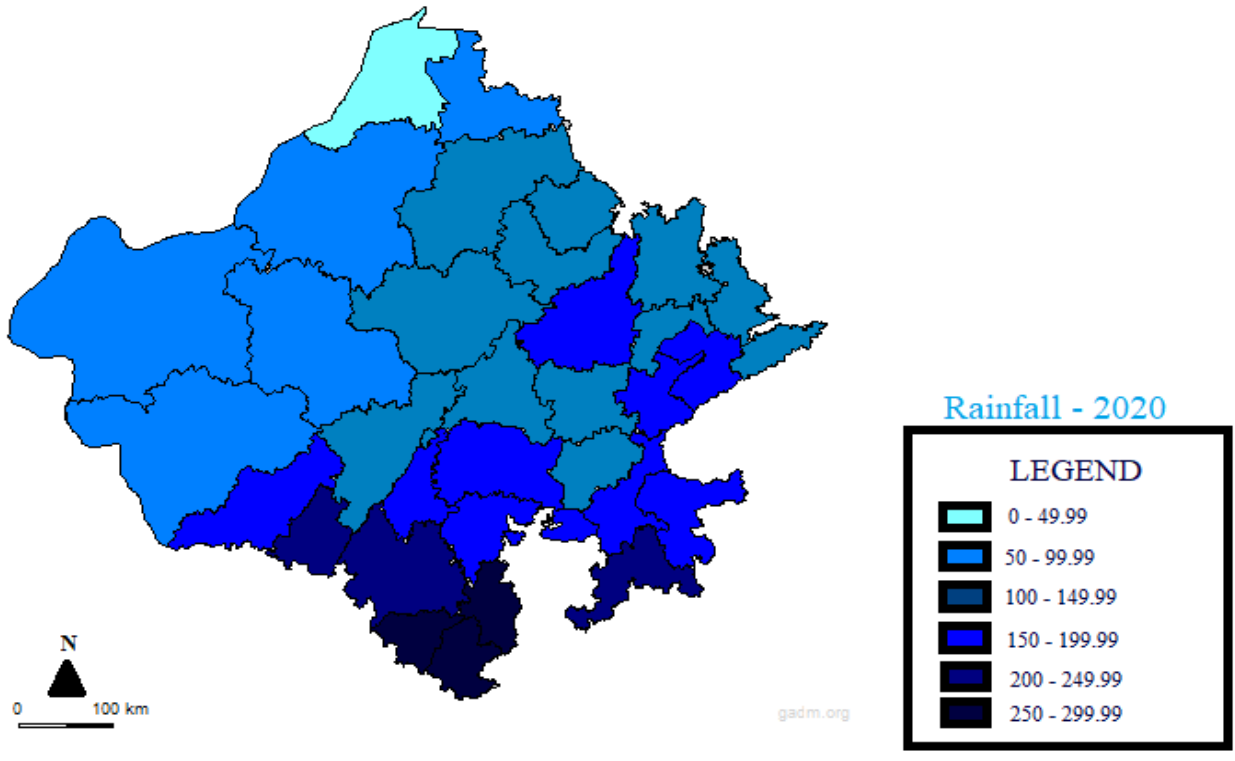
Day temperatures are more or less uniform over the plains except during the winter and monsoon season, when temperatures increase southwards and northwards respectively. In general, the night minimum temperatures are lower in higher latitudes except during the southwest monsoon when they are more or less uniform. Both day and night temperatures are lower over the plateau and at high level stations than over the plains. The maximum temperature rises rapidly from February onwards till May and minimum temperature from February onwards till June. From the beginning of June to the end of July, the maximum temperature falls by about 3°C to 7°C whereas the minimum temperature falls only by about 3°C to 5°C from June to September. Diurnal range of temperature is the difference between the maximum and minimum temperature of the same days. July and August have the smallest diurnal range of temperature of about 9°C in the state.

5.2.2 Average Rainfall (in mm) for 2019 & 2020

Average Rainfall data was calculated by taking Total Average for the months of June, July and August for both the years of 2019 and 2020. Amounting individually to about 34% of the annual rainfall each, July and August are generally the rainiest months. Map 5-3 displays the Average Rainfall (in mm) for 2019; Map 5-4 displays the Average Rainfall (in mm) for 2020.



Map 5-3. Average Rainfall (in mm) for the year 2019.



Map 5-4. Average Rainfall (in mm) for the year 2020.

The southwest monsoon is the principal rainy season when the state receives 91% of its annual rainfall. The average rainfall in state varies from 0 to 49.99cm over the extreme northwestern parts to 299.99cm over the southeastern parts. Southern/southeastern districts adjacent to Madhya Pradesh constitute the area of maximum rainfall in the state. Pali and Jalore districts on the west of Aravalli hills receive maximum amount of Average rainfall from 50 cm to 149.99cm in West Rajasthan. In the north/northwest districts Bikaner, Sri Ganganagar, Jaisalmer receive Average rainfall of 0 to 99.99cm respectively, with Sri Ganganagar being the lowest. These districts and the adjoining areas constitute the driest zone of the state. The southwest monsoon sets in over the eastern parts of the state by about the last week of June and extends over the entire state by the first week of July. July and August are the rainiest months, each accounting individually to about 34% of the annual rainfall. In each of these months, there are about 5 rainy days (with daily rainfall of about at least 2.5 cm) in West Rajasthan and about 9 -10 rainy days in East Rajasthan.

In 2019: The southwest monsoon entered in Rajasthan through south eastern part on 2nd July, it further advanced rapidly and covered the almost whole state in fourth week of July. After analyzing the monsoon map of Rajasthan, it clearly indicates that central, southern & south eastern part of the state received excess rainfall where as remaining part of state received normal rainfall, except Alwar & Sri Ganganagar districts. Overall performances of monsoon remain excess (43.4%) in the state.

