Could Shea be the next gold for Ghana?

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Graphical Abstract

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Abstract

In numerous shea producing regions of Ghana, rural women benefit significantly from the gathering, initial processing, and eventual selling of shea-based goods for their cash income. On a global scale, shea butter has emerged as a trendy ingredient in premium beauty products, due to its healing qualities, moving away from its traditional role as a cost-effective replacement for cocoa butter. International development organizations have focused on the shea value chain in Ghana as a component of their efforts to support private sector growth and decrease rural poverty. The shea value chain gives Ghanaian women the ability to take control of their financial, social, and entrepreneurial well-being, provide opportunities to earn money, enhance skills, and have more influence in their families and communities. Shea butter production in Ghana has the capacity to boost the productivity of shea butter enterprises, create employment opportunities for marginalized groups, particularly women, and ultimately support women's empowerment by reducing poverty. Shea ecological zones contain a diverse range of plants and animals and play a key role in storing carbon. In addition to the ecological significance, the shea parklands and ecological zones hold significance as vital resources and symbols of identity, spirituality, and tradition for Ghanaians, contributing significantly to the nation's cultural heritage. Shea butter from Ghana is highly desirable in global markets because of its superior chemical composition, derived from quality shea nuts. This means that Ghana can grow its shea industry, which will also increase foreign earnings. Therefore, shea could become the next gold for Ghana. In this regard, nature-based solutions and innovations can be employed to agronomically facilitate the supply of quality shea nuts to the shea industry. In alignment with this vision, a new open-access journal called "Journal of Nature-based Solutions and Innovations" has been launched. This journal is targeted to inspire and communicate imaginative research and innovations in the intersection of nature, sustainability, and novel technology. It is aimed at targeting global challenges such as depletion of resources, loss of biodiversity, climate variability, and environmental degradation through encouraging and disseminating new perspectives that leverage the power of nature and human creativity to provide informed decisions. We welcome impactful submission of impactful papers. Come explore the intricacies of using nature-based solutions and innovations to solve societal and environmental problems.

Keywords: good health; journal of nature-based solutions and innovations; poverty alleviation; shea value chain; socio-economic transformation; women empowerment

1 Introduction

Shea butter is derived from the kernels of the shea tree (Vitellaria paradoxa), which is native to Africa (Seghieri, 2019). The shea tree is primarily located in the Sahel Region of Africa. Shea trees live for 200 years and begin bearing fruit when they are 15 years old. Traditionally, women have been responsible for gathering shea nuts and producing shea butter, with the knowledge being handed down from one generation to the next. The procedure is very demanding in terms of labor and continues to be so even now, despite the implementation of some technology. Shea butter has long been known as 'women's gold" because of its golden hue and purported ability to help countless impoverished women improve their financial status through employment opportunities. In 2020, the global shea butter market was estimated at approximately USD 690.1 million, with a projected increase to USD 849 million by 2027 as per the 2022 Cosmetic Shea Butter Market report (Mensah and Turvey, 2023). In West Africa, exports bring about annual revenue of USD 90 million to USD 200 million. Shea is one of the top export products in Ghana. Recent reports suggest that the worldwide shea butter market is valued at 2.75 billion, with predictions showing an increase to 5.58 billion by 2033 (UNDP, 2024). In West Africa, more than 16 million women earn a livelihood by farming and processing shea nuts (https://globalshea.com). Ghana is one of the top producers of shea butter globally, and reports indicate that shea nut exports are currently worth 66 million, and approximately 1 million rural women are employed in this sector (UNDP, 2024). Shea butter is a precious resource that is extensively utilized for cooking, making cosmetics, producing food and medicines, and, especially, as a replacement for cocoa butter in making chocolate. Despite the significant influence and numerous stories on the matter, there has been minimal investigation into how the industry benefits Ghana and how shea could possibly become the next "brown gold" for Ghana. This editorial piece sheds light on how shea could become the gold for Ghana.

