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Full Length Research Paper

An analytical assessment of brick moulding processes and its impact on local ecosystems, biodiversity, environment and human health in a rural Zimbabwean village

Vitalis Goodwell Chipfakacha

School of Sciences and Technology Health Systems, Botswana Open University, Gaborone, Botswana.

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Climate change, environmental degradation, loss of biodiversity, changes in the ecosystem and disasters play an important role in the development and economic advancement. In Zororo Village, Zimbabwe, environmental degradation, changes in the ecosystem and biodiversity have occurred rapidly during the last few decades. A literature review, key informant interviews, and focus group discussions were the methodologies used for this research. All the participants agreed that environmental changes had occurred during the last few decades, however, they could not connect these to activities such as brick moulding. Brick moulding is a lucrative and economic backbone of many communities in rural Zimbabwe and other Southern African countries. It is a way of value adding to the clay deposits for economic development but the practice is associated with various environmental challenges linked to the various stages in the brick production process. The process impacts on the environment, ecosystem, biodiversity and human health. Vegetation, indigenous trees, edible insects, small animals and wild fruit trees have disappeared from the environment. Children and domestic animals drown in uncovered holes which also become breeding sites for mosquitoes and other vectors. This article discusses community contributions to the negative impacts of environmental degradation, changes in the ecosystems, biodiversity and human health, through the destruction of anthills in the process of brick moulding in rural Zimbabwe.

Key words: Brick moulding, kiln, climate change, communities, disasters, anthills (mounds), health impact, sustainable livelihoods, vertical shaft brick kiln.

INTRODUCTION

During all winter seasons, rural communities in Zimbabwe and other Southern African countries destroy many anthills/mounts in order to make clay bricks either for sale or for their own consumption in building infrastructure. Brick moulding commences with land clearing, followed by excavations of the clay materials, moulding and baking

E-mail: vitalisgoodwellchipfakacha@gmail.com. Tel: +267 71 85 9993.

bricks in kilns. Massive tree and vegetation cutting is a normal practice in brick moulding during site clearing and wood is the preferred method of the brick-making process. There is a resulting loss of animal and insect habitat. Most rural brick kilns are fired by wood whilst commercial brick moulders use coal-fired kilns. Coal is a non-renewable energy source. Deforestation and carbon dioxide emissions have further indirect effects on the ecosystem and climate. In the rural areas fire may be used in the clearing of targeted anthills, and the collateral damage is the burning of whole veldts resulting in carbon dioxide emissions. The pits that develop during excavation collect water during the rainy season becoming breeding grounds for pathogens and vectors such as mosquitoes, which may cause malaria and dengue fever, and can also cause the drowning of animals and humans. Anthills are also a supply chain for some very nutritious foods for the communities, including termites, white flying termites, wild fruits, and small animals that hide in their undergrowth, destroying the anthills plays a role in limiting food availability (Calvalcanti, 2015; Van Huis, 2017). It is important to note that the bricks are from clay deposits that occur in the solum. The solum is the part of the soil profile that constitutes the top and sub-soil horizons both of which are important for agriculture and the ecosystem (Herald, 2017). Mounds (Anthills) and soils of termite have numerous functions in African communities. These include geochemical properties, making bricks, plastering houses, making pots, and use as fertilisers (Van Huis, 2017). Geophagy (the practice of eating soil) especially among pregnant women is an important practice on the African continent (Van Huis, 2017). Mounds are also used as important burial places. Anthills play a very important role in the economies of communities in most African countries. They provide food such as vegetables, termites and other insects with high micronutrient and protein content (Srivastava et al., 2009). The soil is also used as fertiliser for fields and small gardens that communities use for their daily foods (Macheka et al., 2018). They are also very important for the environment because of the vegetation and trees that grow on them. In most countries of Southern Africa, they are the source of bricks for the villagers and in poor communities, people mould bricks using these same anthills thereby making money for sustenance as shown in Figures 2, 3 and 4. In the past, communities applied good conservation practices by using only parts of the anthills allowing them to reform. However, the current practice is to completely destroy the anthills creating negative environmental impacts and accentuating climate change impacts. Figures 3 and 4 show how anthills are stripped of vegetation and trees.

The destruction of the anthills also causes the migration of termites and other insects. Termites have been delicacies in most African societies for centuries. They contain many micro-nutrients including Iron which would be a very good source for people to avoid anaemia which is a big problem in the region (Costa-Neto, 2005a). Crickets which have a high protein content also migrate when ant-hills get destroyed. These are also cuisine in most communities, other insects also edible will move away. These termites and insects are usually harvested especially in summer and are free of charge since anyone can lay the traps. With the destruction of anthills, this source of food also disappears and the poor lose some of the easily available food sources. This definitely has a health impact on nutrition amongst the poor when malnutrition is already a problem in most communities. Some of the insects also have medicinal values that are lost by the destruction of anthills (Calvalcanti, 2015; Costa-Neto, 2015a, b). Some edible vegetables are also found on some anthills. These vegetables are of great nutritional value to the rural and poor folk.

Figure 1 shows an example of excavated holes that are never filled and are left in the ground, whenever bricks are made. These holes during the rainy season, become reservoirs for stagnant water, which in turn become breeding ponds for mosquitoes. This increases morbidity and mortality due to malaria. In countries with collapsed health systems, these ponds increase not only the burden of disease but costs to the health system. This could be avoidable if only bricklayers could use the broken brick to fill these holes so that they do not accumulate rainwater. Council environmental and health departments should play a role in behaviour change through communication and mobilization of affected communities. Community and opinion (elder) leaders could also assist because the negative consequences have an impact on the social and health well-being of their people. Figure 5 shows an anthill half destroyed with plenty of clay bricks ready for being burnt in kilns. At the end of the day this whole anthill will be completely destroyed. This labour-intensive work is done mostly by jobless youths and women in the villages to make brick to sell to those constructing buildings within and outside the villages. Brick moulding only takes place during the winter months that stretch from March to the end of August. As soon as the rainy season comes around September, the excavated areas become reservoirs for stagnant water and breeding grounds for mosquitoes.

Bricks only become strong after being baked red. A kiln is built for this purpose and firewood is needed (Figures 6, 7 and 8). Big logs are needed for this purpose and in abundance since burning may take up to 12 h. This requires plenty of firewood most of which is cut from forests that have lost plenty of trees already. In most instances, anthills are cleared of any trees they may have, not only to pave way for brick moulding but the wood will also be used to burn the bricks. Many forests have been decimated due to this process that takes place every winter. This naturally will have a major impact on climate change. Unfortunately, most communities do not connect the felling of trees to climate change and its negative impacts.

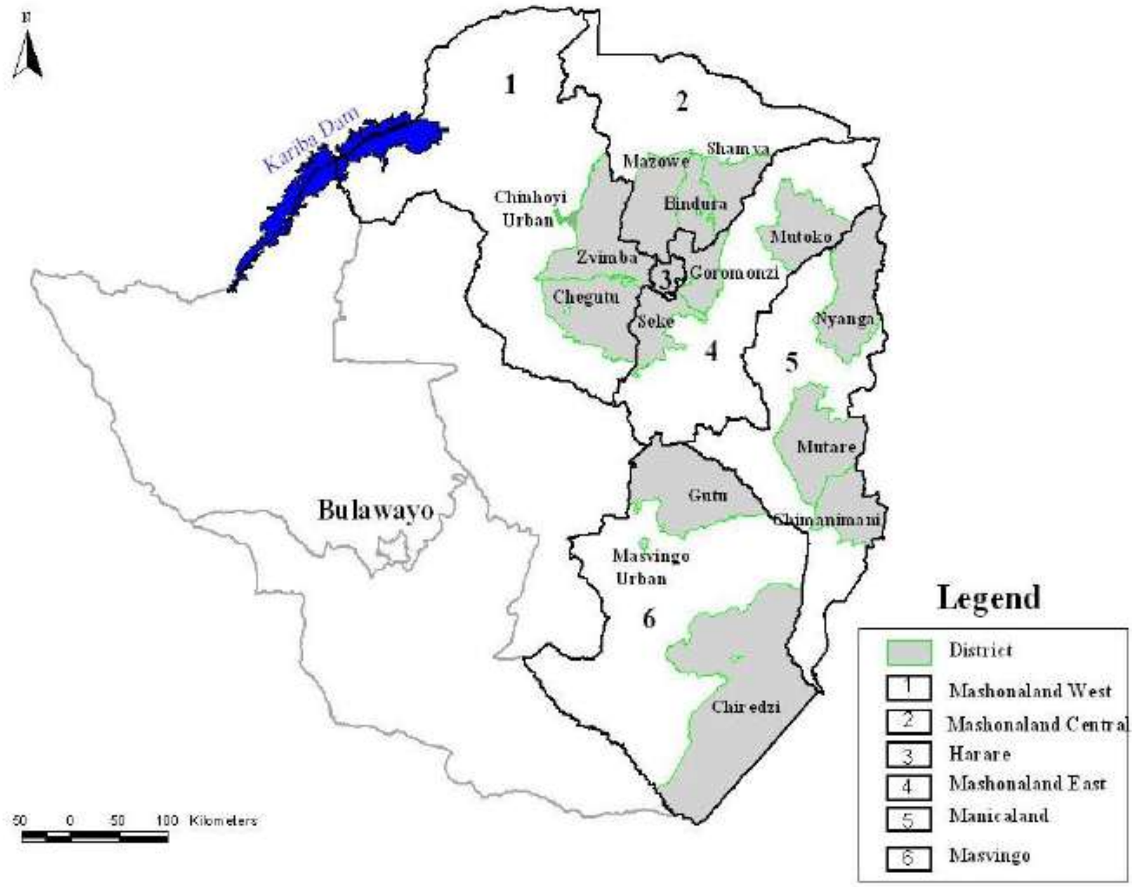

Figure 1. Provinces and districts chosen for the studies on plant virus knowledge and perceptions by stakeholders in Zimbabwean agriculture. The provinces are numbered 1 to 6 while districts are shaded grey.
Source: Charles et al., 2017

Figure 2. Termite Mount (Anthill) being prepared for brick moulding.
Source: Author

Figure 3. Termite mound (Anthill) totally stripped of vegetation including trees.
Source: Author

Figure 4. Dug out holes/excavations that are let unfilled.
Source: Author

Figure 5. Moulded clay bricks before they are baked in kilns.
Source: Author

Figure 6. Example of a Kiln for baking moulded brick.
Source: Author

Figure 7. Fired used as energy source for baking bricks to make them stronger.
Source: Author

Figure 8. Burning of bricks to make them brown/red and stronger.
Source: Author

LITERATURE REVIEW

Very few articles have been written and published on the impact of both rural and commercial; brick moulding in Southern Africa. There was a very good piece on the subject matter in the business section of the Zimbabwe Herald on the 10th of May 2017. Interesting, no comments were made on this piece as if it was a negligible problem. Many studies have been done in both South Africa and Uganda on the brick moulding but most have been concentrating on the strength of the bricks or how they conserve heat on the resultant buildings (Perex, 2009). However, a paper in Sustainability by Hashemi et al. (2015) mentions the environmental impact of brick moulding although the paper concentrated on construction methods and materials in low-income tropical housing. A study by Macheka et al. (2018), in the rural Chivi District of Zimbabwe, shows the impact of mining of sand and clay for brick moulding, illegal mining and cutting down of trees for firewood harvesting on the environment. The paper concludes that poor people have resorted to various environmentally hazardous activities as a means of earning livelihoods.

A 2021 article from Chembe, Malawi by Mahdjoub et al. (2021) suggests that instead of using clay soil, communities could use stockpiled and unsorted crushed post-consumer waste glass as partial aggregate replacement in burnt or fired clay brick. This would actually preserve anthill/mounts and is a way government could invest into for their communities. Whereas in the developed North, circular economy strategies such as landfill mining, urban mining, and recycling have contributed to sustainable resource recovery and reuse, this is not the case in the developing South (Mahdjoub et al., 2021).

Research into this should be encouraged, however, this needs investment by local authorities into engineered landfills or even consolidated dumpsites. Anaikaiye et al. (2021) argue that the use of locally available materials such as clay from riverbeds and anthills, firewood from a nearby forest or waste products from agriculture makes the brick-making process cheap and contributes positively to the socio-economic status of brick moulders. However, the low-cost firing technique contributes to emissions that are detrimental to the health of the brick moulders and the environment. The green method of brick production which entails recycling of industrial wastes would enhance the development of a sustainable environment (Anaikaiye et al., 2021). The gradual transition from traditional techniques of brick baking to an environmentally friendly technology is necessary. Research in South Africa has shown that the establishment of a community-owned energy-efficient kiln such as the vertical shaft brick kiln (VSBK), serving as a source of employment for local brick makers would go a long way in reducing emissions associated with brick production. The VBSK has been shown to be highly efficient, energy saving and environmentally friendly compared to other modern technologies (Anaikaiye et al., 2021).

This paper looks at the environmental impact of brick moulding in Zororo Village, Seke District, in Mashonaland East, Zimbabwe and other southern African countries including the impact on vector borne diseases and nutrition. It also discusses ways to mitigate some of the impacts on the environment, ecosystem, biodiversity and health.

Objectives of the study

The following were some of the objectives of this study:

(1) Assess the knowledge of communities and local authorities on changes in the ecosystems and environmental degradation, and the roles of their activities such as brick moulding play.
(2) Assess whether communities are observing the changes in ecosystems, biodiversity and changes in climatic conditions particularly rain patterns
(3) Assess whether brick moulders and wood harvesters understand the impact of their activities on the ecosystem, biodiversity, environment and health of the communities
(4) Develop responses to the negative impacts of the activities of communities on the ecosystems, biodiversity, environment and health including capacity building of communities using their own indigenous knowledge.
(5) Develop recommendations for national, district and local levels to counter the negative impacts of some local activities that impact on the ecosystem, biodiversity, environment and health of communities.

Description of the study area

Zororo Village, as shown in Figure 1, is one of the several villages that are part of the Seke District Council which is Mashonaland East in Zimbabwe and falls under Chief Seke. The village is 30 km from the Capital City of Harare and 10 km from Chitungwiza which is one of the biggest townships under Greater Harare. The village is separated from the commercial farmlands on the East by the Manyame River and on the West the Masikandoro River. These rivers only flow during the rainy seasons if there are enough rains, whereas 10-20 years ago they flowed all year round. Figure 1 shows a sketch of Seke District under which Zororo Village falls. The last 20-40 years have seen major environmental and ecological changes to the study area (observed by the Author who grew up here). The area has become semi-arid with sandy soils and very little and sporadic rainfall. Several species of trees including Msasa tree/*Brachystegia spiciformis* (Zebrawood), tsubvu tree/*Ziziphus abyssinica* (Smelly

Table 1. Categories of community members interviewed during the research study.

Category of community member	Numbers	Male	Female
Village elder	21	13	08
Brick molders	69	60	09
Wood harvesters	23	20	03
Others including politicians and local government employees	15	07	08

Source: Author

berry fingerleaf fruit tree), mazhanje/*Uapaca kirkiana* (wild loquat) to name but a few have disappeared from the environment. This also has been followed by the disappearance of edible and non-edible insects, such as mandere or chafer beetles, tsambarafuta/*Carebara vidua*, gurwe/*Brachytrupes membranaceus* (tobacco cricket) and termites, to name just a few. Whereas, in the past, villagers would go hunting for wild small animals such as rabbits, kudus and springbok, there are no more trees and vegetation for cover and food. The young children of today only hear the names of most of these trees, insects and small animals from their elders but can only see them either at zoos or in their books.

MATERIALS AND METHODS

The destruction of anthills/mounts in the rural village at an alarming rate during the last 5 years was observed and decision was made to research the negative impacts of the brick moulding production, which was responsible for the destruction of these anthills. To generate sufficient evidence to fulfil this research the methodological approach combined a desk review and application of qualitative techniques to obtain information from various sources that include traditional leaders, elders from the village, brick moulders, local council officials and local political leaders. Focal group discussions were held with brick moulders, their assistants and harvesters of wood. A questionnaire was developed for key informant interviews which were held with councillors, elders, etc. Fieldwork consisted of FGDs with brick moulders and harvesters of wood. The desk review of literature on brick moulding using clay from excavations of anthills was mostly done on the SADC region.

RESULTS

Table 1 shows the category of people who either answered questionnaires or were part of the focus group discussions. This was an unstructured methodological approach in the sense that the researcher could ask any villagers met on the way a few questions as just a conversation. This was made easy because the researcher was from the village and virtually everyone knew him. One of the questions asked to the elders was to state some ecological and climatic changes in the last 20-40 years; all of them mentioned the disappearances of certain trees and vegetation, the disappearance of certain edible insects and small wild animals including hares/ rabbits, kudus, springbok, etc. They also mentioned the disappearance of several wild fruit trees. Women were found to be more observant than their male counterparts, this might be because they are responsible for subsistence farming and gathering of wild fruits and edible insects. Most of the brick moulders and wood harvesters were young people, most of whom had secondary education. They understood the issue of climate change from their social studies at schools; but had the misconception that it is the problem of industrialized countries where there is a lot of pollution and commercial agriculture on a larger scale. They did not connect the felling of trees and destruction of anthills/mounts with the negative ecological and environmental observations, everyone seemed to be noticing. Politicians seemed to be the least informed about climate change and its negative impacts; one had the audacity to say, “These are tricks of the opposition parties to confuse communities”. Local government employees responsible for both health and the environment showed the least interest, in fact, they seem to politicize the issue. Politicization is a weapon used by many people in order to curtail a conversation on something.

It was disappointing to find out that there were no community based organizations (CBO) and non-governmental organization (NGO) assisting communities on climate change and the environment, most respondents felt that it is because of bills passed by the government (Private Volunteer Organization Bill) that made it hard for NGOs to operate in rural areas. Some chiefs insist that any NGOS or CBO to operate in their area must have permission from them, which in most cases is impossible to achieve.

DISCUSSION

The youths who do most of the brick moulding are educated and understand the issue of climate change, however, most of them have the misconception that negative climate change impacts are caused by big industry emissions, vehicles and animal husbandry. Further, they were of the opinion that the impact is currently being felt more in industrialised countries than in Africa. When they were asked whether their activities could play a role in climate change, they felt it was too small an industry to cause a major impact although the felling of trees was something, they observed had caused desertification in some areas. It was interesting however to note that older people, were of the view that the whole anthill should not be utilized so as to allow termites to rebuild it back as good ways of conservation. Older people felt that the young generation did not understand that their activities were destroying nature with no replacement. It is also interesting to note that the older people can talk about how weather and environment has changed, although not connecting it to some of the activities such as brick moulding. The older people however like everyone else mentioned that the cutting of trees has had a major impact on subsistence farming. The elders have also noticed the disappearance of fruit trees, vegetables, insects and small animals of “their time”. This definitely has had an impact on nutrition. It was disappointing to note that Council Officials seemed not to be concerned and worried about the impact of brick moulding with some of them saying it is an old age activity. Local politicians and local government employees do not take issues of the environment as a priority, they seemed oblivious of what was happening around them are and not interested in the issues of the ecosystem and the environment. This is unfortunate since these are the cadres who could develop the relevant policies and encourage capacity development of communities on relevant issues around the impact of climate change and environmental degradation.

Poverty plays an important role in the destruction of the environment in many African countries (Macheka et al., 2018). As income generating projects, brick moulding, selling firewood and charcoal is big business where many trees and anthills are destroyed with little chance of recovery. Many indigenous foods such as mushrooms, small animals like rabbits and kudu, termites (Shona: Ishwa), red ants (Shona: majuru) and the white ants (tsambarafuta shona, Zimbabwe), vegetables such as *Brassica carrinata* (Shona Zimbabwe: chembere dzagumana) and wild okra or *Corchorus asplenifolius* (Shona Zimbabwe: derere), honey from honey-pot ants (Shona: huchi whe monga), cleome gynandra (Shona: Nyevhe), etc., are also completely destroyed. These foods are easily accessible and available to most members of the communities especially the poor members of communities. In Southern Africa there are mainly three types of malnutrition: under-nutrition which includes stunting, wasting and underweight, overweight including obesity, and micronutrient deficiencies, including deficiencies of Vitamin A, Iron, Zinc and Iodine; entomophagy which **is** the practice of eating insects as part of human diet has played an important role in the history of human nutrition in Africa, Asia and Latin America (Srivastava et al., 2009).

In most African societies, *Macrotermes bellicosus* stands out as the species used in diets. *M. bellicosus* has a very high content of calcium and iron, whilst Pseudacanthotermes militans (P. militans) has highest zinc content (Kinyuri et al., 2013).

Thus, termites eaten by African communities have high levels of micronutrients, proteins and unsaturated fatty acids (oleic and palmitic acids) (Kinyuri et al., 2013). Another important use of insects by humans is medicinal which is called entomotherapy (Costa-Neto, 2015a; Srivastava et al., 2009). In Nigeria, *Macrotermes nigeriensis* is used as a medicine against anaemia (Calvalcanti, 2015).