Category	Number of districts
Abnormal (60% or more)	12
Excess (20 to 50%)	09
Normal (19 to -19%)	10
Deficit (-20 to -59%)	02
Scanty (-60% or less)	00

Table showing status of Districts as per Rainfall received.

In 2020: The southwest monsoon marked its first presence in the state a day ahead of time. Favorable condition of winds and other weather parameters makes the monsoon to cover the 12 Southern and southeastern districts of the state, namely Banswara, Dungarpur, Sirohi, Rajsamand, Udaipur, Chittorgarh, Pratapgarh, Bhilwara, Bundi, Kota, Baran, Jhalawar, and some parts of Ajmer and Sawaimadhapur on 26th June 2020. Normally western part of the state receives lesser rainfall compared to the eastern part, but this year monsoon was more active in the western part. Jaisalmer received abnormal rainfall while Churu, Nagaur, Jodhpur, Barmer and Jalore received excess rainfall. Districts of eastern Rajasthan such as Alwar, Baran, Bundi, Bharatpur, Dausa, Dholpur, Kota & Tonk received less rainfall than normal and came under the deficit category. Overall, 1 district received abnormal rainfall, 10 districts received excess rainfall, 13 districts received normal rainfall while 9 districts had rainfall less than normal thus coming under deficit category.

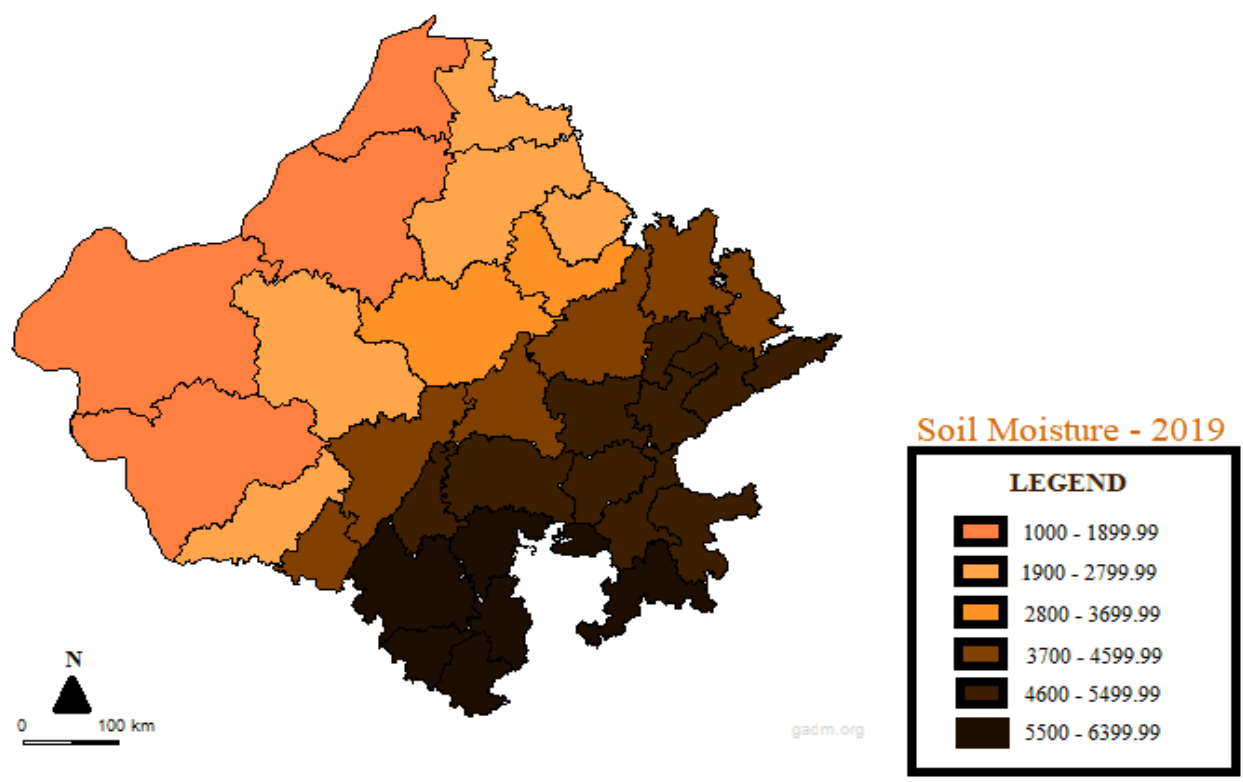
5.2.3 Average Soil Moisture (in inches of water per foot) for 2019 and 2020

Daily District level Percent Available Soil Moisture (PASM%) data was processed for the months of June, July and August. Total Average for the years of 2019 and 2020 was calculated and then converted to its original unit (in inches of water per foot). Choropleth Maps for 2019 and 2020 were prepared using this data