2 Socio-transformative Impact of Ghana's shea industry

According to the Global Shea Alliance, approximately 16 million women in 21 African nations, ranging from Senegal to South Sudan, rely on the shea tree for income (https://globalshea.com). Women in Ghana are essential to every step of the shea value chain, from collecting nuts in rural regions to producing and selling shea butter in local and international markets. Engaging in the shea industry gives Ghanaian women the ability to take control of their financial, social, and entrepreneurial well-being, provide opportunities to earn money, enhance skills, and have more influence in their families and communities. Adams et al. (2016) emphasized that shea butter has the ability to improve the Ghanaian economy and the quality of life in rural communities, especially for women. It can act as a more affordable option compared to other items, highlighting its considerable value and acknowledgment globally. Shea butter processing is a prominent traditional business in the northern parts of Ghana, being the main source of income for numerous rural women. Nevertheless, despite their vital role, women in the shea industry frequently encounter barriers that hinder their economic potential and uphold inequality, such as scarce resources, meager earnings, difficulties in market entry, and discrimination based on gender. Starting and supporting women's cooperatives is essential for tackling these difficulties. Women can secure quality permits and access the global market when they join cooperatives. The shea nut industry plays a crucial role in improving economies, particularly in rural regions of developing nations where poverty is widespread, especially in regions where the shea tree grows naturally (Adams et al., 2016). It acts as an important source of earnings and support for numerous local communities, particularly rural women involved in gathering, processing, and selling shea nuts. This activity offers them chances for both employment and starting their own businesses. The income created from the production of shea butter aids in reducing poverty and enhancing living standards in these regions, backing education, healthcare, and other crucial necessities (Ayelazuno and Yaro, 2024). Economic empowerment has a positive influence on different aspects of their lives, such as social and political, and also improves food security (Pouliot, 2012). In the northern part of Ghana, more than six hundred thousand women rely on earnings from the sale of shea butter and other shea-related items to support their everyday expenses (Ayelazuno and Yaro, 2024). Ibrahim et al. (2016) emphasized that shea butter is an important export commodity to Europe and the United States, which helps boost foreign exchange earnings. The monetization of shea items is an important revenue stream for many people, and the shea sector has played a significant role in the economic growth of northern Ghana. The consistent market for shea butter is guaranteed by the global demand from industries like cosmetics, food, and pharmaceuticals. This, in return, encourages economic development at the country level and offers governments a source of income through taxes and tariffs on exports. The economic importance of shea butter extends beyond the areas where it is produced, highlighting the value of this natural resource for both local and global economies. Furthermore, aside from the earnings of rural families, the shea sector employs more than three thousand individuals involved in gathering, refining, and marketing shea nuts and butter in northern Ghana (Ayelazuno and Yaro, 2024). Ghana has the capability to supply up to ninety percent of the global shea nuts. WATH (2004) states that shea butter from Ghana and Burkina Faso is highly desirable in global markets because of its superior chemical makeup, derived from quality shea nuts. This means that Ghana is capable of growing its shea industry, which will also increase foreign earnings. Hence, shea butter could become the next gold for Ghana.

3 The role of shea in empowering women economically

The shea tree (Vitellaria paradoxa) is a significant source of income for many women across Africa. Naughton et al. (2015) provides a comprehensive analysis of the shea tree's distribution and its potential for income generation, estimating that 18.4 million women collectors are involved in the shea industry across 23 countries. This figure slightly exceeds the number provided by the Global Shea Alliance, indicating the extensive role of shea in rural livelihoods. Naughton et al. (2017) further emphasizes the importance of shea butter to women's empowerment and household economy, aligning with the Global Shea Alliance's focus on the socio-economic impact of shea on women. The shea tree's significance extends beyond economic benefits, contributing to food security, social capital, and cultural practices (Naughton et al., 2017). Therefore, the shea tree is not only a source of income but also a cornerstone of community well-being and women's empowerment in the regions where it grows (Naughton et al., 2015, 2017). Ghana has a high capacity to process shea butter. Shea butter production in Ghana has the capacity to boost the productivity of shea butter enterprises, create employment opportunities for marginalized groups, particularly women, and ultimately support women's empowerment by reducing poverty. The Ghana Export Promotion Council (GEPC) stated that the quantity of shea butter exported varied from 1,310 MT in 1998 to 2,539 MT in 2002 (Mohammed et al., 2013). Recently, shea butter has become economically significant owing to its increased presence in the global market. The shea industry's significant export potential is aiding the growth of the national economy, industrial development, and creating job opportunities for the disadvantaged. Hyman (1991) estimated that shea butter is made by more than two million women in 13 African nations for personal use and as a source of income. The shea butter sub-sector in Ghana helps reduce the movement of young people and women from rural areas in the north to urban centers, such as Sunyani, Kumasi, Takoradi, Cape Coast, and Accra. In many shea-producing areas of Ghana, the collection, initial processing, and sale of products made from shea nuts plays a significant role in providing women with additional income. Women in northern Ghana earn money from the shea business, which they use to support their families with expenses, such as children's school fees, health insurance, and food items. Therefore, financial support for the family enhances the status of the women in the community.