Furthermore, the disappearance of vegetation cover has an impact on the feeding patterns of domestic animals such as goats, sheep and cattle. These are the very subsistence economies of the poor village communities. Another problem associated with leaving behind open holes/excavations has caused the drowning of small children in these pools of water while trying to learn how to swim. Many small livestock were also drowned either whilst trying to drink water or in other accidents. Snakes which control the mice population which destroy cereals and other foodstuffs are also disappearing. Deforestation plays an important role in the increase of green gases by increasing carbon dioxide content in the atmosphere (reduced photosynthesis).

Destruction of forest resources which include fruit trees such as Marula deprives communities of nutritious foods and commercial activities (Tiritose.com). Tables 2 and 3 show the insects and fruit trees destroyed after destruction of anthills whilst making bricks.

Research in many countries has shown that plums are very nutritious; both plums and prunes are sources of vitamins, minerals and antioxidants (Perex, 2009). Other researches have also shown that sour plum for instance is rich in Vitamin A, very high in antioxidants compared to many fruits, high in potassium, also contains b-carotene iron, and vitamin K (Scrivener.co.zw). One cup of plums gives 87% of body recommendation of Vitamin K, 8% of calcium, 72% of B vitamins and 27% potassium (Calvalcanti, 2015; Scriventer.co.zw).

Masawu (Jujube) was originally an Indian fruit but is now available in Southern Africa: a 100 g of jujube contains 79% calories, 1 g proteins, 20 g carbohydrates, 10 g fibre, 77% of daily value (DV) vitamin C and 5% potassium D (Healthline.com and India Today). Matohwe is rich antibiotics, antifungal, antioxidants, anti-hyperglycemic, and good in absorbing iron (Wikipedia). Matamba (African Monkey Oranges) according to recent research contains the following: Calcium 56, Magnesium 49, Potassium 1370, Sodium 21.7, Iron 0.11, and Zinc 0.22 (Pinterest). Mukwakwa (Black Monkey Orange) is another indigenous fruit eaten in most Southern African countries, its skin contains a high level of Oleic Acid, however, its seeds contain a high level of strychnine which is poisonous (some communities use it to catch fish) (Fruitsinfo.com).

Another common rainy season fruit is muonde (common cluster fig), also very common and eaten in the

Table 2. Indigenous edible insects disappearing due to destruction of anthills

Shona name	English name	Nomenclature
Makurwe	Sand Crickets	Gryllidae
Tsambarafuta	Tree ants	Carabera vidua
Ishwa	White flying ants	Macrotermes falciger
Mandere	Christmas beetles	Eulepida masnona/anatine
Majuru	Soldier ants	Macrotermes goliath
Madora	Mopane worms (caterpillars)	Gonimbrasia belina
Mhashu	Locusts	Locusta migratoria
Harugwa	Stink bugs	Haplosterna delagorguei
Chikudyu	Black cricket	Acheta gryllidae
Madumbudya/dandamafuta	Long-horned grasshopper	Ruspolia nitidulus/differens

Source: Scrievener.co.zw: Top 8 edible insects in Zimbabwe (Scrivener.co.zw)

Table 3. Indigenous fruits trees disappearing due to deforestation

Shona name	English name	Nomeclature
Nhengeni	Sour plum	Ximenia Caffra
Nhunguru	Governors plum	Flacourtia Indica
Hacha	Mobola plum	Parinari Curatellifolia
Nyii	Bird plum or African sweets	Berechemia discolor
Tsubvu	Smelly berry	Vitez mombasae
Masawu	Jujube (Indian)	Sishiphus jujube
Matohwe	Snot apple	Gorona tula
Matamba	African monkey oranges	Strychnos spinose
Mukwakwa	Black monkey oranges	Strychnos madagascariensi
Muonde	Common cluster fig	Ficus racemose
Mushuma	Jackal berry	Diospyros mespiliformus
Matufu	False Wild medlar	Vangueria infausta
Mupfura	Marula fruit	Sclerocarya birrea
Tsambatsi/Tsombori	Wild grapes	Vitis Vinifera
Hute	Water berry	Syzygium cordatum
Mazhanje	Wild loquath	Aupaca Kirkina

Source: Tiritose.com: Wild Fruits in Zimbabwe (Tiritose.com).

Southern African region. This plant is not only nutritious but has medicinal qualities 100 g of common cluster fig contains 81.9 g of water, 1.3 g of proteins, 0.6 g of total fat, 0.6 g of ash, 0.21 g of nitrogen (no carbohydrates), 37.77% of vitamin B2, 16.2% of iron, 11.11% of copper, 10.81% of potassium, 8.33% of magnesium, 7.20 calcium and 6.71 phosphorous 15 (Calvalcanti, 2015). Common cluster figs also have medicinal qualities including phytochemicals for the prevention and management of muscular pains, pimples, boils, cuts, haemorrhoids, anti-diabetic, antioxidant, ant-asthmatic, ant-malarial, anti-diarrhea, anti-pyretic and the juice from Muonde is used to treat hiccups (Calvalcanti et al., 2015).

Mupfura (Jackal Berry), contains ascorbic acid, calcium, carbohydrates, water, iron, phosphorous, fibers, riboflavin, saponins, fat, magnesium, proteins, tannin, niacin and Vitamin B group. Mupfura also has very important medicinal properties: the leaves, the bark and roots contain tannin which is used as a styptic to staunch in bleeding (Healthline, Pinterest.com and Tiritose.com). The roots are also consumed to purge parasites and are thought to be a remedy for leprosy. It is also used in dealing with boils (abscesses), as an analgesic, as treatment of bronchitis and as a local antibiotic.

Whilst poor people suffer more through the negative impacts of climate change, in Africa they also play an important role in causing it albeit on a small scale. Although the old people may not talk confidently about changes in weather and climate variability as compared to "their time", they do not understand the causes thereof.

Not only are there no programs to capacitate them but the literature on climate change and its impact is out of reach of them.

Conclusion

The negative impacts of climate change have become a global problem and the effects can be observed on the African continent. Communities in Africa are lagging behind other continents in understanding the roles they play in creating some of the causes of climate change. There is, therefore need to capacitate communities, politicians and local authorities on the negative impacts of some of the activities on the ecosystem, biodiversity, environment and health.

Governments should develop behaviour communication strategies on climate change and also adopt some of the approaches suggested by the Intergovernmental Panel on climate change (IPCC) (IPCC Report, 2013). These approaches would include prioritization and adaptation of efforts for local levels in communities where vulnerability is highest, prioritizing the strengthening of existing capacities at the sub-national levels and leveraging the opportunities in disaster prevention and response, to promote effective community-based adaptation and risk reduction (IPCC Report, 2013).

The Government of Zimbabwe and governments in the SADC region should develop climate change strategies that include education, training and public awareness on climate change for a good community response. There is a need for the production of environmental education fact sheets for communities, preferably in the vernacular languages. These should have been disseminated to the villages, schools, churches, etc. Capacity building on climate change and disasters is required at all levels in society and particularly at the village or local levels.

It is clear that the current anthill/mount utilisation by communities is not sustainable. To ensure sustainability utilisation should promote mount restoration by termites, by adopting indigenous methods of utilising only half of the mount and leaving it fallow so as to allow termites to migrate and build back. Unfortunately, the young generation now utilising the mounds does not understand and practice this.

The recommendations may assist countries and communities to respond better to the negative impact of climate change, environmental degradation, changes in the ecosystem and loss of biodiversity.

RECOMMENDATIONS

(1) Commercial clay bricks should be moulded at designed sites; operators should be given a licence after doing an environmental impact assessment and the site inspected regularly by environmental authorities. The local authorities and government can give grants to youths to start such programs as income generators.

(2) Apply positive indigenous/traditional approaches like harvesting only half of the anthill and then leaving it for a few years to recover. There is also need for regulation by rural district authorities; it might be necessary to issue licences and do regular inspections of brick moulding sites by environmental officers to ensure open sites are filled and restored. Currently, no one seems perturbed by the rate of destruction, including the killing of termites, clearing of vegetable cover and creation of mosquito breeding ponds which in the long run affects the health of local communities. Indeed, most rural were actually surprised and amazed by my queries and enquiries.

(3) Both rural and commercial brick moulders should be encouraged to use efficient heating kilns. In this way, the carbon footprint of the brick kiln heating can further be reduced by using renewable energy such as natural gas, fast regenerating tree species that are re-grown, sawdust and other timber offcuts from other products. Countries on the African continent should share technology skills on brick production which are environmentally sustainable. Green technology should also be encouraged.

(3) Countries should review their Environmental Management Acts/Legislation to include the issues of brick moulding particularly in the rural areas and put in place prevention and mitigation factors. Veldt fires destroy the environment, life and property; rural councils should have legislation and policies that control this as many are started by farmers and also during brick moulding.

(4) There is need for capacity development of communities in Africa on Climate change; causes and negative impacts. Communities need to know the roles they play both in causation, prevention and control. It might actually be necessary to introduce climate change, disasters and related subjects in school curricula so that people know from an early age in life.

(5) There is also need to review policies on climate change to include some of the issues happening at community levels instead of concentrating on traditional Eurocentric issues. Countries should look at indigenous causes of climate change at all levels, national and sub-national and disseminate the results of this information to all levels as well.

(6) There is need to fight corruption at all levels; most local government authorities, traditional leaders and politicians give a blind eye to communities breaking environmental policies and legislations because they are paid bribes. These same leaders need to be capitated to understand the impact of their decisions on both environmental impact and negative impacts of climate change.

(7) Governments, non-governmental organization and other stakeholders in the environmental field and ecosystems need to start capacitating communities on

issues on the environment, ecosystems and negative impact of climate change.

8) Communities need to understand that there is need for change of behaviour and practices that are not (environmentally friendly. There is need by all stakeholders to develop behaviour change communication strategies on the environment and impacts of climate change.

(9) There is need for both national and community based non-governmental organizations to assist government in making communities aware of their roles in mitigation of climate change impacts and skills to assist in preserving the environment and ecosystems. There is need for political dialogue between governments and NGOs since there is a lot of mistrust amongst them which hinders progress; unfortunately, except in South Africa, most governments in the SADC region look at NGOs with suspicion and curtail their activities or ban them altogether.

(10) More research works need to be done on issues pertaining to the roles on communities in the degradation of the environment. This should be done in consultation and collaboration with communities so they understand the subject matter better. Literature on climate change should also be produced in the vernacular languages, and not in English, French, Portuguese, etc.

ABBREVIATIONS

CBO, Community Based Organization; **FGD,** Focus Group Discussion; **IPCC,** Intergovernmental Panel on Climate Change; **SADC,** Southern African Development Community; **VSBK,** Vertical Shaft Brick Kiln.

CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

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Evaluating SWAT model for streamflow estimation in the semi-arid Okavango-Omatako catchment, Namibia

Kaleb Gizaw Negussie[1,2,5*], Daniel Wyss[2], Nichola Knox[1], Miguel Vallejo Orti[1,4], Eva Corral-Pazos-de-Provens[3], and Martin Kappas[2]

[1]Department of Land and Spatial Sciences, Namibia University of Science and Technology, 13388 Windhoek, Namibia.
[2]Department of Cartography, GIS and Remote Sensing, Georg-August University Goettingen, 37077 Goettingen, Germany.
[3]Departamento de Ciencias Agroforestales, Universidad de Huelva, 21819 Huelva, Spain.
[4]Institute of Geography, 3D Geospatial Data Processing Group, Heidelberg University, 69120 Heidelberg, Germany.
[5]Earth Observation and Satellite Application Research and Training Centre (EOSA-RTC), Namibia University of Science and Technology, 13388 Windhoek, Namibia.

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A semi-distributed hydrological model was used for runoff estimation in the Okavango-Omatako catchment in Namibia. The model was configured for a 31-year period from 1985 to 2015. Subsequently, calibration and validation processes followed using the SUFI-2 algorithm. For evaluating catchment simulation, two methods were used: i. model prediction uncertainty measured by *P-factor* and *R-factor* and ii. Model performance indicators, that is, Nash-Sutcliffe Efficiency (NSE), Coefficient of determination (R^2), Percent bias (PBIAS), and Residual variation (RSR). The *P-factor* achieved 0.77 and 0.68 while *R-factor* attained 1.31 and 1.82 for calibration and validation, respectively. The following indicators were used to evaluate the model performance through calibration and validation results respectively; NSE with 0.82 and 0.80, R^2 with 0.84 and 0.89, PBIAS achieving -20≤PBIAS≤-1.1 and RSR performing 0.42 and 0.44. All performance indices achieved very good ratings apart from PBIAS validation which rated as satisfactory. The semi-arid characteristics together with relatively flat terrain features justified the need for the evaluation of model performance using discharge data in our study region. SWAT demonstrated reasonable results in modelling semi-arid streamflow with high and low flows adequately captured. Consequently, this evaluation was necessary for further investigations into impacts of climate change on scarce water resources highlighting the challenges of SWAT model applications in our study area climatic regime and other similar regions globally for further model improvements.

Key words: Stream flow, catchment, semi-arid, SWAT, SUFI-2, calibration, TanDEM-X, Okavango, Namibia.

INTRODUCTION

Hydrological models represent the real-world system in a simplified manner through simulations of water resources (Sood and Smakhtin, 2015). Such models follow complex processes to integrate different spatial and temporal variables to better understand catchment heterogeneity (Mengistu et al., 2019). However, acquiring data that accurately represents these variables is a major challenge. Field data acquisition methods are expensive, time-consuming, tedious and error prone, causing limitations in the measurement of hydrological variables (Al-Sabhan et al., 2003). Over the years, traditional techniques for in-situ observations of precipitation, temperature, streamflow, geohydrology, soil moisture, dam levels, etc. have dominantly provided data for catchment monitoring worldwide (Essou et al., 2017). Such ground-based measurements create limitations based on the spatial distribution of the observing stations, which may insufficiently assess catchment evolution over a large area (Lai et al., 2019; Stehr et al., 2008). Considering these constraints, various hydrological investigations around the world explore the integration of satellite-based data and ground measurements to monitor large and complex catchment behavior (Abbaspour et al., 2015; Hashim et al., 2016; Thavhana et al., 2018). A model is a simplified real world representation of a certain phenomenon applied to predict system behavior and understand processes such as stream flow, droughts, floods, vegetation cover, etc. (Devi et al., 2015). The features of models are defined by the parameters used to represent the reality.

In places where natural disasters (e.g. droughts and floods) occur frequently, hydrological models are vital to characterize various processes in sustainable water resource management (Emam et al., 2017). The Soil and Water Assessment Tool (SWAT), is one of such model capable of simulating water balance in large geographical catchments and sub catchments using a time continuous semi-distributed hydrological model, integrating various parameters like land cover/land use, soil types, precipitation, temperature, topography and climate conditions (Arnold et al., 2012).

Namibia is an arid country located in Southwest Africa with regular occurrence of dry periods. Annual rainfall ranges between ~ 50 mm in the west to over 600 mm in the northeast of the country (Mendelsohn et al., 2006). Taking into account the low rainfall and variability of rainfall within the country, water management is vital to conserve the existing water resources (Palmer et al., 2008). According to the Integrated Water Resources Management report, the country is divided into eleven water management areas, each are further sub-divided into water basins (IWRM, 2010). These water management areas are defined by similar drainage systems of rivers, catchment areas, underground water, water supply lines and canals. One such area is the Okavango-Omatako catchment which extends from Central to the Northeastern regions of Namibia. The Okavango-Omatako water management area also referred to as a “catchment” is comprised of the Omatako-Omuramba and Okavango catchments. The ephemeral Omatako is a tributary to the perennial Okavango. According to IWRM (2010) report, the catchment has indisputable socio- economic importance to activities in proximity to it. Water extracted from the catchment caters to approximately 15% of the Namibian population through livelihood activities such as irrigation, mining, tourism, livestock, etc. Considering this, it is vital to monitor and explore the catchment’s behavior to different variables influencing its dynamics. This study emanated from limited comprehensive assessments exploring this catchment (Mendelsohn et al., 2002; Strohbach, 2008), and its dynamic response to different variables.

Several studies have been conducted since the 1990’s on catchments in Namibia; from investigations of large ephemeral catchments in Jacobson et al. (1995) to small-scale catchment analysis in O’Connor (2001), as well as more detailed work on various individual catchments (Manning and Seely, 2005; Marsh and Seely, 1992; Mendelsohn et al., 2000). Although considerable studies attempted to map catchments in Namibia, according to Strohbach (2008), many have methodological inaccuracies or non-repeatable methodological descriptions. Further, the coarse resolution from freely available Digital Elevation Models (DEM) supplemented with missing data due to atmospheric interference, shadow effects, etc., has created a challenge to unpack Namibia’s hydrological systems and realistically simulate catchment behavior.

To understand streamflow processes, it is essential to evaluate the SWAT model performance (Meaurio et al., 2015), especially when considering large catchments as depicted in this study. To date, no peer reviewed studies have used the SWAT model in the Okavango-Omatako catchment, denoting a general lack of knowledge on hydrological processes in these semi-arid catchments (Strohbach, 2008). To fill the gap, this study evaluated the SWAT model for streamflow estimation using remotely sensed data supplemented by ground observation measurements. It is further imperative to evaluate hydrological models and uncertainty methods in areas with different climatic zones (that is tropical, arid, semi-arid, etc.) (Emam et al., 2018; Rafiei Emam et al., 2015). The semi-arid characteristics of the study site and its relatively flat terrain features justified the need for evaluation of the SWAT model performance using discharge data in an intermediate gauge. Krysanova and White (2015) highlighted the challenges of SWAT model applications in different climatic regimes and specific regions, globally, suggesting the need for several model

*Corresponding author. E-mail: knegussie@nust.na. or kaleb.gizaw@gmail.com.

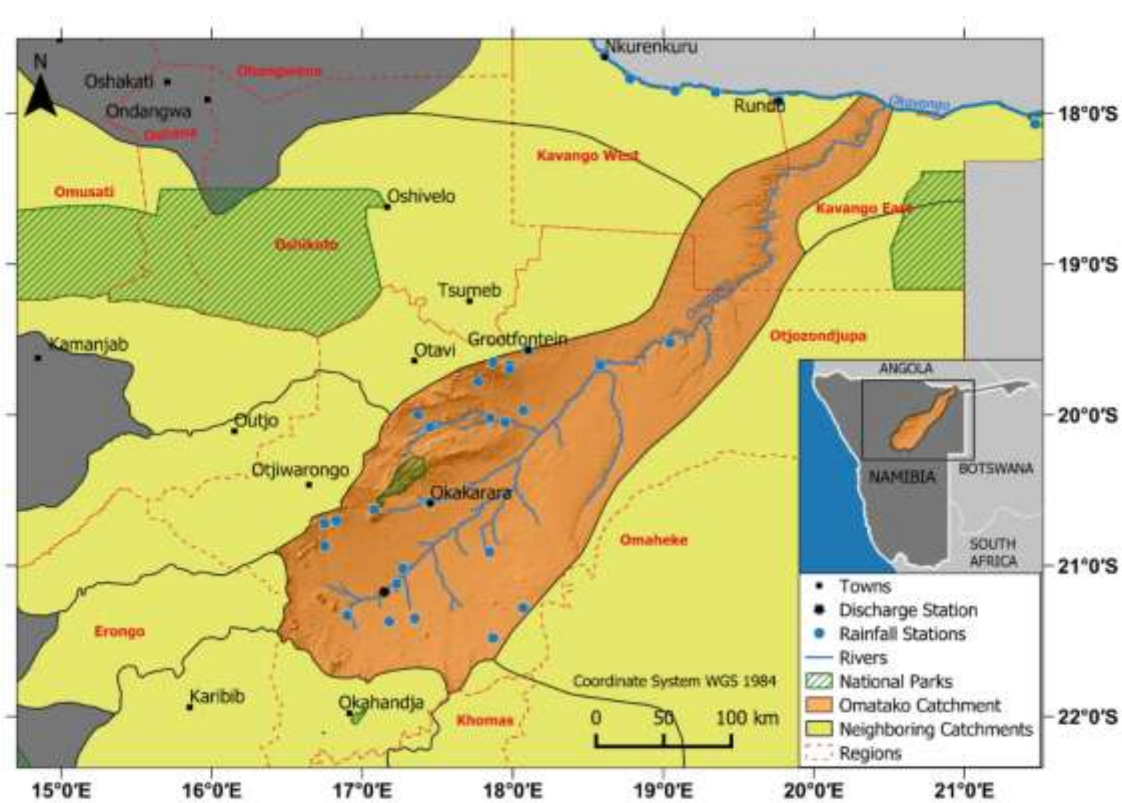


Figure 1. Location of the study area, Okavango-Omatako and neighboring catchments.
Source: Authors

evaluations and improvements. One such area is SWAT applications in regions where water management is crucial due to water scarcity. Estimation of streamflow using historical variables over the semi-arid water scarce environment of the Okavango-Omatako expose catchment behavior, which in turn can be used to prepare short term and long-term water management plans. SWAT depends on the basic units of sub-basins and Hydrological Response Units (HRUs) for streamflow estimation. Due to the study catchment flat terrain, the z-resolution of freely available DEM data is insufficient to generate accurate HRU's, this study therefore used state of the art, high resolution DEM - TanDEM-X (Rizzoli et al., 2017; Wessel et al., 2018). Enhanced knowledge on hydrological processes through modelling improves future investigations on impacts of climate conditions and LULC changes on water resources and management. The study thus supports Namibian National Climate Change Strategies and Action Plan with proposed strategies to counteract impacts of climate change. This includes understanding climate change and its related policy responses, using monitoring and data collection technologies for surface and ground water at the watershed level and promoting conservation and sustainable utilization of water resources.