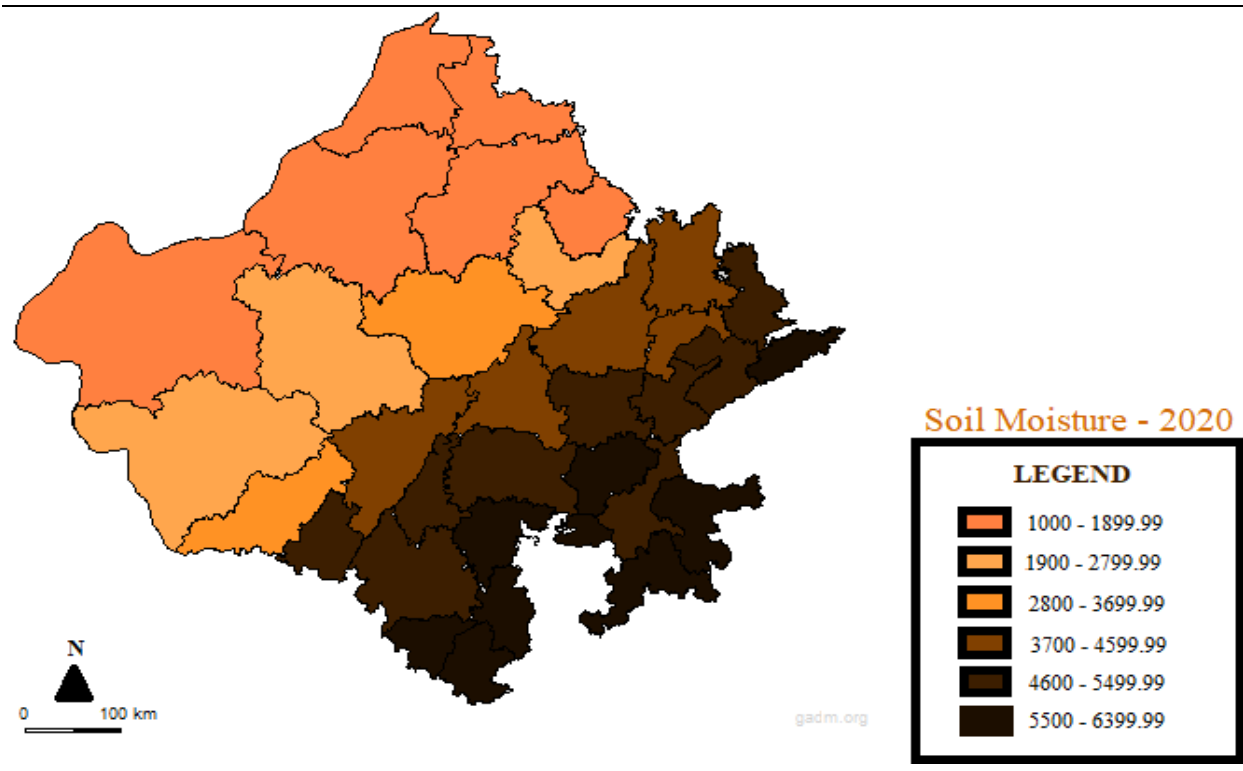
Map 5-5 displays the Average Soil Moisture (in inches of water per foot) for the year 2019;

Map 5-6 displays the Average Soil Moisture (in inches of water per foot) for the year 2020.

soil is the top-most layer of earth crust. The soils of Rajasthan, India have developed under the arid and humid climate over the bed rocks of complex nature predominately through the process of Laterization. Soil Moisture is the water stored in soil, generally measured in inches of water per foot, and is affected by precipitation, temperature, soil characteristics, etc.



Map 5-5. Average Soil Moisture (in inches of water per foot) for 2019.



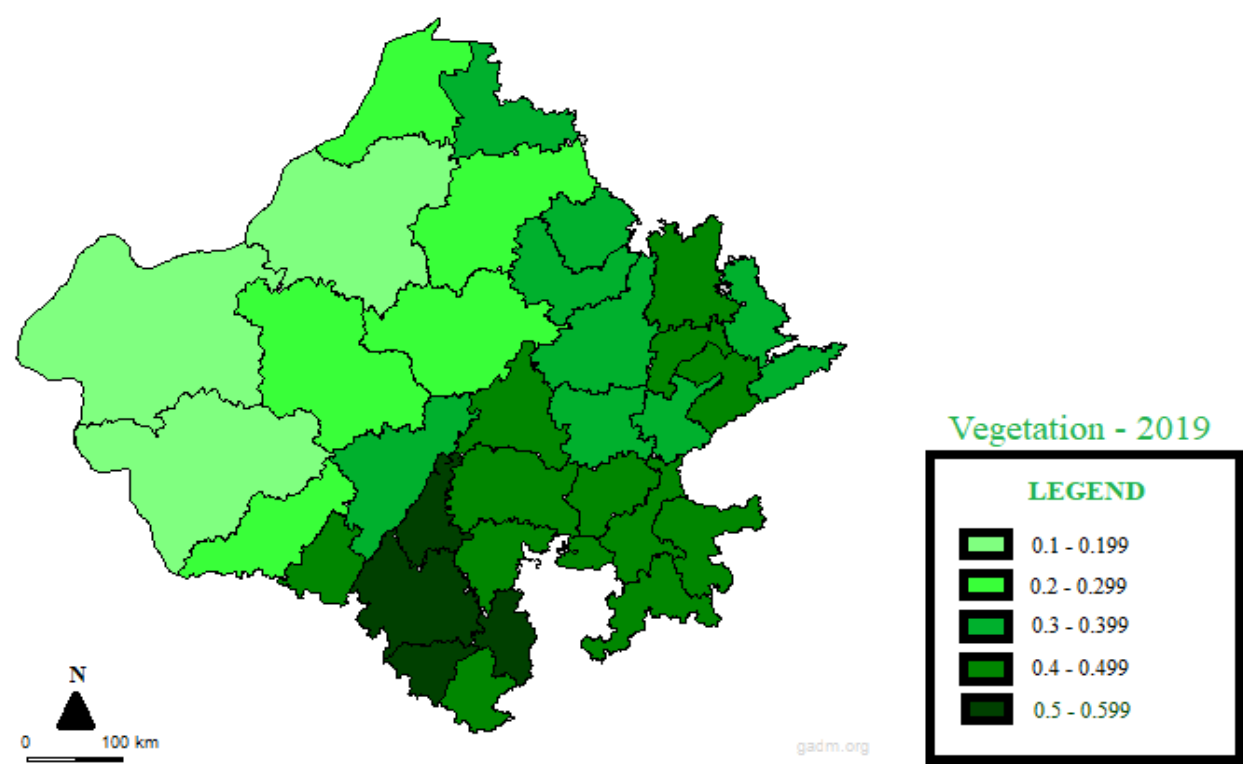
Map 5-6. Average Soil Moisture (in inches of water per foot) in 2020.