4 The role of shea ecological zones in combating climate change

The conservation and management of shea ecological zones, such as the Northern Savana Ecological Zone in Ghana, is vital for supporting local communities reliant on shea resources, combating climate change, and protecting biodiversity. Shea ecological zones contain a diverse range of plants and animals and play a key role in storing carbon (Elias and Carney, 2007). The shea trees of the West African region, totalling approximately one billion, along with the ecological zones around them, absorb approximately 1.5 million tons of carbon dioxide every year (UNDP, 2024). In addition to their ecological significance, these ecological zones hold significance as valuable assets and representations of customs, faith, and sense of identity for the people of Ghana, contributing significantly to the nation's cultural legacy. Currently, these distinctive savanna terrains are encountering numerous dangers, mainly because of the clearing of extensive agriculture and the deforestation caused by the logging of shea trees to make charcoal (Seghieri, 2019). Furthermore, they also face challenges such as soil erosion, susceptibility to climate change, and water shortages (UNDP, 2024). Rehabilitating deteriorated shea ecological zones and advocating for sustainable land management practices in order to preserve both ecological and economic well-being are recommended.

5 Call for Papers

The peer-reviewed, open access Journal of Nature-Based Solutions and Innovations is targeted to inspire and communicate imaginative research and innovations in the intersection of nature, sustainability, and novel technology. It is aimed at targeting global challenges such as depletion of resources, loss of biodiversity, climate variability, and environmental degradation through encouraging and disseminating new perspectives that leverage the power of nature and human creativity to provide informed decisions. The Journal of Nature-Based Solutions and Innovations aspires to be a premier platform for interdisciplinary research, fostering collaborations between scientists, policymakers, practitioners, and communities. The journal works to close the gap between research and practice by encouraging evidence-based decision-making and the wider adoption of natural solutions and technologies. The journal also seeks entries that explore nature-based solutions to environmental, social, and economic issues. This encompasses, but not limited to, ecosystem restoration, green infrastructure development, sustainable agriculture, water resource management, and disaster risk reduction. JNSI is dedicated to elevating the views and experiences of researchers and practitioners from the global south. We welcome contributions that highlight innovative ideas and best practices emerging from developing nations, promoting knowledge exchange and capacity building throughout the South. The journal accepts articles that investigate the use of artificial intelligence (AI), machine learning, and other cutting-edge technologies to address environmental and sustainability issues. We are particularly interested in research that combines artificial intelligence with natural solutions and indigenous knowledge systems. Under the leadership of Prof. Amos Kabo-Bah and Prof. Chukwuemeka J. Diji as Editors-in-Chief as well as Dr. Emmanuel Daanoba Sunkari as Associate Editor, the Journal of Nature-Based Solutions and Innovations guarantees a committed and effective peer-review system, upholding top production quality.

6 Conclusion

Supporting women's financial empowerment in industries like shea production in Ghana is not only about fairness but also a smart economic choice with wide-ranging advantages for society and future generations. By dismantling structural obstacles and allowing women to participate fully in value chains, we can unlock their potential as drivers of innovation and productivity while also reducing poverty and promoting gender equality. Shea butter has gained economic importance recently due to its growing prevalence in the global market. The export potential of the shea industry is playing a key role in boosting the growth of the national economy, fostering industrial development, and generating employment for marginalized individuals. This indicates that shea could become the next gold in Ghana considering the numerous benefits it brings to the individual, nation and the global economy.

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Assessment of Sub-Watershed Contributions to Flooding in Magarya Catchment, Gombe Metropolis, Gombe State, Nigeria