Study site

The Okavango-Omatako catchment (Figure 1) extends from central to North-eastern Namibia, bordering Botswana to the east and Angola to the north at approximately 74,700 km2 (Strohbach, 2008). According to IWRM (2010), it is one of the eleven water management areas classified along shared drainage systems (that is, aquifers, canals, rivers and pipelines). This catchment is comprised of perennial (Okavango) and ephemeral (Omuramba-Omatako) rivers as well as groundwater. The Omatako dam which has been built on the Omuramba-Omatako ephemeral river and the ground water of Tsumeb, Otavi and Grootfontein Karstveld are major water sources to central Namibia. The main water inflow sources to this catchment are the perennial Cubango and Cuito rivers located in southern Angola. After heavy rains, other ephemeral streams such as Nhoma and Kaudom also join the drainage system of the river basin. The Omatako river is similarly a tributary to the Okavango, however, the contribution is minimal as

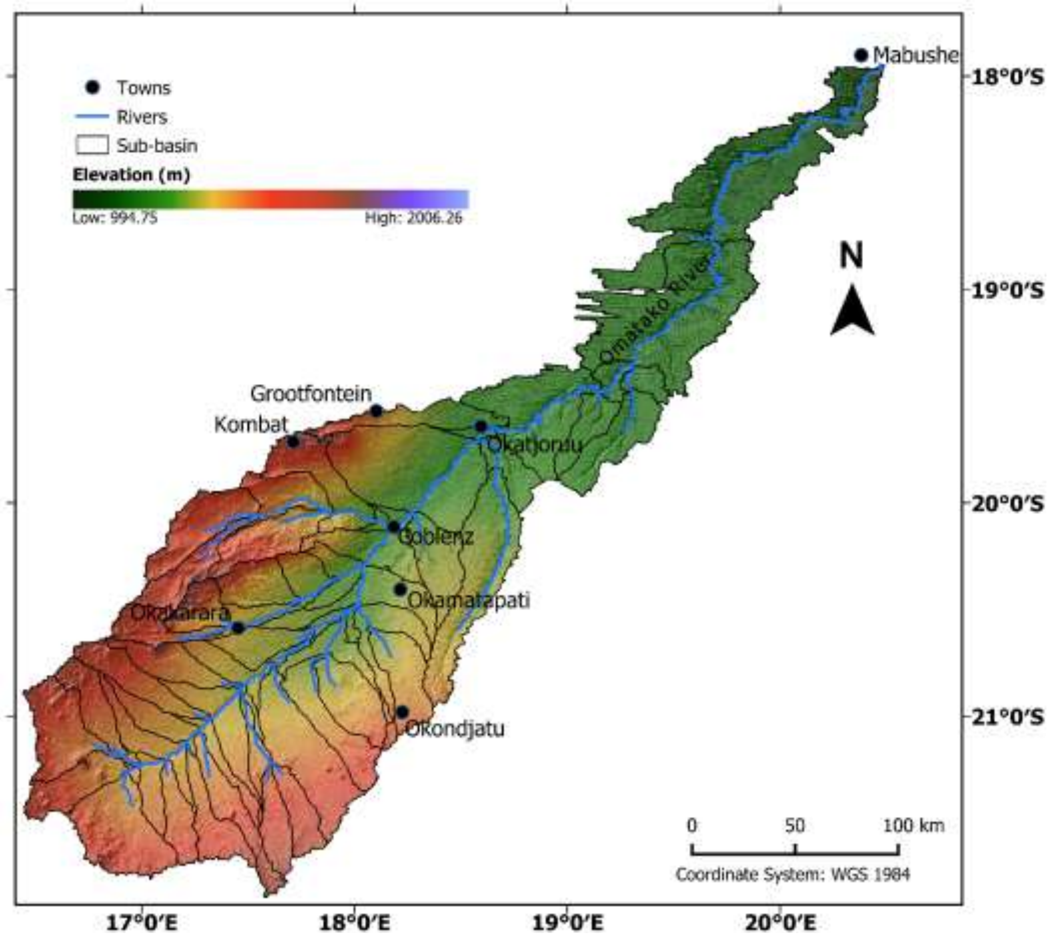


Figure 2. Elevation map showing the 60 sub-basins of the Okavango-Omatako catchment.
Source: Authors

the river originates from the dry central plateau of the Kalahari with limited run off either evaporating or draining into the sand along its course (IWRM, 2010). The catchment's average annual rainfall varies between 300 mm in the west to 600 mm in the north-east with an average loss of water through evaporation between 2,600 and 3,200 mm per annum (Mendelsohn et al., 2002).

The Okavango-Omatako catchment is predominantly a flat sandy plateau categorized as the Kalahari Sandveld landscape (Mendelsohn et al., 2002). Although known for its flat terrain, the sandy deposits form dunes in some areas. The landscape near Grootfontein is known as Karstveld and is Namibia's largest underground aquifers, its elevated terrain receives 550 to 600 mm rainfall annually (Mendelsohn et al., 2002). The highest elevation is observed in the south-west of the catchment with a gentle downward slope towards the northeast where it meets the Okavango valley (Figure 2). The vegetation varies from moderate-dense shrubland in the south west, a shrubland-woodland mosaic towards the center of the basin and a dry woodland-grassland mosaic in the north eastern parts (Mendelsohn et al., 2002).

According to IWRM (2010), the supply of water in Namibia is primarily allocated for domestic use such as livestock farming (communal and commercial). In the Okavango-Omatako catchment, large scale irrigation for, maize, sorghum, cotton and wheat are predominant water consumers, followed by livestock and urban consumption. To a lesser extent, rural domestic consumption, tourism and mining also utilize water from this catchment.

MATERIALS AND METHODS

Data

The data used in this study includes climate data, elevation, soil characteristics, Land Use Land Cover (LULC) and streamflow data (Table 1). Daily in-situ measurements of precipitation and temperature from eight weather stations (Table 1), which cover the

Table 1. Data used and sources.

	Data	Sources	Resolution
1.	Meteorological Variables: Precipitation(mm), temperature (°C), Solar radiation (MJ/m^2), Relative Humidity (%), and Wind Speed (m/s)	Namibia Meteorological Services (NMS) 1985-2015 and Climate Forecast System Reanalysis (CFSR) (Weather Stations: Awagobibtal, Grootfontein MET, Kalidona, Omambonde Tal, Otjikururume, Otjirukaku, Rundu and Simondeum)	Daily meteorological records
2.	Discharge of Omatako Dam (m^3/s)	Hydrological Services of Namibia	Monthly discharge from 1990 – 2008
3.	TanDEM-X Digital Elevation Model (DEM)	German Aerospace Center (DLR)	Relative vertical accuracy of 2 m and a Spatial resolution of 12 m
4.	Land use and land cover (LULC)	Sentinel-2 Products from European Space Agency (ESA) and Directorate of Survey and Mapping (DSM), Namibia	Spatial resolution 10 m
5.	Soil Information	SOTER (Soil and Terrain Database) (Coetzee 2001, M. Coetzee, personal communication, December 6, 2019, Batjes 2004) Updated Soil Map (from Agro-Ecological Zoning)	Scale 1:250 000

Source: Authors

extent of the study area were identified and prepared for the period 1985-2015. While solar energy, relative humidity, and wind speed data were sourced from the Climate Forecast System Reanalysis (CFSR) of The National Centers for Environmental Prediction (NCEP, 2020). Moreover, the internal “weather generator” from SWAT generated missing weather data to fill the climatic gaps. The soil information over the river basin under study was sourced from an ongoing project to update the Soil Map of Namibia (Coetzee 2001, M. Coetzee, personal communication, December 6, 2019). Land use and land cover (LULC) information was derived from the Copernicus Sentinel-2 mission products supplemented by existing information from the Directorate of Survey and Mapping (DSM) in Namibia. The runoff discharge data measured by the Hydrological Services of Namibia at the Ministry of Agriculture, Water and Forestry was solicited for calibration/validation purposes. The following subsections will further discuss the datasets mentioned above in detail.

Digital elevation model

Stream flow simulation is a complex process with several uncertainties arising from input variables, missing assumptions in the model and lack of knowledge on the catchment being modeled (Abbaspour et al., 2007; Rostamian et al., 2008).

Imperatively, while modeling a large and complex catchment as presented in this study remote sensing plays a major role to successfully model streamflow. This is especially valid in data poor countries where lack of frequent high-resolution data is not accessible. For this reason and due to the flat terrain characteristics of the catchment in this study, a high-resolution TanDEM-X product was sourced to improve simulation capacity as recommended by (Archer et al., 2018). Thus, accurate watershed delineation (stream slopes and total length of streams) and HRU definition were achieved in this study catchment which were further used to simulate the streamflow effectively as established by Buakhao and Kangrang (2016) and Tan et al. (2015), where the accuracy of the DEM was sensitive to streamflow.

Due to the flat terrain characteristics of the Namibian Northern regions, elevation data of TanDEM-X from the TerraSAR-X DLR mission was used in the study with a relative vertical accuracy of 2 m and a spatial resolution of 12 m sourced from German Aerospace Center (DLR) (Wessel et al., 2018). According to Archer et al. (2018), Maharjan et al. (2013) and Rizzoli et al. (2017), without the High Resolution Terrain Information-3 (HRTI-3) from TanDEM-X, the study area of relatively flat terrain would not define an accurate watershed to create Hydrologic Response Units (HRUs), which are the smallest representation of the basin used in the simulation of streamflow in SWAT. In Figure 2, the elevation map of the river basin derived from TanDEM-X is displayed together with the generated sub-basins of the study area.

Land use land cover mapping

Land use land cover (LULC) is an essential input variable for simulation of streamflow in the SWAT model. An assessment of global LULC products indicated insufficient detail for runoff modelling purpose, therefore a LULC map was generated for the catchment. The LULC was generated using multiple scenes of Sentinel-2-A data of 2017 acquired and mosaicked from Copernicus Sentinel-2 mission (European Space Agency, 2020). This product further attained the Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI) and Normalized Difference Built-up Index (NDBI) indices to facilitate the differentiation of vegetation, water and built-up areas. Using high

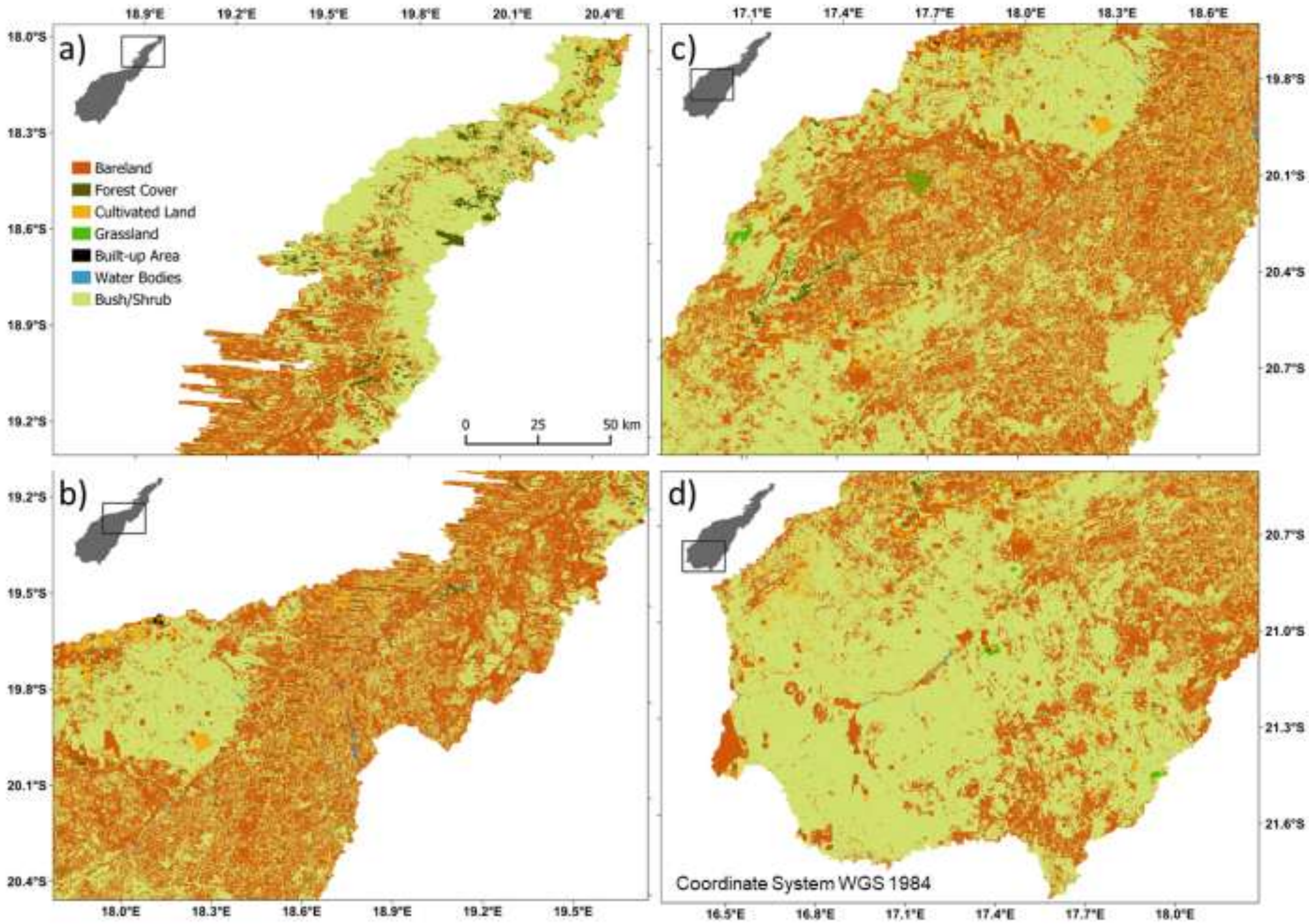


Figure 3. Land Use Land Cover (LULC) map of Okavango-Omatako catchment.
Source: Authors

resolution topographic maps obtained from the Directorate of Survey and Mapping (DSM) for the same timeframe as the Sentinel-2 imagery, seven land cover classes (bare land, forest cover, cultivated land, grassland, built-up area, water bodies and bush/shrub) were visually identified. Using polygons of each landcover classes resultantly, a classification training and validation dataset was derived for these classes. Thanh Noi & Kappas (2017) compared and investigated performances of random forest, k-nearest neighbor, and support vector machine (SVM) classification methods for LULC classification with Sentinel-2 and achieved superior accuracy and consistency in their classification results using SVM. Consequently using ENVI 5.5.1 (Harris Geospatial Solutions Inc, 2020), the SVM algorithm was applied to compute the classification and generate a LULC map (Figure 3) of the interest region. For the independent validation dataset, the classification was validated using a Cohen kappa (K) (Cohen, 1960) and overall accuracy assessment (Congalton, 1991). According to Nyeko et al. (2010) and Rani and Sreekesh (2019), approximately 80% and 0.8 is the overall accuracy and kappa for LULC to be suitable for input into the SWAT model . The classification for the catchment data was performed with an acceptable overall accuracy of 84% and a kappa coefficient 0.8.

Soil mapping

Soil type information plays a major role in runoff estimation.

According to Yang et al. (2008), model variable inputs such as soil data and its resolution has an effect on modelling streamflow in SWAT. The Soil mapping of the study area was performed at the scale of 1:250 000 while most of the samples for the profile descriptions was taken along the study area as demonstrated in (Coetzee, 2001). In this study, soil profile data for the catchment was acquired and significant information was extracted such as texture classes, profile depth, soil types, etc.

Once the watershed delineation of the study area was completed using the boundary of the delineated basin, sixteen soil classes were identified and further categorized into six dominant groups: Cambisols, Regosols, Arenosols, Calcisols, Leptosols and Fluvisols. The soil type distribution over the catchment was mapped as shown in Figure 4. Based on the available soil properties for different soil classes, all required information for the model input

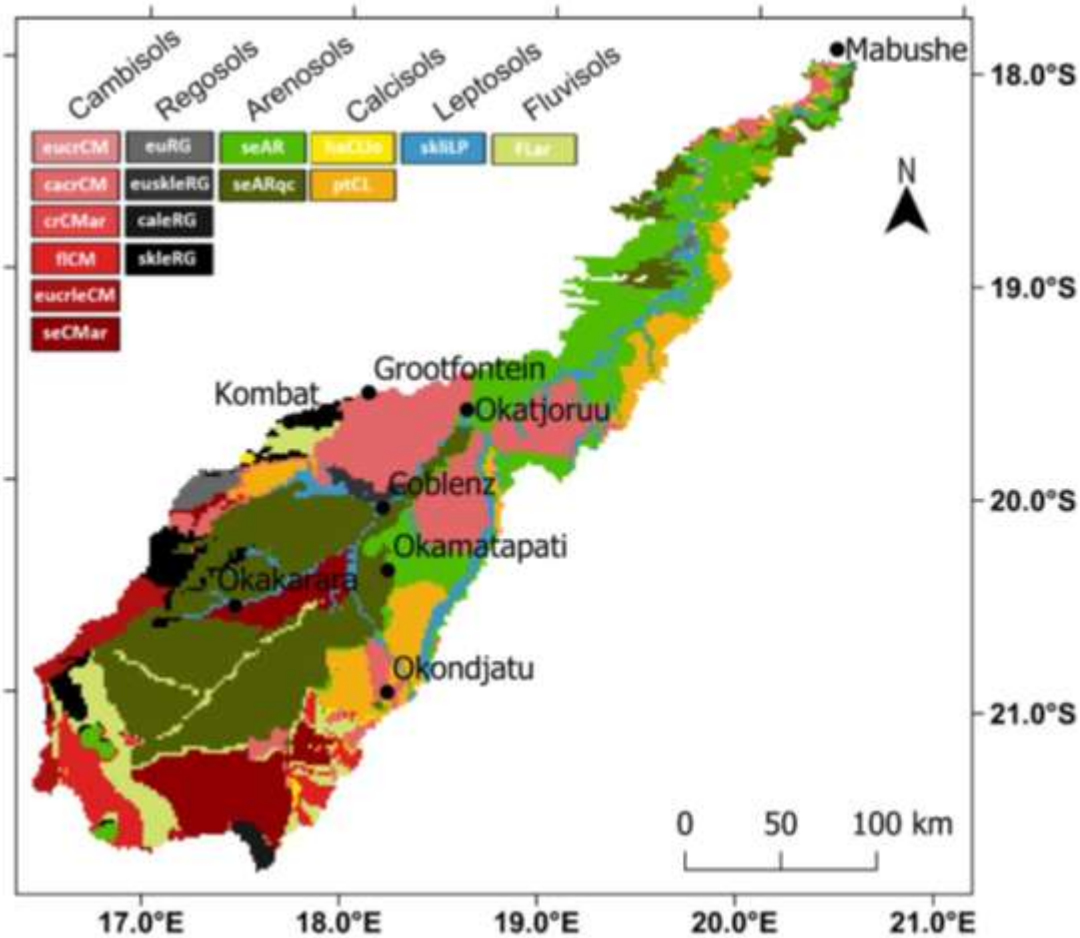


Figure 4. Soil classes of the study catchment.
Source: Authors

was calculated.

Catchment modelling

Model setup and configuration

A hydrological SWAT model (Figure 5) was employed to simulate the water balance components of different sub-basins in the catchment under study. To this end, the Okavango-Omatako catchment was delineated using the SWAT model.

The spatial heterogeneity of the catchment was best modeled through sub-basins and was further divided into HRUs. HRUs represent the smallest spatial units of the catchment with homogenous slope class, soil characteristics and Land use and land cover (LULC) information. HRUs simulated the water balance components with the assumption that different HRUs have different hydrologic characteristics. To execute different SWAT scenarios, the various datasets outlined in Table 1 were utilized. These scenarios were thereafter used to simulate the quantity of water in each sub-basin, computed as the total water departing and arriving into the channel at each time step. Using this model, water balance was computed as shown in Equation (1) (Neitsch et al., 2011):

$$+\sum \quad (R \qquad\qquad\qquad\qquad) \qquad (1)$$

where refers to the soil water content at time t, the initial soil water content is denoted by , R_{day} is the amount of precipitation on day i, indicates surface runoff on day i, E_a refers to the amount of evapotranspiration on day i, specifies the amount of percolation on day i and denotes groundwater return flow on day i.