Lowest Average Soil Moisture was found to be in the West and Northwestern districts of Sri Ganganagar, Bikaner and Jaisalmer in both the years, whereas in 2019: Barmer district was in the lowest class, and in 2020: Hanumangarh, Churu and Jhunjhunu were present in the lowest class (1000 – 1899.99). These areas are classified by Dune type soil. Highest Average Soil Moisture was found to be in the East and Southeastern districts of Dungarpur, Banswara, Pratapgarh, Chittorgarh and Jhalawar in both the years, whereas in 2019: Udaipur district was in the highest class, and in 2020: Bundi, Baran and Dholpur districts were present in the highest class (5500 – 6399.99). These areas are classified with Brown soil.

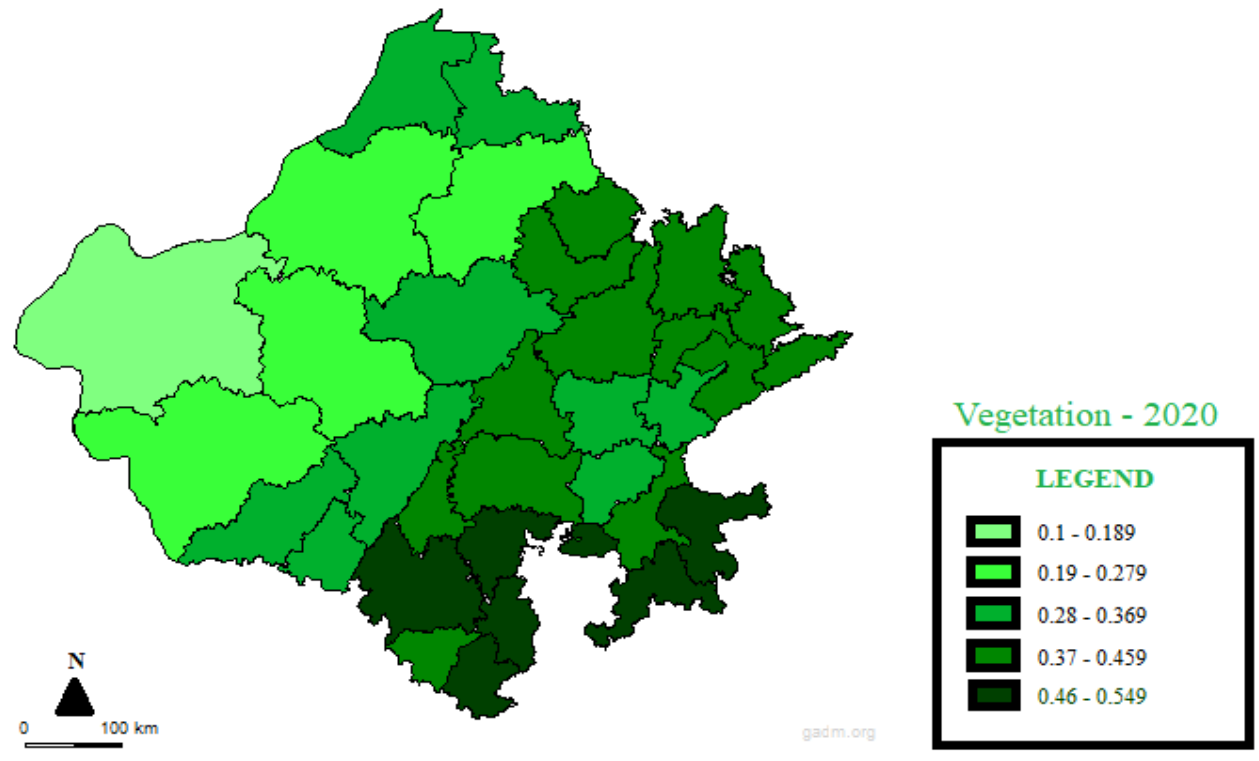
5.2.4 Average Normalized Difference Vegetation Index (NDVI) for 2019 & 2020

Vegetation factor changes spatio-temporally in its extent and distribution. District level Average Normalized Difference Vegetation Index (NDVI) data was calculated for the months of June, July and August for both the years of 2019 and 2020. The results of the Normalized Difference Vegetation Index (NDVI) calculation range from -1 to +1. Bare soils usually fall within 0.1 – 0.2 range, plants will have positive values between 0.2 and 1. Healthy, dense Vegetation canopy is above 0.5 and sparse Vegetation falls within 0.2 and 0.5.

Map 5-7 displays Average Normalized Difference Vegetation Index (NDVI) for the year 2019, Map 5-8 displays Average Normalized Difference Vegetation Index (NDVI) for the year 2020. The Vegetation of Rajasthan is diverse as it varies with the decreasing order of aridity and number of rainy days from Western Rajasthan to less arid Eastern plains to slightly sub-humid conditions over South-Eastern plateau. Districts with most healthy and dense Vegetation are: Udaipur and Pratapgarh in both the years. Whereas, in 2019: Rajsamand and Dungarpur districts were in the highest class (0.5 – 0.599). Districts with Bare soils or minimal Vegetation is Jaisalmer in both the years. In 2020: Banswara, Chittorgarh, Jhalawar and Baran were in the



Map 5-7. Average Normalized Difference Vegetation Index (NDVI) for 2019.



Map 5-8. Average Normalized Difference Vegetation Index (NDVI) for 2020.

highest class (0.46 – 0.549). Jaisalmer District with Bare soils or minimal Vegetation is present in both the years. Whereas, in 2019: Bikaner and Barmer districts were present in the lowest class (0.1 – 0.199). In 2020: minimum Vegetation was only seen in Jaisalmer district, with lowest class (0.1 – 0.189). This was probably because of good and effective rainfall covering the State in 2020.