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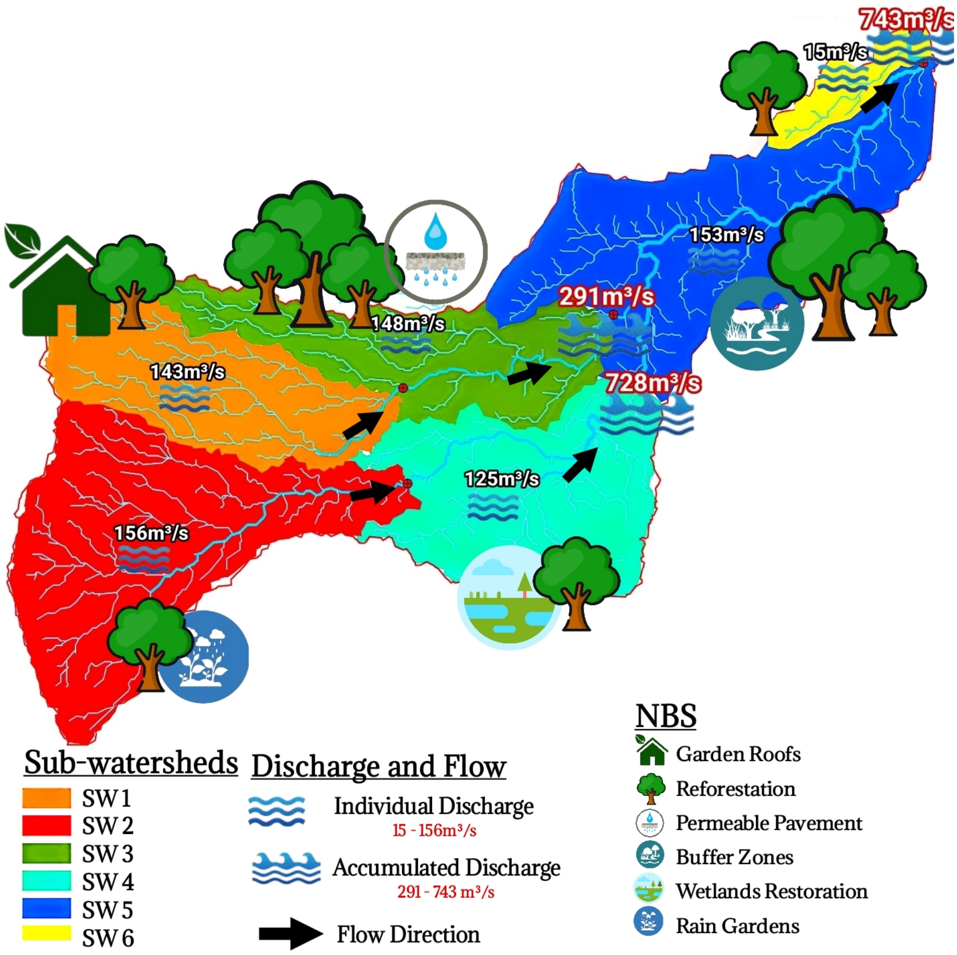
Graphical Abstract



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Abstract

This study investigates sub-watersheds role in contributing to flooding events within the Magarya Catchment, located in Gombe Metropolis, Nigeria. The primary objectives were to delineate sub-watersheds, calculate runoff coefficients, and estimate peak discharges using GIS techniques that integrate digital elevation models (DEMs), land cover data, soil classifications, and rainfall data. The results identified six delineated sub-watersheds ranging from 2.56 to 22.63 km^2, with composite runoff coefficients varying from 0.31 to 0.61. Peak discharges ranged from 15.00 to 156.90 m^3/s, with Sub-Watershed 3 exhibiting the highest peak discharge. Cumulatively, Sub-Watershed 6 manages a combined runoff of 743.08 m^3/s, highlighting critical flood protection needs. The study underscores the potential of Nature-Based Solutions (NBS) in mitigating flood risks. Recommendations include implementing targeted flood management strategies such as reforestation in Sub-Watershed 6 to enhance soil permeability and reduce runoff, and restoring wetlands in regions with mixed land use to buffer peak flows and improve flood resilience. Future studies should focus on continuous monitoring to inform adaptive flood management practices, integrating NBS to promote sustainable water resource management and enhance community resilience to climate change impacts. Keywords: Flooding, Sub-watershed, Runoff Coefficient, Peak Discharge and Magarya