Surface runoff originates when precipitation received on the ground surface surpasses the rate of infiltration. The Soil Conservation Service Curve Number also referred to as SCS-CN is used in this study to simulate the surface runoff (USDA, 1986). To determine surface runoff CN in a specific location of the catchment during a rain event, the method considers the soil hydrologic group, soil moisture conditions and LULC types. The Penman-Monteith approach (Allen et al., 1989; Howell and Evett, 2004) using solar energy, wind speed, humidity and temperature was used to estimate the potential evapotranspiration (PET) for the entire catchment area. Water flowing into the stream network of the basin is simulated using the variable storage routing method developed by (Williams, 1969). The SWAT model setup was adopted to delineate the Okavango-Omatako catchment into sub-basins using the high-

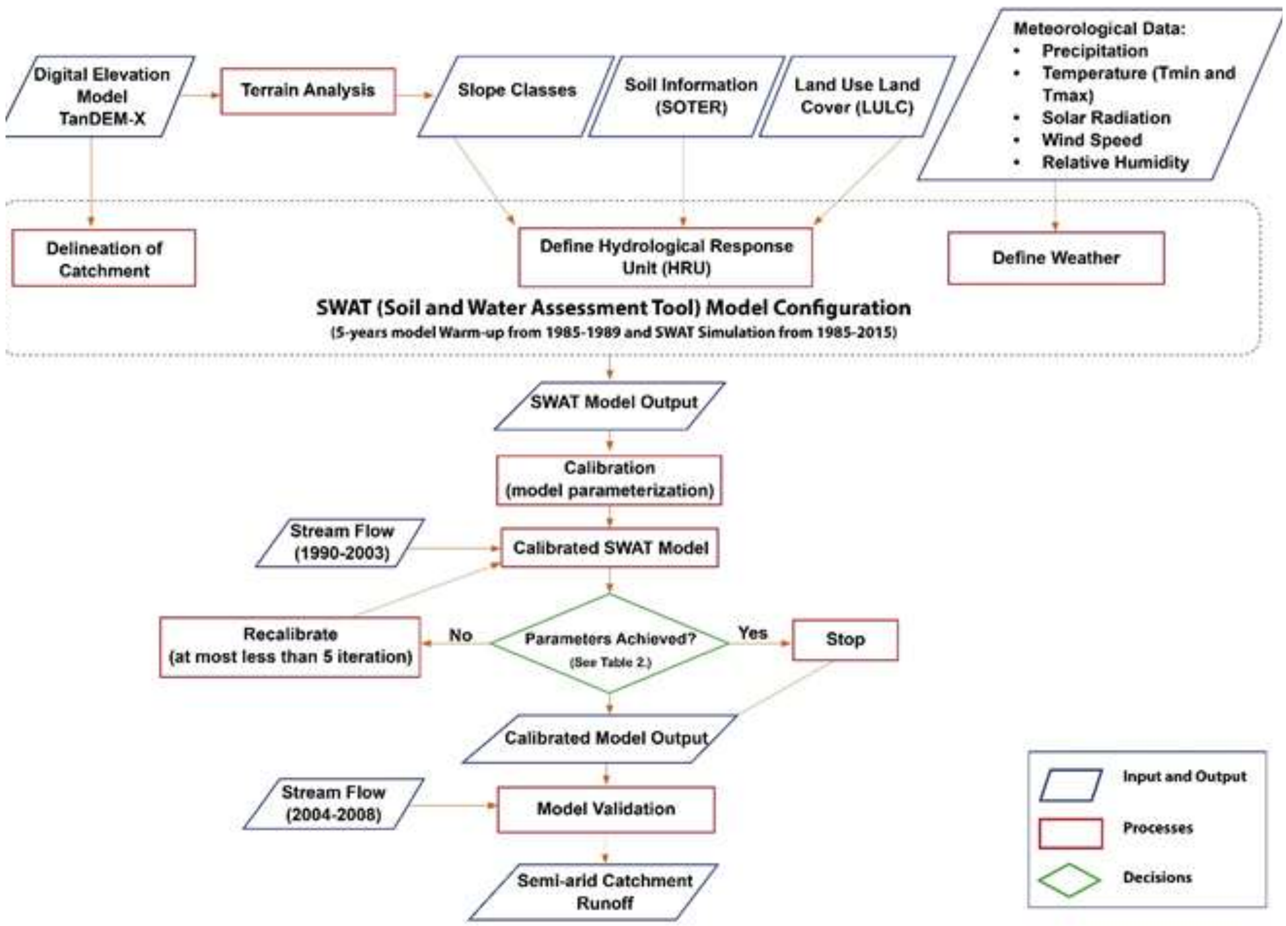


Figure 5. Framework of model setup and configuration using SWAT as well as calibration and validation processes in SUFI-2.
Source: Authors

resolution TanDEM-X digital elevation product due to its flat terrain characteristics. These processes were followed to fill DEM depressions, compute flow direction and accumulation, which are further used to apply thresholds for stream definition, subsequently determining stream networks and the number of sub basins. Thereafter, HRUs were created using unique combinations of LULC, Soil and Slope information within each sub basin. As discussed in Table 1, the precipitation and temperature (Tmin and Tmax) data for eight weather stations optimally distributed throughout the study area were defined and SWAT input tables were created. As a final step, the simulation was performed over 31-years (1985-2015), with a five-year warm-up period (1985-1989). The warm-up is an adjustment process used by the model to achieve a stable state (e.g. streamflow values), as initial conditions of a catchment are usually underestimated during simulation in SWAT (Kim et al., 2018). Consequently, the study simulated 26-years (non-inclusive warm-up period) of hydrological parameters of the catchment.

Parameter sensitivity analysis

Sensitivity analysis of parameters is the main driving force for a successful application of streamflow simulation (Mengistu et al., 2019; Thavhana et al., 2018). Sensitivities of parameters are computed through regression between parameters and the objective function. This process calculates the mean change in the objective function which results from changes in each parameter. Twelve parameters were selected through a careful review of related literatures and considering the semi-arid characteristics of the area under study. The parameters, that is, CN2, OV_N, FFCB, ESCO, EPCO, CH_K2, CH_N2, ALPHA_BF, GW_DELAY, GWQMN, SURLAG and MSK_CO1 (abbreviations are explained in Table 3) were chosen based on their sensitive behavior to streamflow (Aqnouy et al., 2019; Desai et al., 2021; Mengistu et al., 2019). The list of parameters associated with streamflow was applied for further evaluation in a calibration process. Thereafter, a sensitivity analysis was performed by considering the changes in the objective function as a result of the sensitivity of one parameter to other parameters, which determines its influence on streamflow. The t-stat and p-value are used to quantify the sensitivity of a parameter and its significance. A higher t-stat value and a lower p-value demonstrates a more sensitive streamflow in the catchment (Abbaspour, 2015; Arnold et al., 2012).

Calibration, validation, and uncertainty analysis

Evaluation of hydrological models is performed, using performance criteria through comparison of simulated variables or processes in the basin against measured data. The model calibration and validation are the final vital step to assess the accuracy of the runoff simulation. Once the simulation process is completed in SWAT, the hydrological model undergoes calibration and uncertainty analysis as shown in Figure 5. SWAT Calibration and Uncertainty Procedures (SWAT-CUP) was employed for further processing, which is a program with five different algorithms commonly used in calibration and validation of simulated hydrological models. Large-scale and complex models usually make use of the Sequential Uncertainty Fitting also known as SUFI-2 due to its efficiency and reliability (Yang et al., 2008), especially when compared with deterministic approaches to calibration (Abbaspour, 2015). Given the scale and complexity of our catchment, the study therefore used this stochastic approach. In this algorithm, ranges associated with uncertainty of all variables convey the uncertainty of each parameter by considering the conceptual model, the data measured and its parameters. Uncertainties in parameters lead to uncertainty in model output which is commonly expressed in SUFI-2 by 95% probability distributions which are computed between 2.5 and 97.5% of cumulative distributions for an output variable. This is referred to as 95% prediction uncertainty or a confidence interval (95PPU). This output acquired from the stochastic calibration approach is the most suitable solution at 95% significance level, generated from specified parameter intervals and defined by the modeler.

The calibration and validation process in this study was performed using the split-sample approach with monthly stream flow data from Omatako gauge station used for the period 1990-2003 (calibration) and 2004-2008 (validation).

This was performed to evaluate the efficiency of streamflow simulation compared to the observed data. The splitting of observed data based on time-period ensures data independence to assess the model performance. Moreover, the selected period for calibration and validation process was due to lack of in-situ data spanning the model duration. During calibration (1990-2003), four iterations each with no less than 500 simulations were executed to refine the model parameters (Abbaspour, 2015; Hajati et al., 2020). With each iteration performed, values of each parameter range become smaller approaching the best solution and achieving better models than previous iterations. According to Abbaspour (2015) the best solution is usually achieved within the above stated iteration. Thereafter, independent observed data can be used to validate the 2004-2008 period. During this process, the exact calibrated parameter ranges and same simulation quantity as defined in the final calibration was repeated, aimed to assess model performance. The calibration and validation results were both quantified using statistics known as P-factor, R-factor, and objective function value (Abbaspour, 2015; Abbaspour et al., 2004).As expressed by Abbaspour (2015), in SUFI-2, a good fit between observation and simulation results is conveyed using two indices ‘P-factor’ and ‘R-factor’. P-factor refers to the observed data enveloped by 95% prediction uncertainty. While the R-factor refers to the thickness of the 95PPU. The P-factor is measured between 0 – 1 with 1 being the perfect result indicating 100 % of the observed data enveloped in the 95PPU, while 0 being the worst with none of the observed data represented within the envelope. In the case of R-factor, possible values range between zero and infinity. The recommended value for R-factor is less than 1.5 for streamflow, (Abbaspour et al., 2004, 2015), whereas P-factor is acceptable with values greater than 0.7. However, the former depends on the project scale, input data, etc. Hence, the above indices can evaluate the goodness of fit between our observed and simulated results in the calibration and validation process. Values slightly outside the acceptable range are still possible, as the recommended values are not necessarily fixed numbers, rather a quest to reach a balance between R factor and P factor (Abbaspour, 2015).

In this study the good agreement between the observed and simulated streamflow is evaluated through the objective function Nash-Sutcliffe coefficient (NSE) as shown in Equation (2),

$$\frac{\sum_{i=1}^{n}(Q \qquad d)_i^2}{\sum_{i=1}(Q \qquad -\bar{Q}_{Obse} \quad d)} \qquad (2)$$

Coefficient of determination (R2) as shown in Equation (3),

$$\frac{\left[\sum_{i=1}(Q \qquad -\bar{Q}_o \quad d)(Q \qquad -\bar{Q}_{simu} \quad d)\right]}{\sum_{i=1}(Q \qquad -\bar{Q}_O \quad d) \ \sum_{i=1}(Q \qquad -\bar{Q}_{simu} \quad d)} \qquad (3)$$

Percent bias (PBIAS) as shown in Equation (4), and

$$\frac{\sum_{i=1}^{n}(Q \qquad d)}{\sum_{i=}^{n}} \qquad (4)$$

Ratio of RMSE to the Std. Dev. of observed data (RSR) as shown in Equation (5)

$$\frac{\sqrt{\sum_{i=1}^{n}(\qquad d)_i^2}}{\sqrt{\sum_{i=1}^{n}(\qquad -\bar{Q}_o \quad d)}} \qquad (5)$$

Where Q is the variable under observation or simulation, that is discharge, $Q_{observed}$ and $Q_{simulated}$ are discharge data, which have been measured and simulated respectively, while n refers to the number of total records and $\bar{Q}_{observed}$ denotes the average measured data while i is the ith measured or simulated data. Similar to the P-factor and R-factor, there are no specific numbers to achieve, however, the recommended values for watershed scale (Gupta et al., 2009; Hajati et al., 2020; Moriasi et al., 2007, 2015) are as follows; $R^2 > 0.6, NSE > 0.5$ and $P_{BIAS} < \pm 25\%$. Hence, the model performance is evaluated as per the performance rating criteria listed in Table 2.

RESULTS AND DISCUSSION

Results of SWAT

In the process of delineation, the catchment was divided into 60 sub-basins and further subdivided into 762 HRUs. The simulation was executed for a 31-year period between 1985 and 2015 with the initial five years from 1985-1989 used as model warm-up. The simulated results showed precipitation in the basin to be low and potential evapotranspiration being expectedly high for simulated timeframe. During the simulation, the ratio of surface runoff to total flow was very low at 0.27, the evapotranspiration to precipitation recorded was 0.57, and the baseflow to total flow ratio was a high 0.73. These results clearly show that the surface runoff was very low and most of the precipitation was lost to the shallow aquifer and the evapotranspiration process.

Sensitivity analysis

Out of the twelve parameters discussed above (that is,

Table 2. Performance Rating for a Monthly Time Step

Model performance rating	RSR	NSE	R^2	PBIAS
Very Good	$0.00 \leq RSR \leq 0.50$	$0.75 < NSE \leq 1.00$	$0.75 < R^2 \leq 1.00$	$PBIAS < \pm 10$
Good	$0.50 < RSR \leq 0.60$	$0.65 < NSE \leq 0.75$	$0.60 < R^2 \leq 0.75$	$\pm 10 \leq PBIAS < \pm 15$
Satisfactory	$0.60 < RSR \leq 0.70$	$0.50 < NSE \leq 0.65$	$0.50 < R^2 \leq 0.60$	$\pm 15 \leq PBIAS < \pm 25$
Unsatisfactory	$RSR > 0.70$	$NSE \leq 0.50$	$R^2 \leq 0.50$	$PBIAS \geq \pm 25$

Source: Koycegiz and Buyukyildiz, 2019; Moriasi et al., 2007

Table 3. Parameters and range of values used in the calibration.

Parameter	Description	Parameter Range	Fitted Value	t-Stat	p-Value
CN2	**SCS runoff curve number f**	**-0.2 – 0.2**	**-0.1804**	**-11.697**	**0.000**
OV_N	Manning's "n" value for overland flow	-1.5 – 1.5	-0.273	1.496	0.135
FFCB	Initial soil water storage expressed as a fraction of field capacity water content	0.12 – 0.69	0.20037	-0.102	0.919
ESCO	Soil evaporation compensation factor	0 – 1	0.269	0.570	0.569
EPCO	Plant uptake compensation factor	0.3 – 1	0.9293	0.496	0.620
CH_K2	Effective hydraulic conductivity in main channel alluvium (mm/h)	2 – 140	82.729996	-1.457	0.146
CH_N2	Manning's "n" value for the main channel	0.25 – 0.76	0.73807	0.453	0.651
ALPHA_BF	**Base flow alpha factor (days)**	0 – 1	0.135	-6.334	0.000
GW_DELAY	**Groundwater delay time (days)**	30 – 450	189.179993	7.923	0.000
GWQMN	Threshold depth of water in the shallow aquifer required for return flow to occur (mm).	0 – 2	0.142	-0.195	0.845
SURLAG	Surface runoff lag time	0 – 20	13.86	1.349	0.178
MSK_CO1	Calibration coefficient used to control impact of the storage time constant for normal flow	0 – 10	0.43	-0.274	0.785

Source: Authors

parameter sensitivity analysis), three parameters appeared to be highly sensitive to stream flow in the Okavango-Omatako catchment. The most sensitive appeared to be the runoff curve number controlling the surface runoff followed by ground water delay time and baseflow alpha factor influencing the baseflow of the semi-arid catchment during the period 1990 to 2003. Many of the studies performed in arid and semi-arid environments also confirmed these results with Esmali et al. (2021) observing runoff curve number (CN2) ranked the most sensitive in different climatic zones including semi-arid and arid, while ground water delay (GW_DELAY) was found to be most sensitive in arid and baseflow alpha factor (ALPHA_BF) in semi-arid environment. Additionally, Aqnouy et al. (2019) and Desai et al. (2021) noted that out of the three above parameters, two were the most significant in a semi-arid environment in Morocco and India. The sensitivity analysis as indicated by the t-stat and p-value in Table 3 showed CN2, GW_DELAY and ALPHA_BF as the most sensitive parameters in our catchment. The results agree with similar findings by Thavhana et al. (2018) and Koycegiz and Buyukyildiz (2019), Mengistu et al. (2019) and Leng et al. (2020) on frequently considered parameters which are amongst the most sensitive in the global sensitivity analysis for hydrological processes of semi-arid catchments. The remaining nine parameters were less sensitive with higher p-values and a lower t-stat.

The sensitivity analysis yielded t-stat and p-value for the model parameters as shown in Figure 6. The most dominant significance with the highest t-stat and a low p-value were seen in CN2, GW_DELAY and ALPHA_BF. The parameter CN2 also known as the SCS runoff curve number is used to determine runoff values for the catchment and is found to be the most sensitive parameter with a low p-value ($p < 0.05$) and a high t-stat. According to USDA (1986), this parameter has been used to characterize antecedent runoff conditions in arid and semi-arid watersheds. Following CN2, ALPHA_BF, a parameter affecting base flow, was classed to be sensitive to streamflow in the semi-arid catchment. The

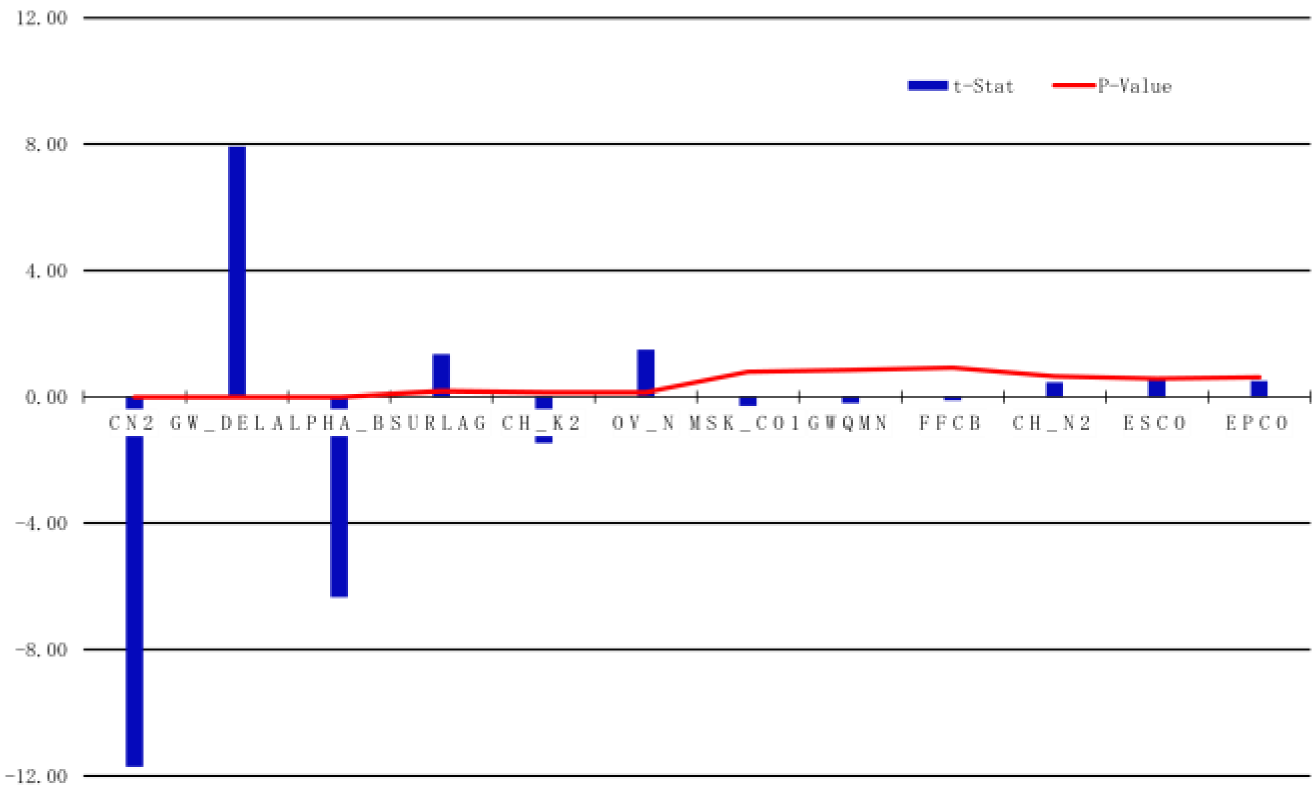


Figure 6. Parameters sensitivity analysis (*t-stat* and *p-value*) of SWAT simulation for the Okavango-Omatako catchment.
Source: Authors

Table 4. Result from calibration and validation.