5.3 Visualizing Desert Locust Suitability Sites

Overall, the result map of Distribution of Desert Locust Occurrence Sites along with Environmental Factors maps when visualized simultaneously indicate that: there is a high probability for Desert Locust Habitat Suitability and subsequent breeding in the Western districts of the State and most districts of Central Rajasthan. These regions include the districts of: Jaisalmer, Bikaner, Sri Ganganagar, Barmer and Jodhpur being the most susceptible extreme Western districts, with Jalore, Nagaur and Churu being relatively lesser susceptible Central districts of the State. There is a moderate probability of Desert Locust Activity in the districts of: Sirohi, Pali, Sikar, Hanumangarh, Jhunjhunu, Jaipur, Dausa and Ajmer. Among these districts of moderate probability, the districts of Sirohi, Sikar, Jhunjhunu and Hanumangarh are highly susceptible. Remaining districts come under areas of low probability, with no or very few Desert Locusts invasions record. Map 5- 9 shows districts of high, moderate and low probability of Desert Locust Habitat Susceptibility.

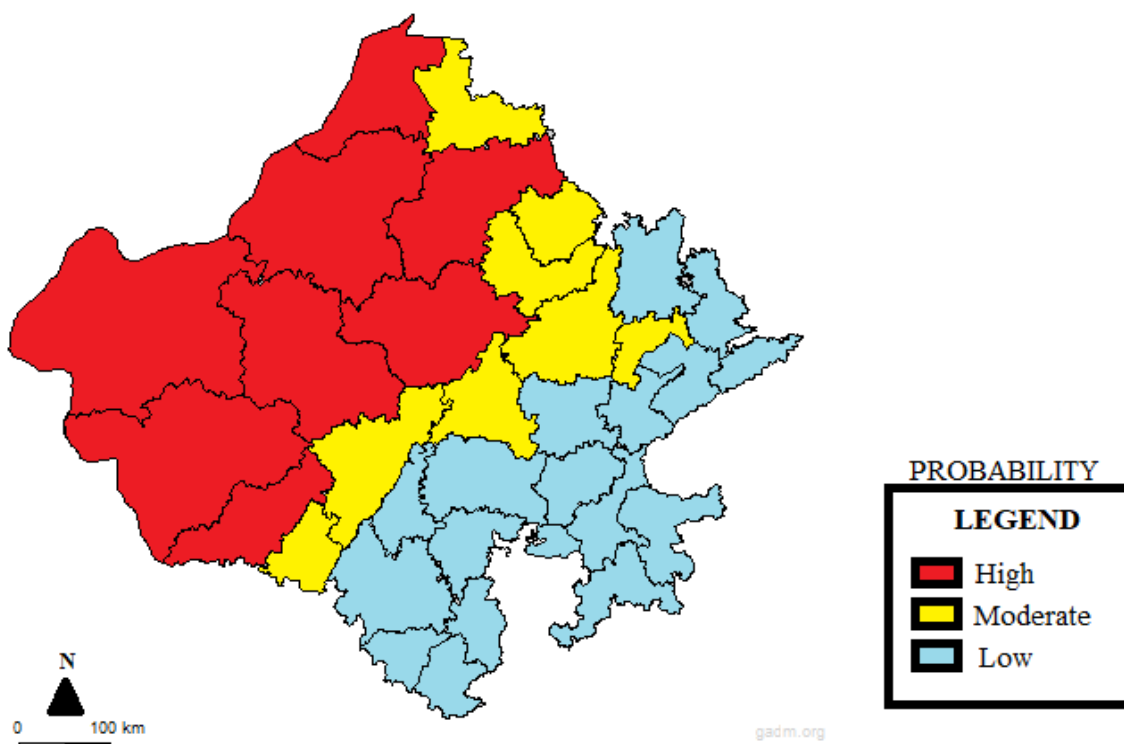
The areas with high and moderate probability are the areas having Average Temperature between 31°C to 36°C. Temperature determines the development rate of eggs and hoppers, as well as indicating whether it is warm enough for adults to take off and fly.

The areas with high and moderate probability are the areas having Average Rainfall between

0mm to 169.99mm. Rainfall determines whether the areas may become suitable for breeding or where green vegetation may be present.

The areas with high and moderate probability are the areas having Average Soil Moisture between 1000 inches of water per foot to 3699.99 inches of water per foot. Female Desert Locusts prefer warmer and more open sites for initiating probing and digging activity for oviposition. Soil Moisture is a critical factor for selection of those sites.

The areas with high and moderate probability are the areas having Average Normalized Difference Vegetation Index (NDVI) between 0.1 to 0.369, indicating areas of Bare soils and very sparse Vegetation. The Prevalence of Vegetation factor provides information about future Desert Locust movement trends.



Map 5-9. Districts of High, Moderate and Low probability for Desert Locust Habitat Susceptibility and Subsequent Breeding.

5.4 Early Warning System for Locust Control in India

The Early Warning System for Locust Control in India is an integration of four key elements, with four sub elements in every key element. The model is in abidance with United Nation's Development Program (UNDP) Guide to Approaches for building functional Early Warning Systems.