Keywords: Flooding;Sub-Watershed; Runoff Coefficient;Peak Discharge; and Magarya

1 Introduction

Floods occur when a river's flow exceeds its normal channel capacity, flooding nearby low-lying areas and often affecting agricultural land and urban structures, including residential areas (Strahler and Strahler, 2003). In recent years, flood disasters have been occurring frequently in urban areas, resulting in many lives and property loss. The increase in extreme weather events such as floods is an annual problem in Nigeria, especially in the northern states (Abaje and Giwa, 2010). The effectiveness of urban drainage systems depends on their ability to drain excess wastewater and prevent flooding. Urban areas with inadequate or poorly constructed drainage systems often experience frequent and severe flooding (Abashiya, 2017; Bello, 2018; Mallo, 2021). The National Emergency Management Agency (NEMA, 2013) reported that approximately 7.7 million people in Nigeria were affected by floods between July and October 2012, killing 363 people and injuring 18,282 people. In 2022, floods in Nigeria claimed over 600 lives and affected over 600,000 people (NEMA, 2023). These devastating events were mainly due to heavy rains in different parts of the country. Gombe State, especially its major cities and surrounding areas, also experienced repeated floods. On August 20, 2004, heavy rains triggered an unprecedented flood disaster, the worst in 30 years, killing 35 people, destroying 1,500 homes, displacing over 30,500 people, and causing a loss of more than 2 million Naira (Ibrahim, 2004). Floods in Gombe Metropolis have become an annual event, causing serious damage to residents. On July 25, 2012, an intermittent rainstorm that began at about 2:30 p.m. claimed four lives and destroyed homes and properties worth N11.5 million. The affected areas include Jeka Dafari, Shamaki, Federal Lowcost, Borari, Pantami, Tudung Wada, Barunda, and Kumbia Kumbia (Lawal, 2012). Furthermore, on July 30, 2012, a 59.7 mm rainstorm that lasted about 2 hours caused building collapses in Madaki, Nasarawo, and Pantami areas, killing three people (Anthony, 2012). Similarly, on September 5, 2014, 92.5 mm of torrential rain that lasted just 48 minutes killed six people and caused property damage worth millions of Naira. Most recently, floods occurred in the Gombe Metropolitan area from May to October 2023, killing six people, injuring 34 others, and destroying 13,242 houses (NEMA, 2023). Despite the major impact of floods on the livelihoods of the people living in the low-lying regions of Nigeria, few attempts have been made to delineate the boundaries of flood-contributing sub-watersheds (Asare-Kyei et al., 2015; Daniel et al., 2020). The limited research that was conducted on flood studies in northern Nigeria has used remote sensing data aided by Geographic Information Systems (GIS). However, they lack certain basic principles in hydrological modeling and prediction, which can be added into flood simulation and mapping in the country for better outcomes (Komolafe, Suleiman, & Francis, 2015; Daniel et al., 2020). Considering the severe impact of recurrent floods in the Gombe Metropolis, it is important to assess and identify the sub-basins that contribute most to flooding in the Magarya River Basin. It is neither economical nor feasible to simultaneously manage or reduce floods across a basin. Therefore, using rational methods that consider runoff coefficient, area, and rainfall intensity will help prioritize flood management efforts and develop targeted mitigation strategies for the most affected sub-basins. This research supports the United Nations Sustainable Development Goals (SDGs), particularly SDG 6 (Clean Water and Sanitation) and SDG 13 (Climate Action), by promoting sustainable water management and climate resilience. Additionally, it aligns with the Science, Technology, and Innovation Strategy for Africa (STISA-2024) by emphasizing innovative and sustainable solutions for water resource management. The potential of Nature-Based Solutions (NBS) in mitigating flood risks is explored, highlighting the importance of integrating ecological approaches in flood management strategies. The aim of this study is to comprehensively assess the contribution of the lower reaches of the basin to flooding in the Magarya River Basin, thereby establishing an effective flood management and mitigation plan in Gombe Metropolis. The specific objectives are to: i. delineate sub-watersheds within the Magarya Catchment; ii. determine the runoff coefficient of different sub-watersheds; and iii. determine the peak discharge of sub-watersheds within the Magarya Basin.

2 Methods

2.1 Study Area

The Magarya River Basin is located between latitudes 10°11′59″N and 10°20′02″N, and longitudes 11°06′01″E and 11°16′58″E in Gombe Urban Area, Gombe State. The study area slopes towards the east and has relatively flat terrain ranging from 640 to 320 meters above sea level. It is made up of sedimentary rocks such as sandstone, with complex crystalline rocks underneath. These Late Cretaceous sedimentary strata influence the topography and are characterized by dissected sections due to fluvial incision (Ahmad & Wanah, 2023).

The region has a tropical continental climate classified as Köppen's Aw, with a strong seasonal rainfall pattern characterized by distinct wet and dry seasons (Ahmad & Wanah, 2024). Precipitation is concentrated from May to September, peaking in August (Amos, Ahmad, Abashiya, & Abaje, 2015; Ahmad & Wanah, 2023). The average annual precipitation is about 863.2 mm.

Hydrologically, the region is located in the Gongora Basin, part of the Upper Benue Trough Plain in northeastern Nigeria. The inhabitants are primarily engaged in agriculture, raising livestock and cultivating crops for subsistence and export. The most important crops for domestic and international markets include rice, maize, and beans (Ahmad & Wanah, 2023).