	Calibration	Validation
P-factor	0.77	0.68
R-factor	1.31	1.82
	0.84	0.89
NSE	0.82	0.80
PBIAS	-1.1	-20.0
RSR	0.42	0.44

Source: Authors

ALPHA_BF fitted value of 0.135 reveals a slow recharge response rate as discussed by Miskewitz (2007), constituting a slow baseflow in the catchment. The next sensitive parameter is GW_DELAY, which is highly influenced by the catchment area size under consideration. The parameter measures the time for water to percolate and reach the water table, being 189 days in this catchment. The remaining nine parameters (OV_N, FFCB, ESCO, EPCO, CH_K2, CH_N2, GMQMN, SURLAG and MSK_CO1) were found to be less sensitive to streamflow estimation causing increased model uncertainties in the study area. As part of this study, a further in-depth investigation which identifies parameter sensitivity to semi-arid environments similar to this study catchment will be valuable for better model performance in stream flow estimation.

Model calibration

The output of the calibration illustrated the capacity of SWAT to simulate streamflow in this study catchment. The 95PPU illustrated in Figure 7(a), with green in the calibration processes displays the uncertainty of this model through computation of the P-factor, and R-factor indicators. As shown in Table 4, the P-factor estimate was 0.77, thus 77% of the observed discharge lies in the 95PPU bracket for the period of calibration, from 1990-2003. Whereas 95PPU bracket thickness was measured by the R-factor, which was 1.31, resulting in both indicators meeting the optimum value as determined by Abbaspour et al. (2015). During the calibration process, the study achieved the best model between observed and simulated streamflow. It is also apparent from Figure 7(a) that the observed mainly falls outside the 95PPU during the descent cycle of streamflow, demonstrating the start of the flow modelled very well as opposed to the end of the seasonal flow. In general, the model also performed well in simulating high and low flows between the observed and simulated streamflow.

In addition to the above model performance parameters, all other performance indicators for the model calibration (Table 4) scored between good to very good according to the evaluation criteria outlined in Table 2 (Koycegiz and Buyukyildiz, 2019; Moriasi et al., 2007). The model performance indices evaluated the agreement between simulation and observation of our catchment as presented in Table 4. The objective function used in this study to evaluate the model performance for the period 1990 to 2003 was Nash-Sutcliffe efficiency (NSE) with a calibration of 0.82. These results depict the model simulation success with good results produced according to the model performance evaluation criteria listed in Table 2. Additionally, other performance indicators such as Coefficient of determination (R^2), Percent bias (PBIAS) and residual variation (RSR) were similarly used to evaluate the model. The calibration results as presented in Table 4, with R^2 (0.84) achieved very good performance rating for the recommended statistics on a monthly basis. The PBIAS scored (-1.1), ranking very good on the calibration while the RSR (0.42) also performed very well with values below 0.5 as recommended by (Arnold et al., 2012; Fernandez et al., 2005; Mengistu et al., 2019; Moriasi et al., 2015).

According to Figure 7(b), the scatter plot representing measured vs simulated discharge, visualizes the success of the model performance. Coefficient of determination (R2) of the scatter plot shows 0.84 for calibration, indicating a higher correlation between observed and simulated data during the calibration period. However, in Figure 7(a) an overestimation during low flow periods were observed. While high flows were simulated satisfactorily, closely matching the observed values, excluding few cases of the peak flow estimations which were slightly underestimated. These findings agree with similar studies by (Koycegiz and Buyukyildiz, 2019; Thavhana et al., 2018; Vilaysane et al., 2015).

Model validation

The validation process compared the simulated discharge of a selected outlet of a sub-basin with observed discharge measured at gauge station nearby, plotted in Figure 8(a) with corresponding precipitation data from the closest meteorological station. As outlined in the methods, the model validation was carried out using in-situ data from 2004 to 2008. The results were a P-factor of 0.68 (that is, 68% of the observed discharge was bracketed by the modeling result of 95PPU), and R-factor of 1.82 (that is, the 95PPU bracket thickness). In both cases, the results were unable to achieve the recommended values of (Abbaspour, 2015), which were set to be greater than 0.7 for P-factor and less than 1.5 for R-factor. These optimum values as endorsed by Abbaspour et al. (2015) act more of a guide rather than absolute numbers which must be achieved. The values are dependent on project scale and availability of input and calibration data as mentioned in (Abbaspour et al., 2015; Beharry et al., 2021; Musyoka et al., 2021; Pontes et al., 2021). In the validation process the R-factor recorded a value > 1.5, which was found to be satisfactory due to the large size of the study area under consideration and limited calibration data availability. Moreover, the recorded R-factor above the recommended value could be attributed to low flow during the years 2004-2005, especially when compared with peak-flow characteristics during the calibration period. Pontes et al. (2021) also recorded similar results during the evaluation of SWAT model to simulate monthly streamflow in a catchment in Brazil. Nonetheless, the objective function results in the validation process achieved NSE of 0.8, R^2 of 0.89 and RSR of 0.44 with all three scoring in the very good category as stipulated by (Moriasi et al., 2007). While the model indicated a PBIAS of -20.0 falling within a satisfactory range for validation as stated by (Koycegiz and Buyukyildiz, 2019; Moriasi et al., 2007). Similarly, the validation also demonstrated poor performance at the end of a streamflow season, but also at times during low flow by falling outside the 95PPU bracket.

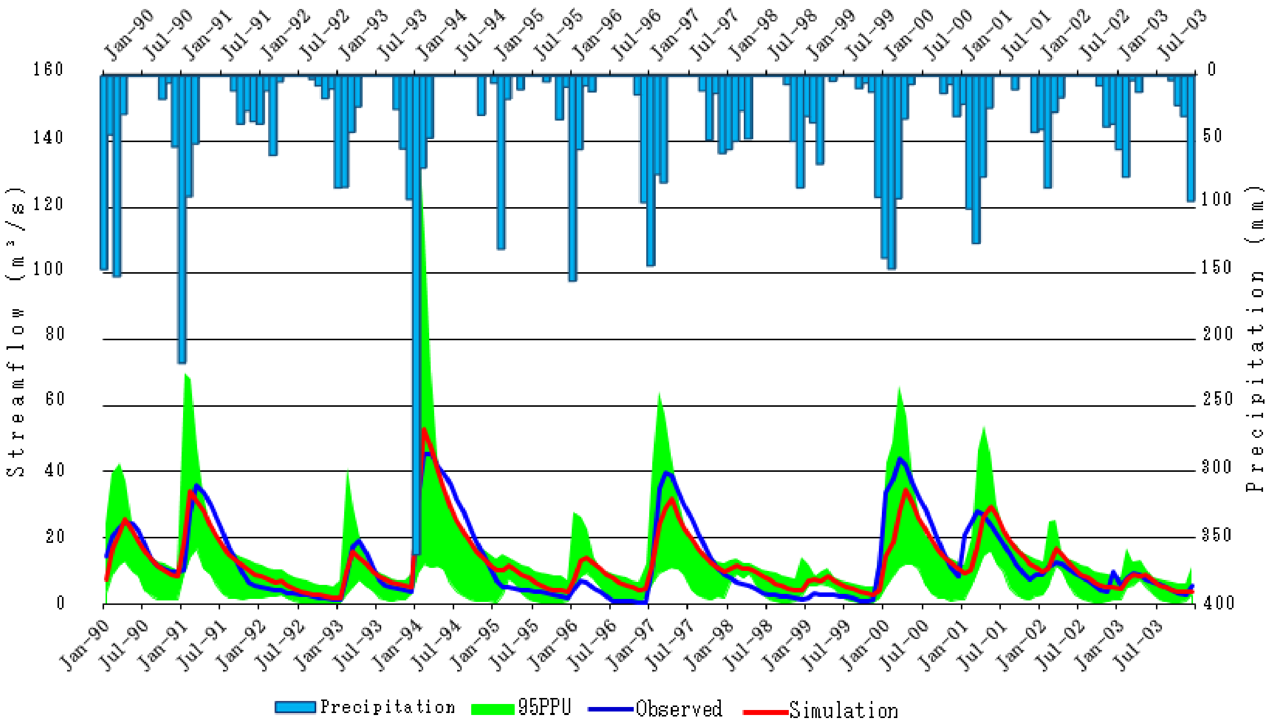
Coefficient of determination (R2) of the scatter plot in Figure 8(b) attained 0.88 indicating a positive correlation between observed and simulated data during the validation period. This result indicates the success of the model performance.

However, in Figure 8(a) a high overestimation during low flow years were seen while closely matched results between simulated and measured streamflow during peak flow years were observed.

Model performance evaluation

A SWAT hydrological model was setup and implemented for a semi-arid catchment in Namibia to evaluate model performance for streamflow estimation. The model was calibrated using the limited available observed river discharge data. Despite the simulation for the study area carried out from 1985 to 2015, the calibration and the validation processes could only be implemented for the periods 1990 to 2008 due to inconsistencies and missing observed discharge data subsequent to this period. Such limitations were also observed by Terskii et al. (2019) in a similar study.

Thus, reliable discharge observation stations collecting a)



b)

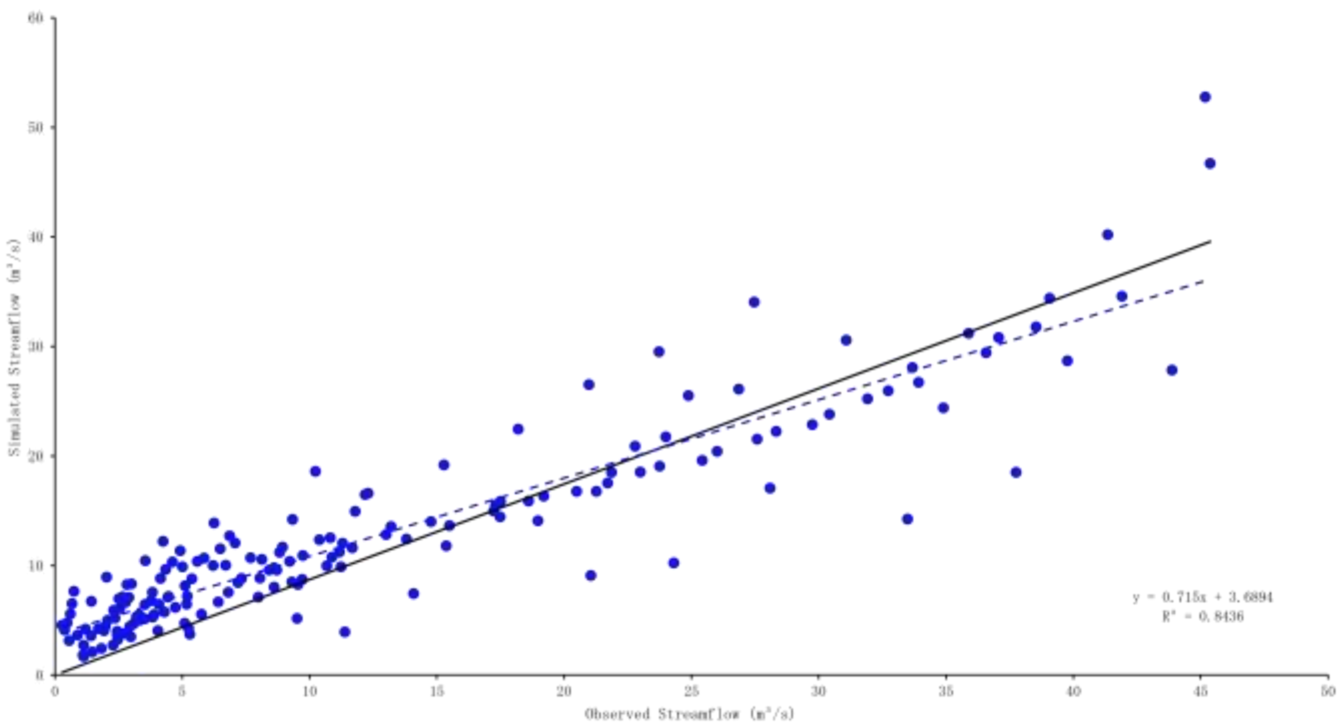
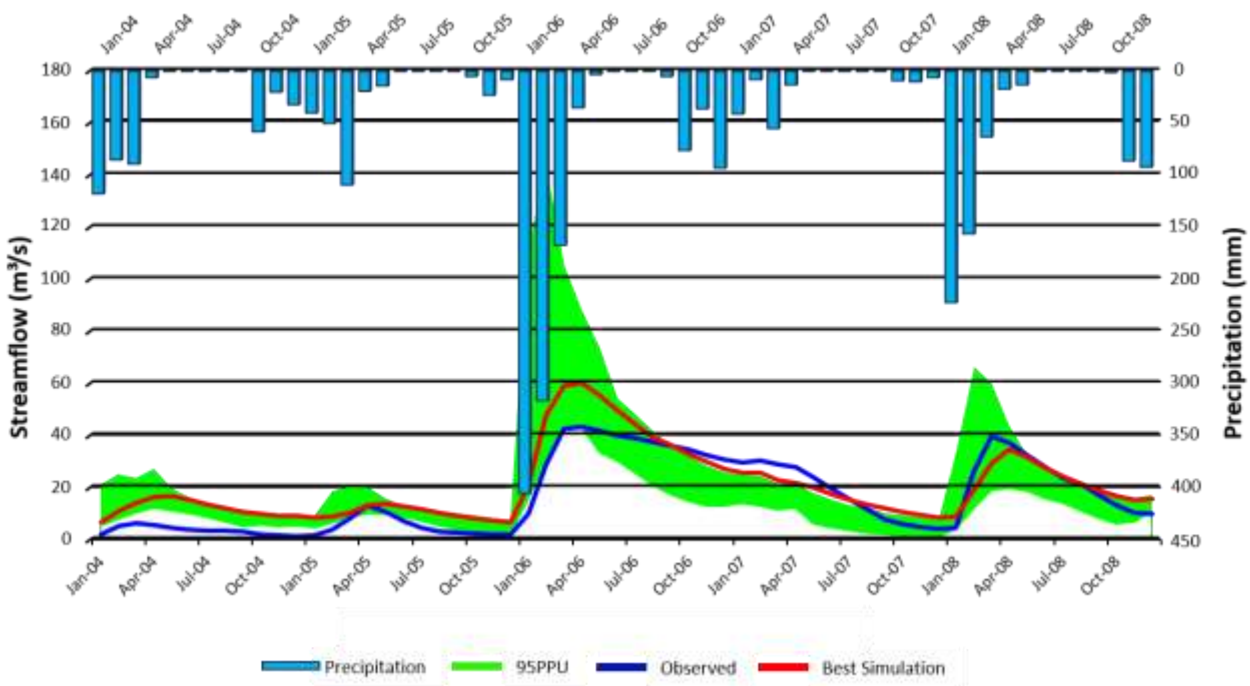


Figure 7. (a) Observed vs simulated monthly stream flow and (b) Scatter plot showing correlation between the observed and simulated for the calibration period (1990 - 2003).
Source: Authors

a)



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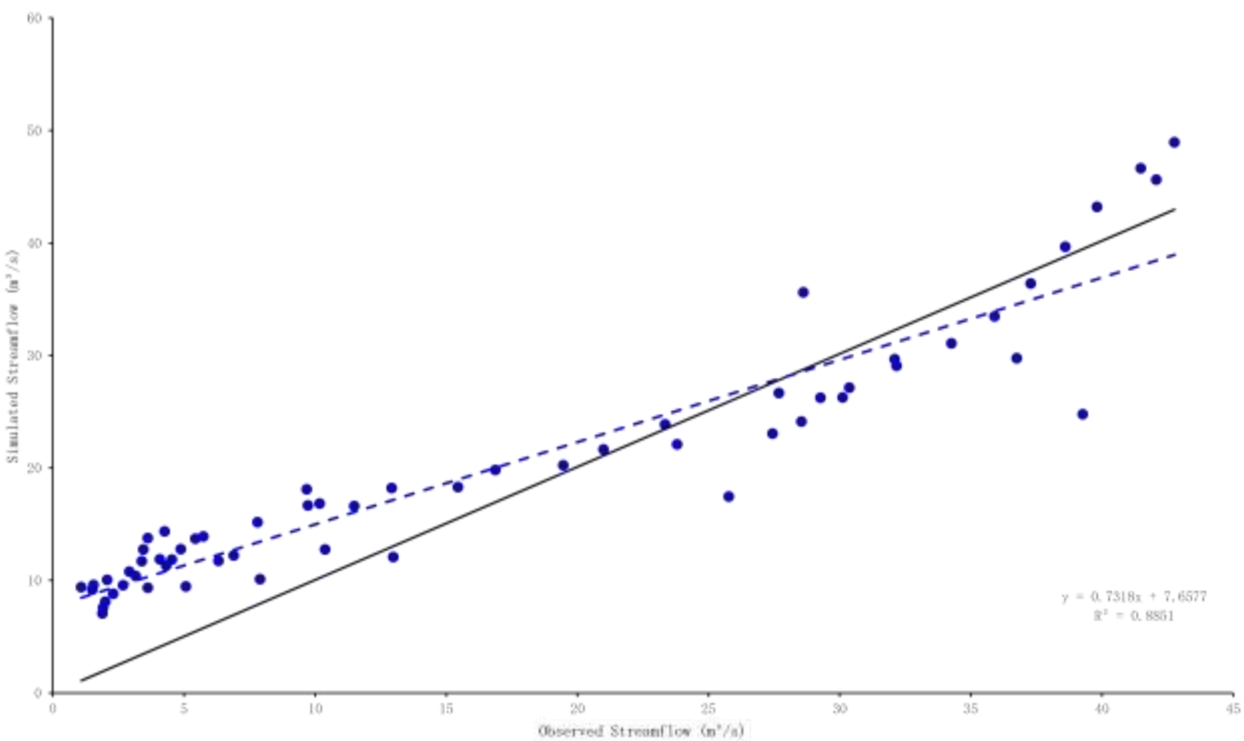

Figure 8. (a) Observed vs simulated monthly stream flow and (b) Scatter plot showing correlation between the observed and simulated for the validation period (2004 - 2008).
Source: Authors

long term flow data could go a long way in modelling catchments similar to the study area.

The general performance of the model as indicated through the values achieved by the different indicators has a good agreement between the observed and simulated streamflow. 95PPU for the calibration and validation processes for the period of study with its corresponding rainfall records are shown in Figure 7(a) and 8(a). It is apparent that after intensive rain occurred, an increased streamflow was observed thereafter. However, this was not the case for all the years of calibration, which could be attributed to climate conditions such as high evapotranspiration, high percolation, abstraction, etc. Despite this, one can still observe the simulated data, predominantly falling within the confidence interval. Similar findings were observed by Koycegiz and Buyukyildiz (2019) and Mengistu et al. (2019), while modelling runoff in a semi-arid catchment, both studies observed an increased flow following a high rainfall event confirming the outcome of simulation in this study.

Prediction uncertainty is used to quantify the agreement between simulated and observed results. The P-factor value for calibration was adequate while the validation value was near the recommended value of 0.7 (Abbaspour et al., 2015). Similarly, the R-factor value of the calibration was within the acceptable range while the validation is slightly on the upper side of the recommended value of 1.5. This could be dependent to and highly attributed to the scale of the project as demonstrated in (Abbaspour et al., 2007, 2015). Hence, the results of this study can be considered to have lower uncertainty in the calibration and slightly higher uncertainty in the validation process. As stated by Abbaspour et al. (2015) while calibrating a continental scale hydrological system, a large-scale catchment as demonstrated in the study could attain slightly higher or lower results than the ranges of the recommended value. Abbaspour et al. (2015) and Beharry et al. (2021), Musyoka et al. (2021) and Pontes et al. (2021) demonstrated that a high R-factor could also occur due to lack of sufficient data for model calibration. To this end, the modelling of the Okavango-Omatako catchment has been challenging due to the quality of input and calibration data with uncertainties leading to a high R-factor.

The model performance indicators used the NSE, R^2, PBIAS and RSR while results were ranked according to (Koycegiz and Buyukyildiz, 2019; Moriasi et al., 2007). All indicators achieved a very good performance rating with exception of PBIAS validation rated as satisfactory. Similar to Abbaspour et al. (2015), Mengistu et al. (2019) and Moriasi et al. (2007), the results indicate a good overall achievement of model performance within the study area with a good level of agreement between observed and simulated streamflow. Taking a closer look, the PBIAS index reveals that the model underestimated stream flow in the process of simulation by 1.1 and 20% respectively for calibration and validation, when compared with observed data. Simulated and observed streamflow for both calibration and validation are demonstrated in Figure 7(a) and 8(a), respectively. The model is capable of simulating low and high flows satisfactorily, closely matched to the observed values. However, in some cases the peak flow estimation slightly falls short in the calibration period. These findings are cohesive to similar studies by (Koycegiz and Buyukyildiz, 2019; Thavhana et al., 2018; Vilaysane et al., 2015). Consequently, low flow might have caused an above limit R-factor in our catchment as supported by Musyoka et al. (2021) and Pontes et al. (2021), during the evaluation of SWAT model to estimate monthly streamflow in the dry season of their respective study areas.