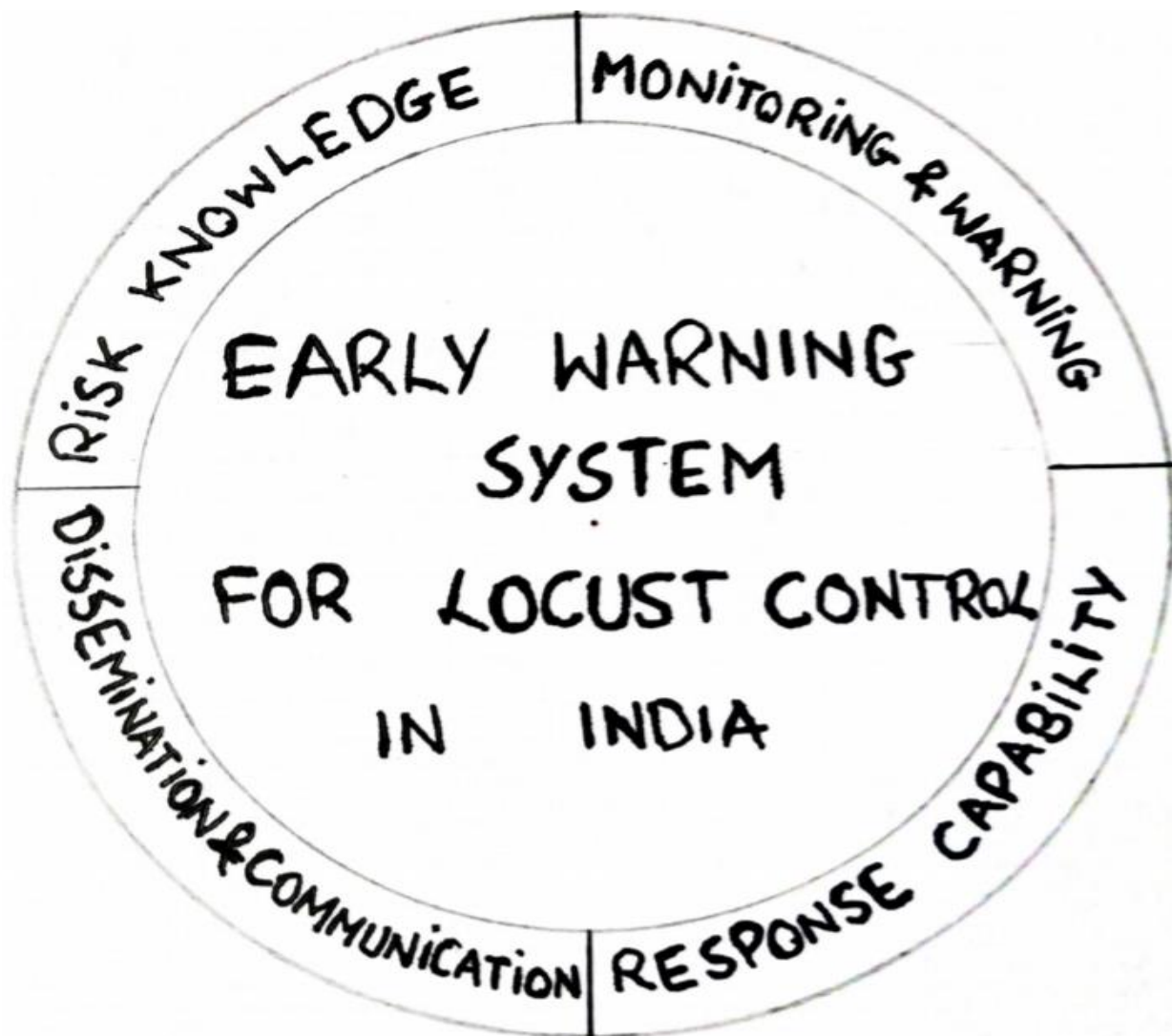


Diagram showing the four key elements of Early Warning System for Locust Control in India.

The diagram was drawn out by taking reference from - Brazzola, N and Helander, S. Five Approaches to build Early Warning Systems. UNDP (2018).

1. Risk Knowledge: - Risk arises from a combination of hazards and vulnerabilities at a particular location, in our case – India. The element of Risk Knowledge contains sub elements of: 1 Institutional Arrangement- The sub element of Institutional Arrangement takes into account factors like Regulatory Framework, Mandate, Roles and Responsibilities and Concept of Operation. Institutions like Locust Warning Organization (LWO) need to be strengthened. Step-by-Step approach shall be adopted, functioning on the basis of the roles and responsibilities assigned to each institution. Regulatory frameworks, mandates, roles and responsibilities and concept of operations shall be revised and refined regulatory. 2. Hazard Risk Assessment- A hazard is a potential for harm. The hazard agent, condition and activity shall be identified and assessed. Risk assessment is a systematic process for describing and quantifying the risks associated with hazardous substances, processes, actions or events. This sub element takes into account factors like Criteria's and Uncertainty Assessment. Characterizing the probability, frequency and severity shall be evaluated. Different models (e.g., Machine learning/Artificial Intelligence) and approaches (e.g., Ecological Niche Approach) can be used to identify and evaluate the risks. The hazard risk assessment provides the factual basis for further activities. 3. Community Vulnerability Assessment- A Community Vulnerability Assessment is a process whereby the community comes together to discuss specific areas of concern and identify possible solutions. Communities based on vulnerability (high to low) shall be identified. Community Vulnerability Assessment shall be carried out at farm and village levels. The process shall involve several detailed community meetings, field trips and interviews conducted by experts from Locust Warning Organization (LWO) with Community leader (Sarpanch) and other prominent

personalities (Patwari, religious heads). 4. Information Collection, Storing and Sharing- Poor Collection and Management of data results to poor early warning system. The qualitative and quantitative data collected and generated through various modes shall be stored and shared in most fruitful manner. The designs shall be evident meeting the needs of everyone. The data shall be designed in such a manner that it provides the opportunity of revision. Data and Information Collection, Storing and Sharing shall be done through various sources of Open Government Data (OGD) Platform.