2.2 Data and Sources

To delineate sub-watersheds within the basin, a digital elevation model (DEM) from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) and the United States National Aeronautics and Space Administration (NASA) was used. This data has a vertical accuracy of 17 meters at a 95% confidence level and a horizontal resolution of approximately 75 meters. Land cover data were obtained from Landsat 8 imagery, which was downloaded from the USGS website. Soil classification data were computed from the Harmonized World Soil Database (HWSD) version 1.2, produced in 2012 by the International Institute for Applied Systems Analysis (IIASA), providing information on soil type and texture classification. Rainfall data were sourced from the Nigerian Meteorological Agency (NiMET), specifically from the Gombe area synoptic station. A topographic map of Gombe Metropolis covering the study area was obtained from the Ministry of Lands and Survey, Gombe.

2.3 Runoff Estimation Model

The methodological approach used in this research is diagrammatically summarized in Figure 2, as Asare-Kyei et al. (2015) described.

2.4 Sub-Catchments Delineation

A DEM was utilized for sub-catchment delineation and slope analysis. The study area was divided into six sub-catchments using the spatial analyst tools in the ArcGIS environment after all the sinks were filled to ensure accuracy. The filled elevation data layer was maintained and later integrated with peak runoff and elevation data to determine runoff concentration at different elevations. The generated sub-catchments, initially in raster format, were converted to polygon format using the conversion tool under spatial analyst tools. Converting the raster format into polygons was necessary to calculate the areas of the sub-catchments and to build the attribute table within the ArcGIS environment.

2.5 Runoff Coefficient Computation

2.6 Land Use Classes

The different bands of the Landsat imagery were combined in the ArcGIS environment to form a composite image, which was further processed into a mosaic raster before analysis. Supervised classification was conducted on the Landsat imagery to identify four broad land use/land cover (LULC) classes after training samples and signatures were created using the training sample manager in ArcGIS. The identified LULC classes were: (1) agricultural land; (2) grassland; (3) bare land; and (4) settlements (built-up areas). Training and validation data for these classes were collected from field campaigns conducted between October 2023 and January 2024. Training and validation samples for the classification were generated by overlaying the training and validation data (polygons) on the satellite image and extracting the corresponding values.

2.7 Soil Type and Texture

The Harmonized World Soil Database (HWSD) was used for soil classification. This database is an image file linked to a comprehensive attribute database containing information on soil mapping units, soil texture for top and subsoils, and several other soil properties (Food and Agricultural Organization [FAO], 2009). Based on this information, the characteristics of the basin were reclassified into the four main soil hydrological groups defined by the United States Soil Conservation Service (USDA, 2009).

2.8 Composite Runoff Coefficient

Each sub-catchment contains multiple LULC types, soil types, and slopes. To find a representative runoff coefficient for a given sub-catchment, average values were calculated based on the different LULC types. The DEM was converted to percent slope in ArcGIS and reclassified into two classes: slope less than 0.5%, and slope between 0.5% and 5%. Table 1 specifies a runoff coefficient for each LULC type, soil, and slope. The average runoff coefficients for each sub-catchment were computed based on the number of LULC types occurring in each sub-catchment. Knowing the runoff coefficients (C), rainfall intensity (I), and areas (A) of each sub-catchment, the discharges (Q) for each sub-catchment likely to cause flooding were calculated.

2.9 Determination of peak run-off using the rational model

The rational model belongs to the group of lumped hydrological models, which treats the unit of analysis as a single unit whose hydrological parameters (e.g., rainfall) are considered as average values. The model is given by the equation:

$$Q = C \times I \times A \tag{1}$$

Where:

- Q = Peak run-off rate (m^3/s)
- C = Run-off coefficient (-)
- I = Rainfall intensity (mm/h)
- A = Drainage area (km^2)

The model operates on a number of assumptions including:

1. The entire unit of analysis is considered as a single unit;
2. Rainfall is uniformly distributed over the drainage area;
3. Estimated peak run-off has the same chances of reoccurrence (return period) as the used rainfall intensity (I);
4. The run-off coefficient (C) is constant during the rain storm.

3 RESULTS

3.1 Sub-Watersheds within Magarya Catchment

The Magarya River Basin is divided into smaller units based on topographic data. This process helps identify natural drainage boundaries and assess the contribution of each basin to flooding, allowing for targeted flood control strategies (Haghipour and Burg, 2014). In the case of the Magarya Catchment, analysis of the catchment topography determined flow directions and accumulation points, dividing the catchment into different hydrological units. Each sub-watershed represents an area where precipitation collects at a single outlet within the watershed.

The results show six sub-basins within the catchment:

- SW-1: 13.29 km^2
- SW-2: 22.46 km^2
- SW-3: 12.85 km^2
- SW-4: 16.64 km^2
- SW-5: 22.63 km^2
- SW-6: 2.56 km^2

Total area: 90.43 km^2 (Fig. 2). This delineation helps to understand the catchment structure and is crucial for subsequent analyses, such as the calculation of runoff coefficients and peak discharges. Dividing the catchment into smaller units allows for accurate assessment and description of the specific hydrological and flood risk characteristics of each catchment.