After a careful assessment of the simulated versus observed results, the performance of SWAT to effectively model a large complex semi-arid catchment with scarce in-situ data was found to be satisfactory, demonstrating the potential of simulating future streamflow events. This indicates the effectiveness and further exploration of this model to assess impacts of climate change in similar catchments within the region. However, evident limitations are seen in overestimated low flows during calibration and validation timeframes, which are vital for extrapolation to forecast and assess climate change impacts. From a catchment management perspective, the model fairly estimated the peak flow in the calibration period verifying its capacity to be used as a water management tool, except in few cases where underestimations occurred. Further investigations into streamflow intensity and time lag between streamflow events are essential for water resource managers. Another relevant factor which must be considered as a potential impact on catchment flow characteristics is the changes in LULC. In this study, the temporal changes of LULC were not examined.

However, the significance of a time-series analysis of the catchment's LULC cannot be refuted and could go a long way in understanding its impacts on streamflow behavior. This study thus proposes a subsequent investigation on this matter.

One of the limitations in this study is the inadequacy to evaluate parameter sensitivity in the entire catchment. The uncertainty analysis of our model estimation can only be quantified in locations of the sub-basin where calibration was performed. Therefore, results in areas further away from calibrated portions should be examined attentively. One of the reasons for such limitation is the lack of data for use in the calibration process. An alternative, which should be considered to overcome such limitation, is the calibration using other variables such as available remotely sensed evapotranspiration and soil moisture as successfully demonstrated by Emam et al. (2017) and Rajib et al. (2016), respectively. The sensitivity analysis found three parameters to have a dominant influence in the model parameterization for the

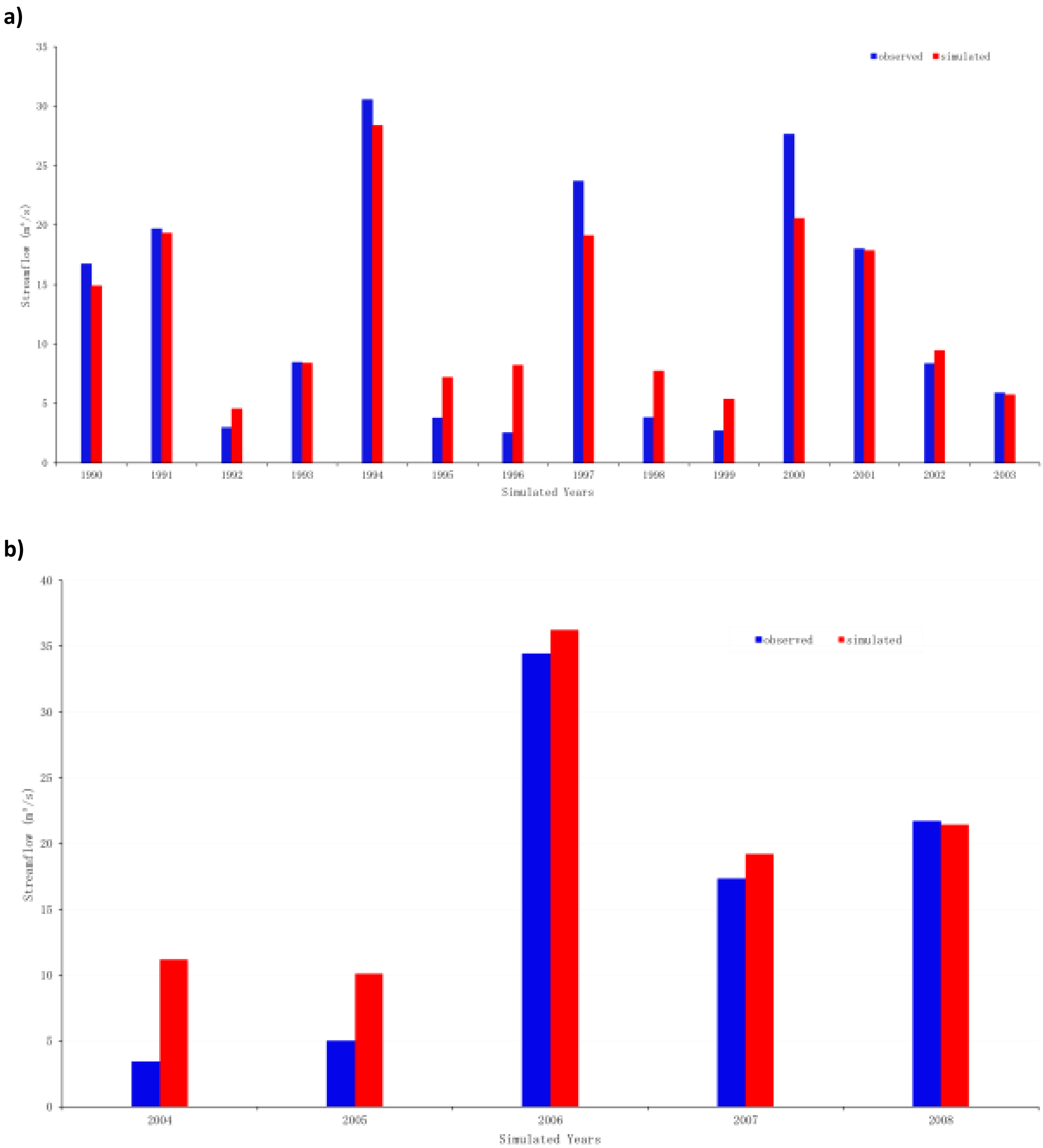

Figure 9. Annual monthly average stream flow of observed and simulated (a) during the calibration period (1990 - 2003) and (b) during the validation period (2004 - 2008).
Source: Authors

catchment under investigation. Water resource managers in the area should collect these essential parameters (that is, the runoff curve number, ground water delay time and baseflow alpha factor) to improve model performance.

Annual monthly average stream flow displayed in Figure 9(a) and 9(b), demonstrates variation of observed and simulated streamflow values with an average overestimation of 1.03 and 16.63% for the calibration and validation periods respectively. The model inclination to overestimate low flows is evident, especially for the periods of 1992, 1995, 1996, 1998, 1999, 2002, 2004 and

2005. The result is confirmed by similar investigations in Tegegne et al. (2017), Thavhana et al. (2018) and Turkmen et al. (2021), and is critical that the model is modified to handle low flows or adjoined with other models for improved estimates. The peak flows were estimated more reasonably and closely matched the observed values with slight underestimations. Bearing the adequate performance of the model estimation and results in mind, hydrological simulation in a semi-arid environment such as Okavango-Omatako catchment can be performed using modified SWAT and/or coupled with other models to manage scarce water resources in the region.

Conclusion

This study evaluated streamflow responses of selected parameters in the Okavango-Omatako catchment and recommends future work to explore the dynamics of the Okavango River basin starting from southern Angola through the northeastern part of Namibia and dissipating in the Okavango delta. Further, to understand the hydrological systems in this area, the link to climate systems such as El Nino/La Nina, Southern Oscillation (ENSO) and Sea Surface Temperature (SST) in the Atlantic and Indian Ocean should be investigated. These links are recommended by Landman and Mason (1999), Namibia Resource Consultants (1999) and Orti and Negussie (2019) to impact the management of water resources in this semi-arid environment, but have not been investigated to date.

It is paramount to understand hydrological systems and their characteristics as well as various parameters which influence these systems. A major part of this process is to recognize the spatial and temporal patterns of precipitation, evapotranspiration, LULC and soil moisture. The varying spatial distribution of these variables in the catchment creates a challenge in simulating streamflow. Serious deficiencies during the modelling process merged from the lack of knowledge on the catchment's physical environment. The need for more comprehensive research to better understand the hydrological processes on catchments in Namibia is obvious. This research is necessary to sustainably use water resources and support water resource managers for efficient planning and management of this scarce resource. This study further recommends the sensitivity of parameters in the catchment under study to be evaluated as familiarities could contribute to a better understanding of streamflow processes.

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CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Increasing soil condensation capacity for agricultural purposes

Samane Arvandi* and Forood Sharifi

Soil Conservation and Watershed Management Research Institute (AREEO), Tehran, Iran.

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The issue of water scarcity in many parts of the world, especially in arid and semi-arid regions, is a major dilemma. The amount of moisture for plants is not comparable to rain, but in arid areas, it is a huge contribution to plant water supply. In this research, the effect of using Peltier to improve soil condensation by performing several tests was studied in order to investigate the possibility of increasing soil capacity and reducing surface evaporation. Due to the Peltier cooling effect, with copper, iron and aluminium plates, results were evaluated in normal water, saline water and soil texture. The results showed that by using the copper plates in Peltier module, temperature dropped and it was 10% more than iron and aluminium one. It showed that there were significant differences in the results.

Key words: Aluminium, cold objects, copper, iron, moisture, refrigerants.

INTRODUCTION

Water combat is expressed as one of the major challenges in agricultural water management. Water is becoming a crucial factor for crop production all over the world (Bijani and Hayati, 2011). Due to climate change, water at low temperature is necessity since the means of cooling the water is not readily available to all sections of the society (Hammad et al., 2017).

It is not shortage or lack of water that leads to conflict (Yoffe et al., 2003), but how water is governed and managed. To regulate water use and enable sustainable and equitable management in areas stricken with water shortages, stronger policies need to be put in place. Yet water management institutions, especially in developing countries, often lack the human, technical and financial resources to develop and implement comprehensive management plans that can properly accomplish the installation of sufficient governing mechanisms.

Iran is located in arid and semi-arid zone and over 90% of available water use for agricultural purposes and faces shortages of water make the statement complete to make sense (Ardekanian, 2003; Khoshbakht, 2011).

A system worked through Peltier Effect as water cooling has many advantages included slight range, handy, mute, natural peaceful and cost-effective in comparison with ordinary systems. This study was about the thermic work of a handy thermo-electric water cooling system. During this research, the adapted voltage on TE switched to figure out its reaction on thermal act. Just

*Corresponding author. E-mail: samane.arvandi@gmail.com.

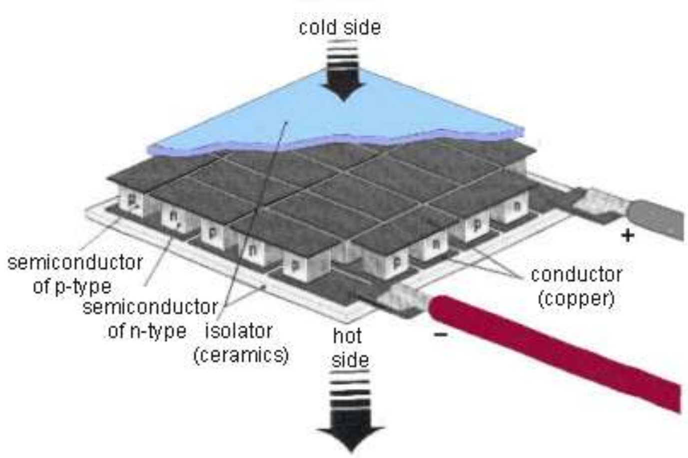

Figure 1. Peltier components.

after increasing voltage, the hot side temperature increases, while on the opposing side of the cold side. Increasing the heat absorbed by the cold side besides the heat rejected from the hot side. Antecedent water temperature has a serious effect on the performance of TE water cooling system. The coefficient of performance was 0.14 when using initial water temperature of 15°C, while it increased and reached 0.5 when the original water temperature increases to 30°C. This happened as a result of the decrease in temperature gradient between cold side and hot side (Al-Rubaye et al., 2018).

Since the development of the theory of Philip and de Vries (PdV model) around 60 years ago, basically all models of evaporation and condensation in unsaturated soils have assumed that soil water vapor at all depth into the soil is in equilibrium with the liquid soil water (or soil moisture) at the same depth. In essence, this local equilibrium assumption means that whenever the soil moisture changes phase, it does so instantaneously. This assumption is quite proper for its original application, which was to describe the coupled heat and moisture transport in soils (and soil evaporation in particular) under environmental forcing associated with the daily and seasonal variations in radiation, temperature, precipitation, etc. (Maulbetsch, 2003).

Peltier effect is the cooling effect that occurs when a small current passes through the junction of two dissimilar wires. This effect forms the basis for thermoelectric refrigeration and is named in honor of Jean Charles Athanase Peltier, who discovered this phenomenon in 1834 (Çengel and Boles, 2006).

The Peltier effect occurs whenever electrical current flows through two dissimilar conductors; depending on the direction of current flow, the junction of the two conductors will either absorb or release heat. In the world of thermoelectric technology, semiconductors (usually Bismuth Telluride) are the material of choice for producing the Peltier effect because they can be more easily optimized for pumping heat (Thermoelectric cooling FAQ, Tellurex Corporation). In this study, in order to improve the cooling capacity and soil condensation, the possibility of using Peltier was examined as a condenser.

In recent years, devices based on the Peltier effect, which is the basis for solid-state thermoelectric cooling, have evolved rapidly to meet the fast-growing industry of electronics. The main point arises from the fact that the heat extraction or absorption occurs at the contact between two different conducting media when a direct current (DC) electric current flows through this contact. A comprehensive study of the mechanisms of heating and cooling originated by an electrical current in semiconductor devices; the Peltier effect depends strongly on the junction surface thermal conductivity. The contribution of this effect to the total effect of thermoelectric cooling increases with an increase in surface thermal conductivity and it slackens with a decrease in surface thermal conductivity (Gurevich and Velázquez-Pérez, 2014).

The Peltier system consists of a semiconductor string. The ceramic outer sheaths are metallized to transmit both heat and electric (Figure 1).

The Peltier's effect applied in the structure of cooling systems based on thermoelectric, where the cooled connection was located to be cooled and the heated connection was located away. The cold point absorbs the heat from the space to be cooled and then the heat is dropped through the hot point. The system in this way drained heat from the cold medium to the hot medium through electric electrons instead of the working fluid in

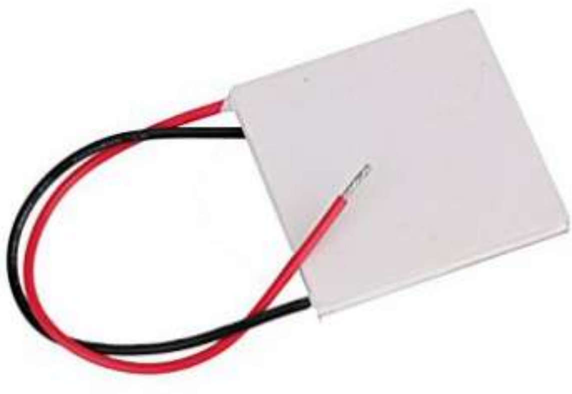

Figure 2. The Peltier.

Figure 3. The computer fan (20 amp).

the vapor squeezing refrigeration systems (Pearse, 2008).

Esfahani et al. (2011) made a movable system (solar still). The research was carried out in nine summers and winter days in Iran. The air temperature and the solar radiation magnitude in the summer is greater than the winter in Iran, hence, the results had a significant difference. The experiment result showed that the solar radiation magnitude affects the productivity of handy solar still.

MATERIALS AND METHODS

The study was conducted in Tehran province, in the Soil Conservation and Watershed Management Research Institute. The present study was carried out in salty (EC= 38 ppt) and normal water then in the soil. The experiment carried out in water was categorized based on water salinity. In this study, Peltier (Figure 2) with heat sink and copper iron and aluminium plates were used in water and salt water (7.5 L) applied. The hot temperature was cooled down by a computer fan (Figure 3).

The heat sink was made of 7 plates that were joined to another horizontal plate, the Peltier module stick on the top of the horizontal one. The plates were connected vertically to the heatsink to enter water and soil, and this lead to an increase in the efficiency of the element (Figures 4 and 5). Heat sink element was connected to the cooling unit. The shape and size of the heatsink have a huge impact on the performance.

In order to study the condensation efficiency and soil moisture content in three selected condensers includes iron, copper, and aluminium plates; experiments were performed in drinking water, saline water and then soil (Figure 6).

Experimental data were recorded each in 30 min, 8 h a day in a week. Water and soil temperature were measured. The energy production and losses were registered. Adjustment was made on the methodology because as it is, the experiment cannot be reproduced.

RESULTS

In order to gather results, at the beginning, the experiment was run in saline and drinking water then in the soil. The reduction in temperature was registered in the early hours, and became steady at the end of the process. The steady trend of the diagrams was due to the heat exchange stability. Output energy balanced by the energy produced, which if insulated, had a downward trend. Minimum temperatures were recorded and they vary due to different environmental temperatures.

The fluctuation of water temperature (in each kind of plates drawn, Figures 7 to 9) in drinking water in comparison with saline water was descending and being smoothed. According to Figure 7, water temperature in drinking water reach smooth trend sooner than saline water and the temperature in saline water decreased during the time.

According to Figure 8, water temperature in both drinking and saline water dropped and past tense tangent was used after 200 min.

According to Figure 9, temperature in saline water reached a constant trend but the temperature in drinking water continued decreasing.

According to Figure 10, the temperature drop in the copper plate is higher than iron and aluminium condensers. The rate of temperature reduction in salinity water with all plates was higher than water. According to Table 1, during the 4 days of experiment, the highest amount of energy in saline water was 195.4 and 12.66 watts in copper plate. The lowest amount of energy loss in drinking water was 498.48 watts, and in salinity water it was 524.6 watts in copper one. (Figure 11 and 12)

The soil temperature changes were evaluated using copper, aluminium and iron plates and the results are as shown in Figure 13. Table 2 shows the equations that indicate the temperature variation of the soil.

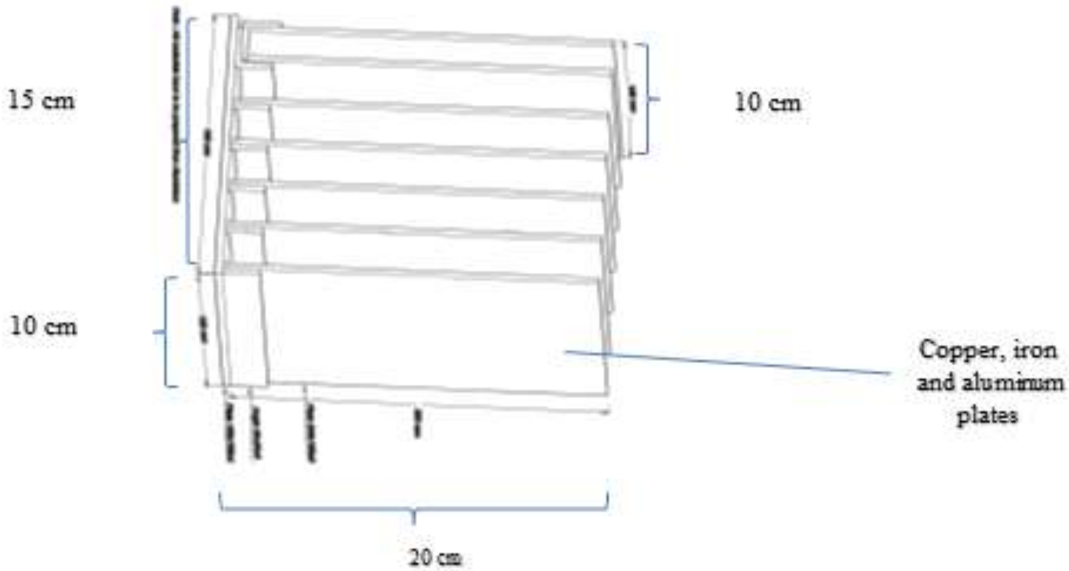

Figure 4. Schematic of the Peltier system.

Figure 5. The set of cooling system.

Figure 6. Refrigerants used in this study.

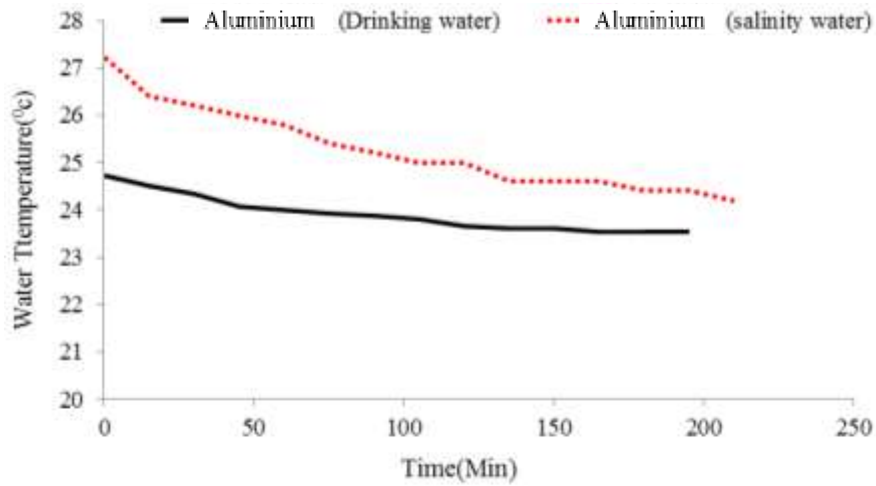

Figure 7. Temperature drop chart in aluminium plate.