- 2. Monitoring and Warning Service:** - This is the infrastructure that delivers forecasts and warnings. Systems with monitoring and predicting capabilities shall provide timely estimates of the potential risk faced by overall communities, economies and environment. Warning services lie at the core of the system. This contains of sub elements of: 1. Continuous Monitoring and Detection- Continuous monitoring of the Desert Locust upsurge parameters and precursors like favorable Environmental Factors is essential to generate evident, accurate and timely warnings. This sub element talks about Hardware, Software, Operation System and Data Analysis Software that work on continuous basis to detect any significant activity. The sub elements need to be technologically advanced and updated regularly. This will lead to improvements in many facets of the system; providing increased lead-time lengths and locally actionable service. 2. Impact based forecasting and warning- Impact-based forecasting and warning enables anticipatory actions and revolutionizes responses to Desert Locust upsurges. These forecasts and warnings provide critical information to help mitigate impacts and losses. Issuing of forecasts and warnings are generated by assessment of Hazards, Vulnerable Communities and Impacts and Risks associated with it. With Impact-based forecasting, respective

institutions assess the impacts of forecasted phenomenon's related to Desert Locust and consider their warnings based on the level and severity of those impacts at those particular locations and communities. Analyzing events of past can help identify the correlations between the magnitude of previous Desert Locust plagues and their relative impacts. Climate crisis has altered the levels of impact of Desert Locust upsurges. With increase in temperature, unusual events of rainfall and shifting wind patterns the maturation rate of Locusts have become more rapid leading to more frequent outbreaks and new invasive areas. Consideration of potential future events and their impacts that may occur shall be incorporated within the functioning of Impact-based forecasting and warning.

3. Warning and other Infrastructure- Resilient Infrastructure helps in improving the utility of Monitoring and Warning service. It includes the drafts of Advisories and Statements that are carried out at Institutional levels. These processes shall function efficiently, involving the respective institutions at State and Central levels of government.

4. Time Responsive Service- Monitoring and Warning service is not useful, unless the information reaches public in evident and timely manner. The Monitoring and Warning Service should be time responsive; it should be quick in issuing forecasts and warnings and should do so time to time. To be effective warnings must be provided timely, with enough lead-time for response. Timeliness is often in conflict with the desire to have reliable predictions, which become more accurate with the input of more information. In such case, the service shall give regular updates, updating every time with the input of new data or information.

- 3. Dissemination and Communication:** - An effective Early Warning System needs an effective communication system. The communication infrastructure must be reliable and

robust incorporating appropriate and effective interactions among the main actors. The distribution of understandable warnings and preparedness information to the vulnerable communities (farmers) underpins the dissemination and communication process. This includes the sub elements of: 1. Dissemination and Notification Methods- This is totally based on the type of population present and their mode of acquiring information. Many tools are generally available for warning dissemination and notifications, the tools shall be used in the most efficient way possible. The use of Newspapers, Radio, Televisions, Warning Notices sent to Panchayats and Televisions can be used as a medium of spreading information related to Desert Locust invasions. The information shall be disseminated rapidly trying to cover each and every stakeholder. Dissemination of warnings and forecast shall follow a cascade process, starting from National level and then significantly moving downward in the scale to State, reaching Regional and Community levels. The Warnings shall be disseminated along scale of initial and final alerts. Additional location wise information related to economic mitigation can also be shared beforehand alongside (e.g., right choice of crops to sow for optimum farming, reducing the economic risk of crop damage by Desert Locust). 2. Risk Communication Mode- The choice of Risk Communication mode shall be made by assessing the population and its subsequent types, if possible, notifications shall be issued at all the encompassing levels. Government Notified, Public Notified and Local Community Notified modes can be selected suitably. These notifications shall be time effective and should cover most of the population depending on the functioning area. 3. Community Connection and Response- A successful Early Warning System shall be people and community centered. Ensuring a two-way communication network, Public Awareness

regarding threats and knowing about Appropriate Response Techniques. Community connected Early Warning System helps to reduce losses by allowing people to better protect their assets (crops) on community level. This relatively helps in community empowerment. This sub element makes sure that the system addresses the needs of all members of the community, along with special needs of the most vulnerable groups. Awareness and knowledge of appropriate response techniques play a key role in response. These responsibilities can be undertaken by the suitable institutions. 4. Compensation Strategy- Assessment of potential damage done by Desert Locust invasion shall be accounted and addressed. Suitably, funds shall be allocated to the inflicted groups present (if any). These funds shall be compensated on the basis of the considerations (preliminary and postliminary). Effectively helping victims after an upsurge often requires government action beforehand, by putting victim compensation arrangements in place.

- 4. Response Capability:** - Is the last component of the Early Warning System. This is the centralized knowledge, plans, and inputs needed for timely and appropriate actions by authorities and those at risk. The response element includes the mobilization of the necessary emergency services and first responders in the upsurge area. There is need for both discipline (structure, doctrine, process) and agility (creativity, improvisation, adaptability) in responding to the Desert Locust upsurge. Combining that with the need to build a high functioning teams of Locust Warning Organization (LWO) to quickly coordinate and manage efforts as the upsurge grows beyond the initial areas of Desert Locust activity. This key element includes the sub elements of: 1. Control Strategies and Types- The preventive control strategy for the management of Desert Locusts shall be based on the severity of Desert Locust Activity in the vulnerable areas. The control

strategies shall be sustainable in nature not having adverse effects on livestock and environment. 2. Application of Evidence based Solutions- Attempts to apply previously developed models of solution have weaknesses. New innovative solutions shall be adopted for Locust Control. Studies and Researches on Locust behavior and control strategies should be promoted, effective solutions shall be applied for response across Desert Locust infected area on trial and actual phases. Quality Control solutions shall be adopted to be used in Control Operations. 3. Institutional Partnerships and Collaborations- Implementation of Effective Desert Locust Response plans require coordination across many institutions, organizations and agencies at national to local levels for the system to work effectively. It is important to tackle the hazard with the collaboration of Science, Technology, Community, Government (State and Central level), Private Sectors and other relevant stakeholders. 4. Capacity Development- Capacity is the ability of institutions to perform functions effectively and in sustainable manner. Institutional capacity, which is the ability of institutions to effectively perform response functions in a long-term sustainable manner, sets up a baseline for smooth functioning of Early Warning System for Locust Control in India. Institutional capacities need to be developed to respond to the hazards, capacities also need to be developed by assessing future trends.