3.2 Sub-Watersheds Gradient

The gradient or slope of a watershed has a significant impact on runoff and flooding potential. The average slope of the Magarya River basin is 0.033 per km. However, variations are observed in individual sub-basins: SW-1: 0.039 per 1 km, SW-2: 0.034 per 1 km, SW-3: 0.032 per 1 km, SW-4: 0.031 per 1 km, SW -5: 0.023 per km, SW -6: 0.011 per 1 km. SW 1, where the steepest slope is 0.039 per km, may have faster runoff, resulting in higher erosion potential and faster peak runoff during rainfall. This steep slope can increase the risk of flooding, especially in urban areas where impermeable surfaces impede infiltration (Abashiya, 2017). SW 6, which has the lowest slope of 0.011 per km, suggests slower runoff and may have lower immediate flood risk compared to areas with steeper slopes. However, this slow water movement can lead to longer saturation periods, which can impact agricultural land by increasing soil moisture content and potentially delaying drainage (Mallo, 2021; Abashiya, 2017). SWs 2, 3, and 4 have slopes close to the catchment average, indicating a balance between runoff velocity and infiltration potential. Typical runoff behavior may occur in the lower reaches of these basins, with no extremely rapid runoff or significant delays in drainage.

3.3 Runoff Coefficient of Different Sub-Watersheds

3.4 Land Use/Land Cover Classes

Land use/land cover classes in the Magarya River Basin include urban areas, agricultural land, grasslands, and bare land. Identifying these classes will help understand the influence of both human activities and natural land features on flood dynamics. For example, urbanization often increases runoff, increasing the risk of flooding (Abashiya, 2017). As of 2024, the land use/land cover distribution in the Magarya River basin has been shown to significantly contribute to flood dynamics. 25.20 km^2 of this area is undeveloped land and has the potential for high runoff due to low vegetation cover. The residential area is 30.07 km^2, which significantly increases the sealing area and the outflow volume. Grasslands with an area of 15.13 km^2 generally help reduce runoff through infiltration and absorption. Agricultural land occupies 20.0 km^2, but crop types and agricultural practices can have varying effects on runoff and erosion. Understanding these distributions is important for basin flood assessment and flood management. LULC class in Magarya is shown in Figure 4 below.

3.5 Soil Classification

Soil classification for the Magarya River Basin classifies soils based on their properties that influence water infiltration and drainage. Different soil types, such as sandy or clay soils, affect how much rainwater is absorbed or drained from the surface, and predict which areas are more susceptible to flooding. Soils such as sand, loamy sand, sandy loam and sandy clay have been identified in the Magarya river basin. Highly permeable sandy soils allow rapid infiltration and reduce surface runoff. Clay sand is also permeable, but it retains more water than pure sand, so there is a better balance between infiltration and runoff. Sandy loam is a mixture of sand, silt and clay with good drainage and moderate water retention, contributing to balanced hydrological conditions. Sandy clays with higher clay content hold more water, which can increase runoff during heavy rains. These soil classes influence flood dynamics by influencing water infiltration and surface runoff.

3.6 Composite Runoff Coefficients (C)

The composite runoff coefficient represents the potential for surface runoff to occur in different regions of the Magarya River Basin, influenced by land use and soil type. A high coefficient indicates an area that is more likely to cause flooding. Composite runoff coefficients for each sub-basin of the Magarya River Basin were calculated based on land use, soil type, and slope. Specific values for each land use type within each sub-basin were combined to derive a composite runoff coefficient for each sub-basin. The composite runoff coefficients for each basin indicate significant differences in surface runoff potential, requiring different flood management strategies. SW 3 has the highest composite runoff coefficient of 0.61, which is due to the extensive built-up area combined with sandy loam soils and gentle slopes. This underwater catchment requires significant flood protection measures. Behind it is SW 1 with a combined runoff coefficient of 0.57 due to its considerable developed land area and relatively steep slope. SW 4 has a balanced potential for runoff and infiltration, and SW 2 has a more balanced land use mix with moderate gradients. SW 5 and SW 6 have low composite runoff coefficients, indicating low runoff potential.