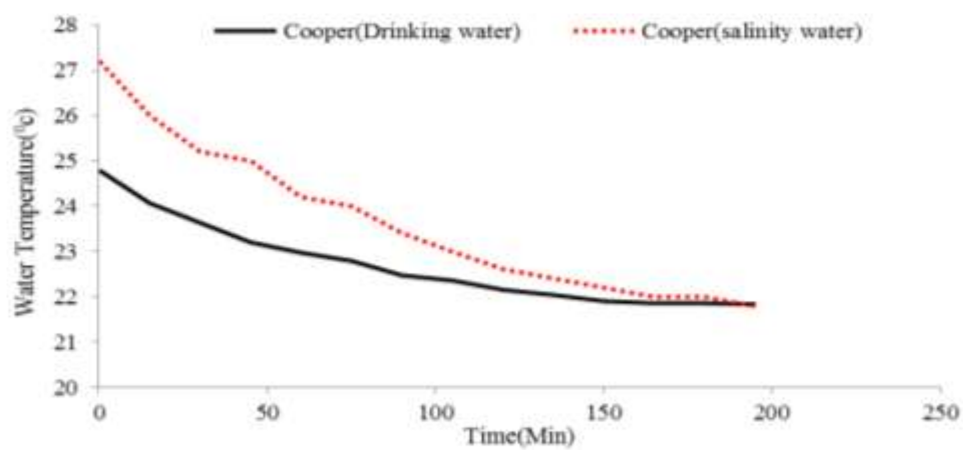

Figure 8. Temperature drop chart in cooper plate.

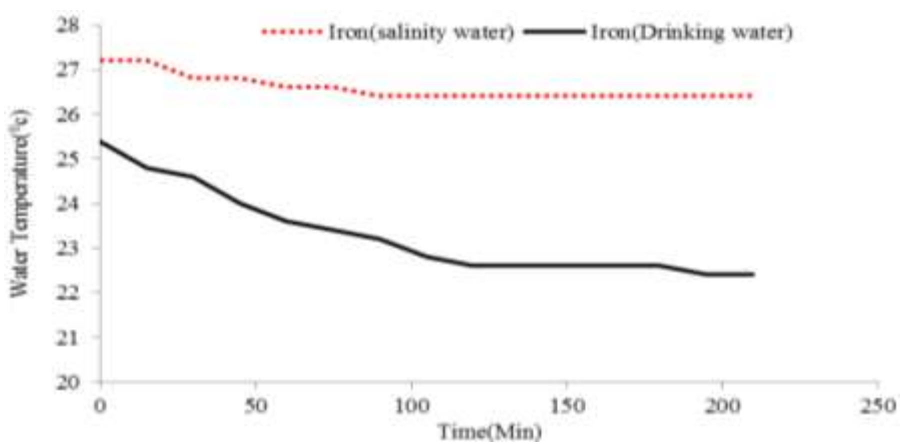

Figure 9. Temperature drop chart use of iron plate.

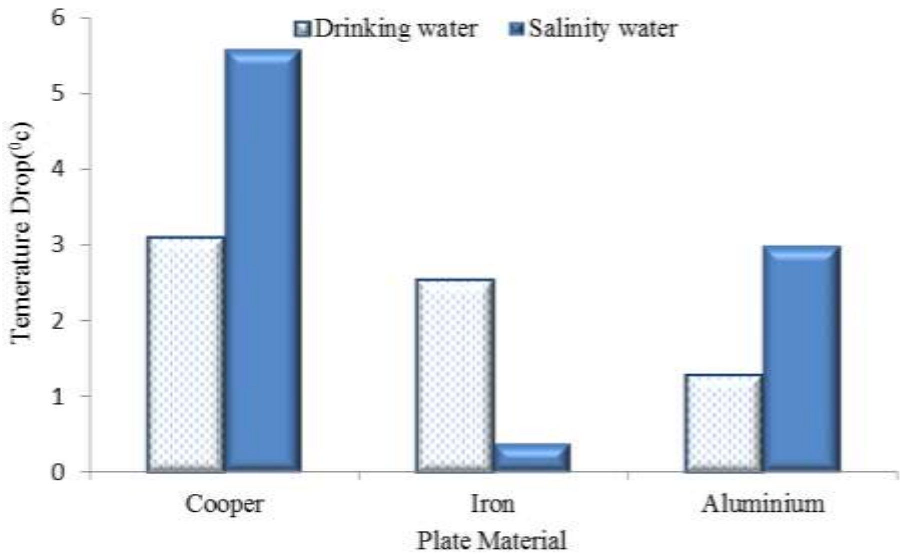

Figure 10. The temperature drop in the use of Copper, Aluminum and Copper plates in water.

Table 1. Energy production and losses.

Energy (watt)	Plates	Drinking water-1	Drinking water-2	Drinking water-3	Drinking water-4	Salinity water
Energy production (watt)	Cooper	115.14	125.61	69.78	125.61	195.39
	Iron	97.7	111.65	48.85	104.68	13.96
	Aluminium	13.96	90.72	20.93	55.83	104.68
Energy losses (watt)	Cooper	508.86	498.39	650.22	594.39	524.61
	Iron	526.3	512.35	671.16	615.33	706.04
	Aluminium	610.04	533.28	699.07	664.17	615.33

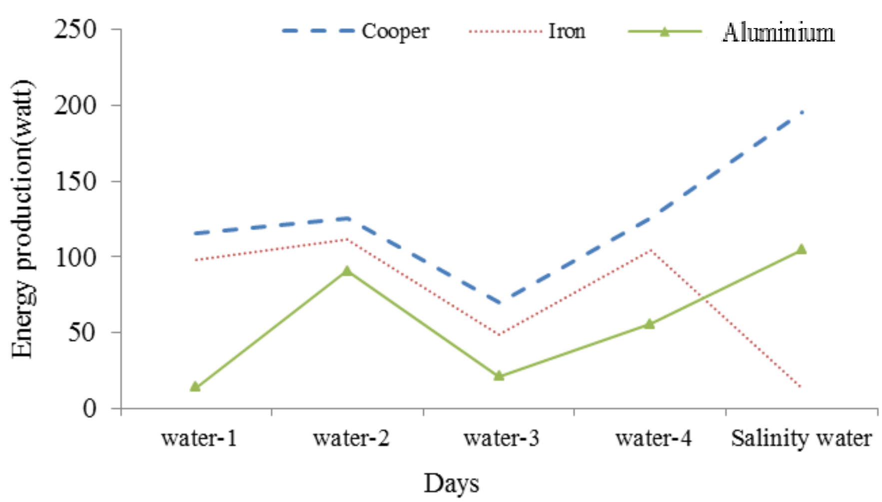

Figure 11. Energy production changes.

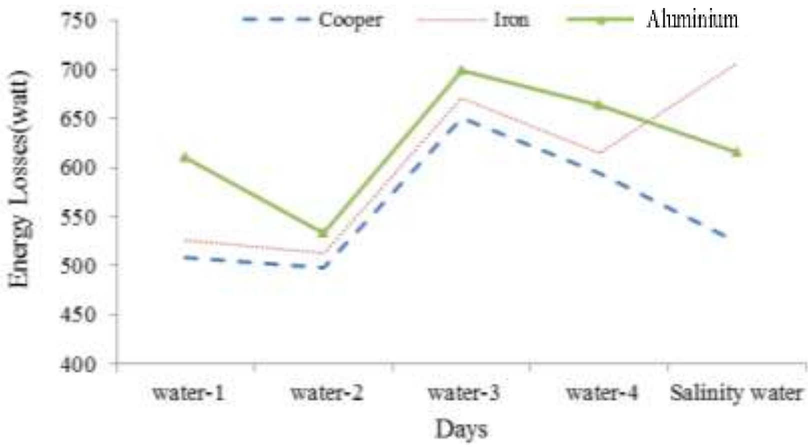

Figure 12. Energy loss changes.

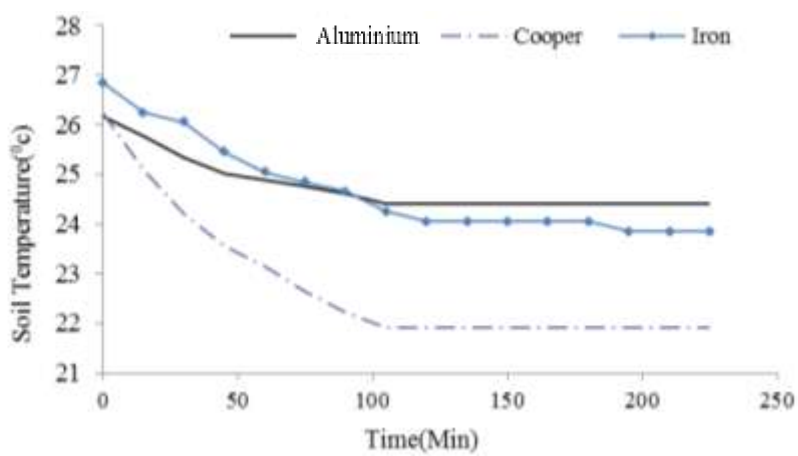

Figure 13. Temperature drop chart in using cooper, aluminium and iron plates.

Table 2. The equations that indicate the temperature variation of the soil.

Plate	Equations
Iron	y = -0.0124x + 26.09
Cooper	y = -0.0156x + 24.531
Aluminium	y = -0.0064x + 25.493

According to the charts in the soil, temperature drop happened in about one third of the time interval sooner than water.

DISCUSSION

The intermolecular force or van der Waals forces have a great influence on fluids, and also the molecular distance in liquids is greater than that of solids. As a result, the amount of thermal conductivity of liquids is relatively small compared to solids. Therefore, according to Figure 13, the temperature drop in copper-based plate was more than two other plates in the soil so using copper in soil was effective in improving soil condensation capacity.

This means that because of the physical properties and the density of the soil, soil temperatures reduced faster. Due to the nature of the plates, the temperature drop in the use of copper reflux occurs sooner than aluminium and iron.

Conclusion

Iran is facing the problem of water scarcity and is one of the countries located on the dry belt of the earth. The increasing population growth and the need for agricultural and livestock products and the limitation of water and soil resources for agricultural production are the problem of water deficit. In order to increase the water retention capacity in the soil and reduce the evaporation from different layers of soil, it is possible to use Peltier with plates in different materials. In the case study, copper-based refrigerant had the greatest reduction in temperature compared with aluminium and iron plate in water. Also, copper-based plates in soil had faster drop in temperature about 10% in comparism with aluminium and iron plates. This research can be expanded with different materials and in the field to ensure its effect and possibility to widespread. The result of the experiment was not checked statistically; the recommendation to address this issue in further experiments by performing more treatments and repetitions.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Determination of effective organic baiting technique for harvesting of termites (*Macrotermes Bellicosus*) for use as alternative protein for poultry

Wilson O. Haira[1*], Dennis O. Ochuodho[2] and Benson Onyango[2]

[1]Department of Agricultural and food sciences, Jaramogi Oginga Odinga University of Science and Technology, Kenya.
[2]Department of Biological Sciences, Jaramogi Oginga Odinga University of Science and Technology, Kenya.

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Experiments at Mbaga hills of Siaya County in Kenya were aimed to determine the most effective organic baiting technique for mass harvesting of *Macrotermes bellicosus*. Around two separate mounds, 5 treatments replicated 3 times, using earthen pot and plastic containers with maize stocks, eucalyptus stems, lantana camara twigs, Napier grass and rice husks, were set up. Termite counts, at 6.00 am and 6.00 pm, and data on temperature and humidity, from a Hobo data logger were collected over the 21 days period. The data were analyzed using Analysis of Variance (ANOVA) at (p=0.05) and Least Significance Difference (LSD) tests. Substrate preference differed significantly (p< 0.05) with highest being maize (2,919). Mean termite count differed significantly by containers (p< 0.05) with highest being earthen pots (1787). Termite count at 6.00 am (2,021) differed significantly (p< 0.05) with at 6.00 pm (1,952). The count further differed significantly by temperature at night (22.1 ^{0}C) and day (30.2±0.13). Finally, count differed by relative humidity (p< 0.05) at night (91.0±0.10) and day (69.1±0.50). Results on the effect of bait type, container type, humidity and temperature on count of termites may have practical, policy and theoretical implications for sustainable agriculture.

Key words: *Macrotermes bellicosus,* substrate preference, mass trapping.

INTRODUCTION

Termites are the largest group of insect detritivores comprising 90% of the insect biomass within tropical forest soils, making them fundamental in decomposition process (Nan-Yao, 2019). They are revered within rural communities due to their use in soil fertility improvement and as a food resource for both human and livestock (Mali et al., 2019). Studies have confirmed that insect entomophagy is practiced by about two billion people on earth (Van-Huis et al., 2013). In Africa, Termites are among the most consumed insects (Kinyuru et al., 2013). In West African states like Togo, Ghana, and Burkina Faso they have traditionally been used to feed poultry (Sankara et al., 2018). This begs the research question “Can *Macrotermes bellicosus* be harvested in large quantities for use as a sustainable and cheaper alternative source of poultry proteins?” The current study aims to determine an environmentally sustainable technique for the mass harvesting of *Macrotermes bellicosus* for use as an alternative source of protein in the manufacture of poultry feeds.

*Corresponding author. E-mail: wilsononyango2020@gmail.com. Tel: +254720340516.

Feeding poultry is costly with the cost of commercial feeds accounting for >70% of the total production cost (Sankara et al., 2018). The high costs of poultry feeds have been a major constraint with most farmers opting for free range indigenous birds. Even so, they still suffer from quantitative and qualitative food shortages (Pousga et al., 2007a, 2007b). This has affected supply of chicken meat and eggs and consequently reducing family incomes. The problem of high cost of feeds may be addressed if alternative sources of cheaper protein, such as termites, are explored. However, researchers are yet to determine the most effective organic baiting technique for the large scale harvesting of termites. Research on termite use as a cheaper source of protein in manufacture of poultry feeds is still in its infancy. Currently, research is yet to determine an environmentally sustainable technique for the mass harvesting of termites. As it stands, the protein component in poultry feeds is costly resulting to unaffordability by poor farmers. The current study seeks to address this problem by determining the most effective termite harvesting technique which is environmentally sustainable.

The literature on substrate preference suggests the use of maize stalks, rice husks, eucalyptus, lantana camara and Napier grass as suitable substrates for mass trapping of termites. Termites are usually found at sites with plant debris or dead animals, and can be spotted through the characteristic soils associated with termite tubes. The traditional baiting technique involves scrapping the soil with a hoe and then placing a trap consisting of a container, overturned and filled with humid organic matter. The trap is placed in the morning (6–8 am) or in the evening (around 6-7 pm) and covered with foliage or pieces of fabric to protect it against the sun. Termites are collected the following morning (6-7 am) or two days later. The organic matter, full of termites, is placed in another container and brought to the farm. If the pot is small and the quantity of organic matter is limited, the collection has to be made the following day otherwise termites will eat the whole content and leave the container (Dao et al., 2020). A variant of the method consists of placing the organic matter, e.g. cow dung, without a container, on the termite nests and tubes, and collecting the matter with termites by hand. Also, farmers may obtain termites by the less environmentally sensitive method of breaking termite mounds.

The use of termite remains a challenge as the traditional technique is not only destructive but may not be suited when high quantities are needed to feed a larger flock or to increase the proportion of proteins in their feeds. Because of this, many farmers stop feeding their poultry with termites, without finding alternative protein sources (Farina et al., 1993).

Other reasons for reduced usage of termites is the lack of time and the lack of knowledge of trapping technique (boafo et al., 2019a). The development of sustainable methods to trap and harvest termites is important for its successful use as alternative protein source for poultry in the traditional poultry keeping systems without affecting the environment and local biodiversity (Dao et al., 2020). Thus, the development of sustainable methods to collect, harvest and store termites is needed to ensure that traditional poultry farmers can provide protein feed to their birds without affecting the environment and local biodiversity (Dao, 2016; Ouedraogo, 2016; Boafo et al., 2019). The current study sought to identify suitable organic forage material and the best technique for collecting large quantities of termites for use as an alternative source of poultry protein.

MATERIALS AND METHODS

Study area

This study was carried out in Mbaga hills area in Hono sub location of Siaya County, Kenya. The County lies between latitude 0° 26'.to 0° 28' North and longitude 33° 58' East and 34° 33' West with a total land surface area of 1520 Km2. The county has six sub-counties namely; Ugunja, Yala, Ugenya, Siaya, Bondo and Rarieda. The county borders Busia county to the north, Kakamega county to the north eastern, Vihiga county to the east, Kisumu County to south east, with Lake Victoria to the south and west. The study site has an altitude range from 1140 M to 1200 M above sea level, with equatorial climate. An average temperature range of 17°C at night to 28°C at day time with a relative humidity of 24% day time and 81% at night (MOA, 2018). The site was chosen as a study area since it had few farmers already involved in termite trapping but using traditional baiting techniques.

Experimental design

A random block experiment comprising of five organic baits (decaying logs of *Eucalyptus* tree, dry maize straws, dried *Lantana* twigs, dried remains of Napier grass and dried rice husks). Each experiment was carried out in 3 replicates and lasted for a period of 21 days. In both the control and experimental groups, termite bait stations were placed around 2 randomly selected active *Macrotermes bellicosus* mounds found within the same plot. Each mound was surrounded by 5 bait stations placed in a circle following Mali et al. (2019). Each experimental units involved hoe-dug circular holes of diameter 30 cm and 25 cm deep. These specifications take into account earlier findings by the researcher, during the preliminary study that most termites are found within a depth of 25cm below the ground.

Baits were uniformly prepared, chopped and packed in plastic containers as illustrated in Figure 1, and then put inside the 25 cm deep pits at uniform depths.

The baits packed in the plastic containers were covered lightly with top soil in the control group experiment 1.This was to provide a dark environment inside and ensure that the termites attracted to the baits are not exposed to external weather factors such as rainfall and direct sunlight. An all-round 1.5 m distance was maintained between and within individual holes so that harvesting the termites in one hole does not influence those in next hole to disappear into their tunnels. In experiment 2, which was the treatment group, equal amounts of the baits were packed in round earthen pots as illustrated in Figure 2.

The pots were also laid inside the holes in an inverted position to guard external weather factors of rainfall and direct sunlight from

Figure 1. Organic baits packed in plastic containers (Control group).
Source: Authors

Figure 2. Organic Baits packed in earthen pots.
Source: Authors

influencing termites' interactions with baits. The arrangements thus involved 2 plots (separate farm lands) with 5 treatments replicated 3 times within a block as shown in Figure 3.

Data collection

Termites were collected daily early in the morning (6 am) and late in the evening (6 pm) from the earthen pots and plastic containers. Number of termites in each container was counted and recorded to give the count of termites attracted to each bait, for the control and treatment group experiments. The data collected was used to compute the average count of termites collected for determining the effect of container type on the count of termites Temperature and humidity data were taken using Hobo data logger (HOBO ware 3.7.22) at hourly intervals for both day and night. An average and standard deviation of the temperature and relative humidity collected was computed to assess the effect of environmental

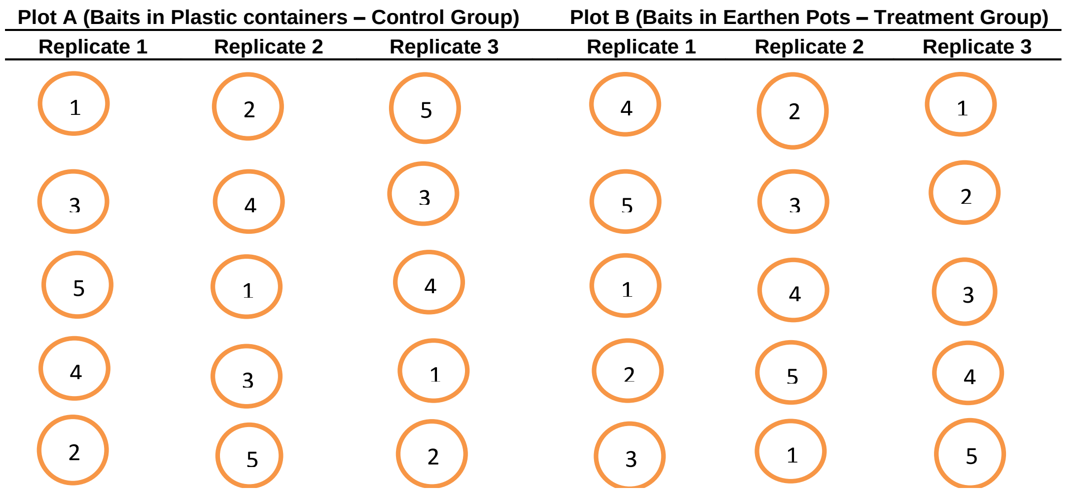

Figure 3. Arrangement of the control and treatment experiments across the plots.
Cycle in plot A represent dug pits fitted with plastic containers while those in plot B represent dug holes fitted with earthen pots all containing baits numbered 1-5.1, Log of *Eucalyptus* tree 2. Dry maize straws 3, Dried *Lantana camara* twigs 4. Dried remains of Napier grass 5. Dry Rice husks.
Source: Authors

factors on the number of termites harvested.