6. Discussion

The Desert Locust is a major migratory pest that causes substantial damage to affected areas. Locusts can cause 80% to 100% crop losses across affected areas. As the locust's swarm, they voraciously feed on nearly all green vegetation, including key staple crops such as Bajra, Maize, etc. India frequently battles Desert Locust onslaughts. In the recent Locust outbreak (2020), Desert Locusts caused major damage in Central and Western states of India, with Rajasthan being the most affected.

Tremendous stride has been made by our country in various fields such as space technology and communication, this has opened up several frontiers which were inaccessible in recent past. In this scenario, development and establishment of Early Warning System for Locust Control in India comes into effect. Establishing an Early Warning System for Locust Control in India is of paramount importance. The system is mainly designed to aid the farmers, as they are the most vulnerable community in an area facing Desert Locust invasion. The system is meant to provide timely and meaningful information about any significant Desert Locust Activity in India. Based on the information provided, timely warnings will be generated and disseminated for response and decision making at different levels.

On 12 June 2020, United Nations Office for Outer Space Affairs (UNOOSA) through its UN-SPIDER program and the International Water Management Issue (IWMI) jointly organized a Webinar on Space based inputs for Locust early warning and preparedness. Experts from Indian Council of Agricultural Research (ICAR), Indian Space Research Organization (ISRO) and Water Risk Disasters (WRD) at IWMI, rightly pointed out to create a sound locust early warning system. According to them, Technology alone will not prevent Locust plagues, but when

integrated with field station and locust preventive program aided with sufficient resources can contribute to improving early warning as a means of reducing the frequency of locust plagues. The current study provides information about the Distribution of Desert Locust in Rajasthan, India and also provides a descriptive model for an Early Warning System for Locust Control in India. The study will assist policy makers and the officers of Locust Warning Organization (LWO) in prioritizing resource allocations and taking effective management actions by having a framework to adhere by. Although, Food and Agriculture Organization (FAO) issues forecasts and warnings related to Locust activity on a multi-national level, having an Early Warning System that is indigenously developed, using the Open Government Data (OGD) is a major achievement for the nation itself. Besides, India is capable in every way to develop and establish its own Early Warning System for Locust Control. The recent Locust Attack (2020) emerged as an agrarian disaster for the nation. This brings out the limitations in current management system for Locust Control, and indicates towards the requirement of innovation and reforms in the scenario.

The study demonstrated the vast area of the state of Rajasthan, India as the Study Area, adhering to the Temporal Scale beginning from 1st June 2019 and going to 31st August 2020. The study also takes into account the Environmental factors like Temperature, Rainfall, Soil Moisture and Prevalence of Vegetation which significantly affect the Locust Activity. Prevailing Environmental conditions heavily determine the Locust Activity in a region (hatching and survival of eggs). Choropleth Maps have been designed for the Environmental Factors. A total of seven maps have been generated showing Average (district wise) Indices for the Environmental Factors. The results indicate that the Locust Activity increases gradually from East to West. A choropleth map showing the areas (at district level) of high, moderate and low vulnerability has

been made for the same. The maps generated in the present study could possibly guide officials to undertake focused and cost-effective monitoring methods. The study further puts forward the model for Emergency Warning System for Locust Control in India and explains its key elements and sub elements under the key elements. The four key elements were: Risk Knowledge, Monitoring and Warning, Dissemination and Communication, and Response Capability.

However, there are some limitations to the study. Average values were calculated and used for map generation for all the Environmental Factors. An average is a single value representing a group of values, concrete interpretations of averages require technicality with greater possibility of jumping to wrong conclusions. The Desert Locust Suitability Sites were visualized. Although, data visualization helps in delivering data in the most efficient ways possible, there are many problems related with the concept of data visualization, for example, e.g., human limitations, structural errors and limitations, etc. Keeping this in mind, easy to understand maps were created and explained accordingly. No statistical analysis was done for the data of Environmental Factors. The rich quantitative aspect of the study was ignored to demonstrate and express the qualitative aspect.

Swarm control operations are generally conducted during day time, but night time control is a significant potential alternative. Special emphasis shall be given to highly and moderately vulnerable areas generated in this study.

7. Conclusion

The study showed the Distribution of Desert Locust in Rajasthan, India and further put forward a descriptive model for establishment of Early Warning System for Desert Locust Control in India. The Distribution of Desert Locust in Rajasthan, India was done by showing the Desert Locust Occurrence records from 1st June 2019 to 31st August 2020. Significant Environmental Factors which affect Locust Activity were also considered. Factors like: Temperature, Rainfall, Soil Moisture and Prevalence of Vegetation were taken to give reasons behind Distribution of Desert Locust in Rajasthan, India. The Environmental Factors were taken in context of the Study Area and the Temporal Scale.

In Future Work, a similar or likewise study can be carried out for the whole country by taking a greater number of Environmental Factors affecting Locust Activity. The Early Warning System for Locust Control in India can be refined by addition of more key elements and sub elements. The model for Early Warning System for Locust Control in India has been designed and formulated in such a manner that it can be used for other disasters also, a study can be conducted describing the operational use of Early Warning System for Locust Control in India using real time geographic area, involving described communities and institutions. Locusts outbreak prediction and monitoring can be modelled using ecological niche approaches. Environmental (or ecological) niche models (ENMs) are a class of methods that use occurrence data to make a correlative model of the environmental conditions that meet a species ecological requirement and predict the relative suitability of habitat. A possible similar study can be carried out using the current paper's Data methodology and results.

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