Data analysis

The data analysis was done using R statistical software (R v4.0.2). Descriptive statistics consisting of mean and standard error were computed to facilitate tests of the hypothesis. Analysis of variance (ANOVA) was done to compare how the various baits performed in attracting termites. Mean separation between the baits used was done using least significant difference (LSD), for counts of termites collected in earthen pots and plastic containers. In all tests, the computed p value was compared with the critical p value to establish the statistical significance of the effects of bait type, container type, collection period, humidity and temperature, on the count of termites harvested. Where the computed p value was compared to the critical p value of 0.05 to test the hypothesis.

RESULTS AND DISCUSSION

Results

The first objective in this study was to identify the preferred organic bait for the mass harvesting of *Macrotermes bellicosus*. To determine the preferred organic bait the study tested the hypothesis that there was no statistically significant difference in attraction of *Macrotermes bellicosus* to different organic baits. Table 1 presents the results of the Least Significance Difference Test for the mean count of termites collected using earthen pots and plastic containers.

Effect of type of organic bait on the count of termites

The results of the Least Difference (LSD) Test, presented in Table 2, shows that at a 5% level of significance there were significant differences in the mean count of termites trapped using the five different types of organic baits. Further, as evident from Table 1, the differences were still significant irrespective of the type of container used to collect the termites. As shown in Table 1, the maximum harvest of termites obtained from the use of maize straws, of 2,919 in earthen pots and 1,543 in plastic containers were statistically different ($p<0.05$) with all the other treatment. Also, the mean count of termites for Rice husks, Napier, *Eucalyptus* log and Lantana twigs were statistically different ($p<0.05$) with each other in both experiments, except in one case. This exception, is evident in Table 1, from the similarity of superscripts following the mean counts for eucalyptus and lantana twigs, in which there wasn't a statistically significant difference ($p<0.05$). Further, Table 1 shows that *Lantana* twigs had the least ($p<0.05$) number of termite-catch in both setups. This was unique in the experiment where termites were trapped in plastic containers but did not differ significantly ($p>0.05$) with those attracted by *Eucalyptus* logs where termites were attracted using earthen pots.

An ANOVA test was carried out to the hypothesis that there is no statistically significant difference in attraction of *Macrotermes bellicosus* to the five organic baits. The result of the test of overall statistical significance in the difference of termite counts for the five types of baits is presented in Table 2.

The last column of Table 2 labeled *p* shows the significance of the statistical test applied to the hypothesis. To reject or not reject a hypothesis, the *p* value in Table 2 is compared to the critical value of $p = 0.05$. The universal rule in all statistical tests is that, the

Table 1. Mean significance difference in attraction of Macrotermes bellicosus to different organic baits.

Baits	Type of Container	
	Earthen Pot	Plastic Container
	Mean count ± SE	Mean count ± SE
Dry maize straws	2,919 ± 6.97[a]	1,543 ± 3.99[a]
Dry rice husks	2,286 ± 5.13[b]	943 ± 3.00[b]
Dried Napier grass	1,775 ± 4.55[c]	653 ± 3.97[c]
Decaying log *Eucalyptus*	1,513 ± 4.69[d]	444 ± 3.76[d]
Dried *Lantana* twigs	1,440 ± 3.78[d]	287 ± 2.61[e]

Means in a column followed by unlike letter (s) are significantly different at 5% level using LSD test.
Source: Authors

Table 2. Analysis of variance on the effect of organic baits on the count of Macrotermes bellicosus harvested.

Variation	DF	Sum of squares	Mean sum of squares	F-value	P-value
Baits	4	192,269,283	48,067,321	114.844	2e-16 *
Period	1	760,174	760,174	1.816	0.178
Residuals	624	261,171,756	418,544		

*Implies significance at 5% level of significance.
Source: Authors

Table 3. Summary statistics on the effect of environmental factors and the count of termites harvested.

Collection Period	Mean Temp (^{0}C)	Mean RH (%)	Mean Count from Earthen Pot Containers	Mean Count from Plastic Containers
Day	30.2±0.13	69.1±0.50	1,952±16.1	742±8.82b
Night	22.1±0.04	91.0±0.10	2,021±14.5	806±9.49a
	*	*	NS	*

NS=Not significant; *implies significant at 5% level of significance.
Source: Authors

decision about significance is made by checking if the computed value of *p* is smaller than the significant alpha level of 0.05. In Table 2, the *p*-value associated with the first source of variation, namely the organic baits used in trapping of termites was 2^{e-16} and less than the decision value of 0.05. This is interpreted to mean that that there is a statistically significant difference in the effectiveness of the various types of organic baits on the count of termites harvested. Accordingly, based on the ANOVA results in Table 2, the null hypothesis that there is no statistically significant difference in effectiveness of organic baits for the mass trapping of termites is rejected.

It can therefore be concluded, from the ANOVA test results in Table 2, that the various organic baits differed significantly in their ability to trap termites. In particular, as indicated in Table 1, the most preferred organic bait by termites, as determined by the highest mean count (2,919) was dried maize straw.

Effect of environmental factors on *Macrotermes bellicosus* harvested

The second objective of the study was to determine the effect of environmental factors on the count of *Macrotermes bellicosus* harvested. Table 3 provides the summary statistics of the effect of environmental factors on the count of termites harvested.

As Table 3 shows, the mean count of termites harvested were highest (mean = 2021) when termites were collected overnight, in earthen pots. This coincided with the lowest mean temperatures of 22.1 ^{0}C and highest mean relative humidity of 69.1 %. From Table 3, the effects of temperature, relative humidity and plastic

Table 4. Analysis of variance (ANOVA) on the effects of environmental factors on the count of Macrotermes bellicosus harvested.

	Variation	DF	SS	MSS	F - value	P - value
Earthen pots containers	Collection Period	1	201	57201	0.7526	0.002116*
	s(avg_temp)	1	952.669	952.669	12.5343	0.001248*
	s(avg_RH)	1	394781	394.781	5.1941	0.029475*
	Residuals	32	2,432.203	76,005		
Plastic Containers	Collection Period	1	141.748	141.748	4.9468	0.0333188*
	s(avg_temp)	1	543.961	543.961	18.9833	0.0001272*
	s(avg_RH)	1	118	118	0.0041	0.0492459*
	Residuals	32	916.966	916.966		

s (avg_temp) is the smoothing function of the average temperature, s (avg_RH) is the smoothing function of the average relative humidity, *implies significant at 5% level of significance.
Source: Authors

containers had a statistically significant effect on the count of termites collected at the 5% level of significance. However, the effect of earthen pots did not have a statistically significant effect on the count of termites harvested.

The data in Table 3 was used to carry out an ANOVA of the effect of environmental factors on the count of termites harvested. The study tested the hypothesis that environmental factors do not have a statistically significant effect on the count of Macrotermes bellicosus harvested. Table 4 presents the results of ANOVA tests of the statistical significance of the effects of types of containers, time of collection, temperature and humidity on the count of termites harvested.

As evident in Table 4, the ANOVA test shows that the effect of temperature (p = 0.001248, for collection in pots and p = 0.0001272 for collection in plastic containers) was less than the critical *p-value* of 0.05%. Also, it is evident that the effect of relative humidity (RH) (p = 0.029475, for collection in earthen pots and p = 0.0492459 for collection in plastic containers) was less than the critical *p-value* of 0.05%. Further, the effect of collection period (p = 0.002116, for collection in pots and p = 0.0333188 for collection in plastic containers) had a statistically significant effect on the count of termites harvested. Evidently, as the computed value of p was less than the critical value of p of 0.05.

Summary of results of hypothesis testing

The first null hypothesis (H_1) sates that there is no statistically significant difference in the count of *Macrotermes bellicosus* attracted to different organic baits was rejected. It was therefore concluded that there was a statistically significant difference in the count of termites attracted to the different organic baits. The second null hypothesis (H_2) that environmental factors have no statistically significant effect on the count of Macrotermes bellicosus harvested was rejected; hence environmental factors had a statistically significant effect on count of termites harvested.

DISCUSSIONS

Effect of Organic Baits on the count of *Macrotermes bellicosus* harvested

Termite preference for organic-based baits can be identified through their presence and activity within biomass litter. This has made it difficult to identify an optimal bait type that may be used in the mass harvesting of termites. To fill this gap, the current study is designed to provide additional evidence on termite preference for organic baits that are abundant in equatorial climate. The current study provides empirical evidence that maize straw, which are abundant in the equatorial climate, in counties such as Siaya, is most preferred organic bait for mass trapping of *Macrotermes bellicosus*.

The finding that maize straws were the preferred organic bait in the mass trapping of termites was evident when both types of containers were used in the mass trapping of *Macrotermes bellicosus*. In particular, the results of the two experiments of 2919 and 1543 termites harvested, were statistically different ($p<0.05$) with all the other treatment. This finding confirms previous research that has suggested that baits with cellulose may be the preferred bait for trapping termites, in equatorial Africa.

Research by Mali et al. (2019) suggested that termites prefer food with high levels of cellulose. On the other hand, since lignin is harder to digest termites do not like it compared to other baits (Judd and Corbin, 2009). Although there is no evidence to conclude that termites have cellulose receptors, it is thought that termites break down the cellulose in their guts and determine the sugar concentrations (Brune, 2014). Foods rich in sugars such as glucose are a preference to termites (Abushama and

Kambal, 1977; Waller and Curtis, 2003). Castillo et al. (2013) had demonstrated that addition of sugars to bait enhanced termite presence in those baits. Thus, the linkage of sugars with cellulose could be the answer to termite's preference of maize straws irrespective of the types of containers used to trap termites. The preference for foods with greater cellulose concentrations could also be adaptive for termites and their symbionts in that higher cellulose concentration would be more digestible.

Wood such as Eucalyptus and Lantana which have higher indigestible components including lignin (Curtis, 2004) can prevent digestion hence reduced feeding rate or preference. This is also in concurrence with Waller et al. (1990) who suggested that the amount of cellulose per unit area be considered in a bait selection study with termites.

The termites could also have made their choices based on nutrient value such as levels of nitrogen, phosphates and micronutrients or proportions of digestible components in the food source. Preference of termites to maize stalk is also in agreement with findings by both Peden et al. (2013) and Wang and Henderson (2012) demonstrating termite preference to maize in laboratory and field experiments respectively. Mali et al. (2019) also suggested that termites had high affinity to maize due to high presence of organic carbon and simple sugars.

Eucalyptus and Lantana are known for the toxic substance, known as allelopathy, which repels termites (Mali et al., 2019). The allelochemicals released from chopped Eucalyptus logs could thus have led to reduced liking compared with the rest of the diets. Mali et al. (2019) also observed that some tree species such as pine are repellants due to production of allelochemicals to naturally deter insect feeding. This property might have worked against Eucalyptus logs being preferred in the current study. It may be concluded that for the mass trapping of termites, in equatorial Africa, the widely available maize stalks ought to be used to optimize the count of termites.

Effect of environmental factors on the count of macrotermes bellicosus harvested

The current study sought to provide empirical evidence on the effect of the environmental factors on the count of termites harvested. To establish the effect of environmental factors the study investigated the effect of temperature and humidity as key environmental factors that drive the count of termites harvested. Following previous studies, the research sought to determine if the use of natural or artificial containers for trapping of termites and the time of their collection, all environments related factors have on the count of termites harvested. From the results it is evident that environmental factors have an effect on the count of termites harvested. The study found out that the use of earthen pots would result in more termites in comparison with plastic containers. In particular, it was established that use of natural containers was more effective collection containers, as they mimicked the type of environmental conditions termites require to survive. In particular, it may be argued that use of earthen pots enabled the researcher to naturally control the effects of confounding factors, such as temperatures and relative humidity. Further, the use of plastic containers may have resulted in the suffocation of termites, as plastic containers trapped heat.

The explanation, in the current study of the effect of containers and collection times, as surrogates of environmental variables resonates with earlier findings that humidity and temperature determine the distribution and availability of termites (Swoboda, 2004). Further, the findings that the termite counts are higher, the higher the relative humidity and lower their temperatures, support assertions that termites love moist environments (Boafo et al., 2019b). Perhaps this is why in the current experiment, termites were less attracted to traps that consisted of a non-natural objects, such as plastics that may have instead acted as natural barriers rather than a preferred container for mass trapping of termites.

The current study sought to find out if the time of collection was a significant effect on the count of termites harvested. In particular, it sought to establish whether the time of day or night at which the termites were collected influenced the count of termites collected. The finding that the time of collection was a significant determinant of the count of termites supports earlier findings by Dao et al. (2020) that termites are sensitive to temperatures and drive deep in the subterranean part of the nest during the day when the sun is shining. The findings in this study provide empirical support to the assertion that the maximum count can be obtained in the morning. The finding of a high termite count in the morning confirms earlier findings on the significance of collection times.

The time of collection was a statistically significant determinant of termite counts in line with previous findings that termites drive deep in the subterranean part of the nest during the day when the sun is shining (Dao et al., 2020). While the time of collection and type of containers were used as indirect variables to capture the best techniques, regarding container types and collection times that suited the environment for termites. In addition, it sought to establish the effect of environmental factors, using the most often cited direct measures of environmental factors, namely temperatures and humidity. The results show that termites were less available in the day when temperatures were high and humidity was low. The findings confirm that termites were more available at night possibly as a result of lower temperatures and higher humidity at night. It was established that nights were relatively colder and more humid than days hence the higher number of termites lured to the baits at night.

The finding on the effect of temperature and relative humidity supports earlier findings by Boafo et al. (2019b) that termites require moist environments, for forming mud tubes that bridge the distance between their tunnels and their food. Zukowski and Su (2017) found that high relative humidity was preferred by most termite species when studying termite survival when exposed to different levels of relative humidity. A study by Swoboda (2004) established that soil chemical composition, moisture and humidity dictate the availability of the termites. They also established that cooler nights with less evaporative potentials saw more termite activity and less stress in burrowing and looking for organic baits in this experiment. It is clear that from the findings in this study that it would be more efficient to place baits overnight and collect termites in the morning rather than do it during the day albeit more pronounced in plastic container pits.

It may be concluded that findings in the current study amplify earlier work in the context of an equatorial environmental conditions, such as that which was obtained at Mbaga hills, in Siaya County, Kenya. Like in previous studies the experiments, in the current study demonstrate the statistical significance of the type of organic bait and environmental conditions, on the count of termites trapped and collected.

Conclusion

A number of conclusions can be drawn from the findings on the most suitable bait and choice of container and the time of collection. First, from the finding that the organic bait types used had significantly different effects on the count of termites collected, it may be concluded that maize straws are the most effective bait. Second, three conclusions may be drawn from the findings on the effects of environmental factors, namely humidity and temperature, collection containers and time of collection, on the count of *Macrotermes bellicosus* harvested.

The first conclusion, related to environmental factors, arises from the finding that the low temperatures at night had a statistically significant difference on the count of termites collected during the day and at night. It may be concluded that in considering the most suitable baiting technique, the influence of temperatures on the time of collection cannot be ignored. In particular, it may be concluded that the best technique of trapping termites of the *Macrotermes bellicosus* species ought to include the period of collection. Thus it can be concluded that collection of termites at night offers the most suitable period owing to the effect of lower night temperatures on the count of *Macrotermes bellicosus* harvested.

The second conclusion related to the effect of environmental factors, derives from the effect of relative humidity on the count of Macrotermes bellicosus collected. It may be concluded that arising from the higher count of Macrotermes bellicosus collected at higher relative humidity at night, an optimal organic baiting technique ought to include the effect of relative humidity.

Thus, it can be concluded that an optimal technique for collection ought to consider the influence of higher humid conditions occurring at night, hence *Macrotermes bellicosus* should collected very early at 6 am when it is still humid this is an important consideration in deciding on the optimal organic baiting technique for the mass harvesting of *M. bellicosus*.

The third conclusion, arising from the effect of environmental factors, derives from the effect of earthen containers on temperature and humidity in the bait stations. It may be concluded that since the type of containers used had a statistically significant difference on the count of termites harvested, an optimal technique for the mass harvesting of *M. bellicosus* ought to consider the type of containers used. In particular, the use of natural earthen pots, owing to their effect of lowering temperatures and increasing humidity, are better that plastic container for the mass trapping of termites.

In a nutshell, an optimal technique for the mass trapping of *Macrotermes bellicosus* ought to consider the effects of bait type, container type, and period of collection. From the findings in the experiments, the effective organic baiting technique ought to consider the type of organic bait used, type of container used and the time at which termites are collected. Previous studies by Ayieko et al. (2010), and Fiaboe and Nakimbugwe (2017) explored the use of different baits to trap termites for poultry feeding. It can be concluded that the current study adds to this stream of research and has aided in the determination of effective organic baiting technique for mass harvesting of *Macrotermes bellicosus* for use as an alternative protein for poultry. More significantly, it answers the call for further research and innovations on methods of collecting termites among poultry farmers by Van-Huis et al. (2013).

RECOMMENDATIONS

Practical and policy recommendations

The finding from this study leads to a number of practical and policy recommendations in relation to the determination of an effective organic baiting technique for the mass harvesting of *Macrotermes bellicosus*. The first practical recommendations are derived from the effect of type of organic baits used on the count of *Macrotermes bellicosus* harvested. To begin with, it was evident that the most effective organic bait is maize straws. It is therefore important that poultry farmers acquire huge stocks of dry maize straws that should then be used to continually bait termites by setting traps around their mounds. The second practical recommendation for farmers is derived from the effect of environmental factors on the count of *Macrotermes bellicosus* harvested.

It can be recommended that farmers set up traps by placing inverted earthen pots filled with dried maize stalks in holes dug up around mounds of *Macrotermes bellicosus.*

The use of earthen pots as opposed to plastic containers will ensure that farmers trap more termites in an environmentally sustainable manner. Earthen pot containers are natural and hence bio degradable, in addition to being able to create a conducive environment for the sustainable mass trapping of Macrotermes bellicosus. This recommendation on the use of earthen pots is a more environmentally sustainable practice as opposed to the traditional practice of destroying the termite mounds. Another practical recommendation for farmers, deriving from environmental factors, is that termites ought to be trapped overnight as the environment is more humid and cooler than during the day.

It may be recommended that traps be set up at night and termites collected in the morning at 6 am and not in the evening as fewer termites would have been trapped during the day.

Policy recommendations

In addition to the practical recommendations to farmers that derive from the findings of the current study, there are also important policy recommendations that may be made from the results of the study. The first policy recommendations derives from the finding that maize stalks are the optimal organic baits for the mass trapping of termites. The ministry of agriculture can consider enhancing the sustainable harvesting of *Macrotermes bellicosus* through encouraging use of maize stalks as a policy. In particular, the policy can target the setting up of agricultural extension services, at National and County levels, to train farmers on alternative and more sustainable approaches to sourcing protein for their poultry.

Currently, there is no policy framework that supports sustainable harvesting of termites in Kenya, and traditional approaches, involving the destruction of *Macrotermes bellicosus* mounds is common. Thus, it will be important for the ministry of agriculture to develop a policy on harvesting *Macrotermes bellicosus* using a more effective and sustainable technique for baiting and harvesting. This will involve the use of earthen pots and the trapping of termites over night to be collected in the morning.

Recommendations for further study

Recommendations on additional further research on the optimal baiting technique for the mass harvesting of *Macrotermes bellicosus* can be derived from the inherent limitations in the methods chosen to conduct the current research. First, it may be recommended that laboratory experiments ought to be set up for a better control of the influence of bait type, container type and time of collection on the count of termites harvested. In particular, laboratory experiments would provide a more accurate set up to isolate the mediating effects of type of container and time of collection on the influence of temperature and humidity on the count of *Macrotermes bellicosus* harvested.

Second, the experiments in the current study were carried out in an area whose climatic conditions are equatorial. Thus it may be important to replicate the study in temperate or tropical environmental conditions. Also, future work could focus on determining the influence of other types of organic baits, in addition to the five considered in the current study.

Finally, as utilization of termites as a source of proteins for poultry will go a long way in bringing down the costs of poultry feeds, more studies are necessary to compare effectiveness of other types of baits and the baited container techniques. Perhaps experiments involving moist baits or adding of glucose to the bait may be more instructive of the techniques that may yield the highest count of termites harvested. Also, there is strong need to carry out further research towards solving the food security challenges facing humanity world over, utilizing different species of insects as a source of proteins for different livestock species.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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