3.7 Peak Discharge of Sub-Watersheds within Magarya Basin

Peak flow represents the maximum water flow from each basin during a storm and plays an important role in understanding flood dynamics. In the Magarya River Basin, peak flow calculations help identify sub-basins that are most prone to flooding. The average rainfall intensity in August 2023 was 18.92 mm/h, and SW 2 recorded the highest peak runoff of 156.90 m3/s. This reflects the combination of its large area, moderate runoff coefficient of 0.37, and moderate slope. This indicates that the potential for rapid surface runoff is large and requires robust flood management strategies. SW 3 followed closely with a peak discharge of 148.15 m3/s and had the highest discharge coefficient of 0.61 due to extensive built-up areas and special soil properties. The peak flow rate in SW 1 was 143.41 m3/s, highlighting the need for improvement of the drainage system. The peak discharge of SW 5, which has a gentle slope, is 153.75 m3/s, indicating that although the discharge coefficient is low, its large area contributes to a significant discharge. The peak discharge of sub-basin 4 was moderate at 125.87 m3/s, while the peak discharge of SW 6 was the lowest at 15.00 m3/s, reflecting minimal and slow surface runoff. Scenarios of increasing rainfall intensity could result in significant increases in peak flows in all sub-basins, creating an urgent need for adaptive flood management strategies to reduce the impact of extreme rainfall and prevent catastrophic flooding. The need is emphasized. This study is in line with previous studies on flood risk and management in urban catchments (Abaje and Giwa, 2010; Bello, 2018; Abashiya, 2017) and details the flood dynamics of specific underground catchments. By considering current and future scenarios, this study contributes to a comprehensive approach to flood risk management and ensures preparedness for increasingly changing weather conditions

3.8 Accumulated Peak Discharge

Cumulative peak flow is intended to provide a unified understanding of which sub-basins are susceptible to flooding. To estimate the cumulative peak value of a sub-basin and highlight the risks of SW5 and SW6, the peak flows of each sub-basin at a specific point were summed. The cumulative peak discharge at the end of SW5 is 728.08 m3/s, which is significantly higher than the peak discharge of the individual basins. This suggests that a significant amount of runoff occurs in SW5 and requires strong flood management strategies to prevent flooding and potential flooding. At the main outlet including SW6, the cumulative peak flow rate is 743.08 m3/s. Although the individual peak flows of SW6 are relatively low (15.00 m3/s), the cumulative impact of all sub-basins contributing to the mainstream highlights the potential for significant flooding. The last subsurface catchment, SW6, has to manage combined runoff, highlighting the need for appropriate flood protection measures at this critical phase.

4 DISCUSSION

4.1 Impact of Sub-Watersheds on Flood Dynamics

This study elucidates the significant role of sub-watersheds within the Magarya Catchment in influencing flooding dynamics, particularly in urban areas with high impervious surfaces and steep slopes, such as SW-1 and SW-3. These sub-watersheds exhibit accelerated runoff rates, contributing disproportionately to peak discharge during rainfall events. The presence of impermeable surfaces exacerbates flood risks by impeding natural infiltration and promoting rapid surface runoff. Identifying these high-risk areas through topographic data is crucial for developing targeted flood control strategies, aligning with the United Nations Sustainable Development Goal 11 (Sustainable Cities and Communities) by improving urban flood resilience (Haghipour & Burg, 2014).

4.2 Nature-Based Solutions (NBS) for Flood Mitigation

Nature-based solutions (NBS) present effective strategies for mitigating flood risks in the Magarya Catchment. Reforestation in sub-watersheds like SW-6, characterized by gentler slopes, can enhance soil permeability and increase water retention capacity, reducing surface runoff volumes. Restoring wetlands in areas such as SW-5, which feature mixed land use and moderate slopes, helps buffer peak flows and enhance flood resilience. Implementing permeable surfaces in urban settings, observed in SW-2 and SW-4, represents another NBS approach that reduces surface runoff and alleviates flood impacts on infrastructure (Abashiya, 2017). These strategies contribute to Sustainable Development Goal 15 (Life on Land) by promoting ecosystem restoration and improving land management.

4.3 Comparison with Conventional Flood Management Practices

Compared to conventional flood management practices that rely on engineered infrastructure, NBS offer a flexible and cost-effective alternative. The composite runoff coefficients for each sub-watershed highlight the effectiveness of NBS in improving natural flood attenuation processes. Areas with high composite runoff coefficients, like SW-3, show how NBS interventions can mitigate flood risks associated with urbanization and intensive land use. Additionally, NBS provide benefits such as carbon sequestration, habitat restoration, and recreational opportunities, contributing to Sustainable Development Goal 13 (Climate Action) and Goal 14 (Life Below Water) by enhancing climate resilience and supporting ecosystem health.

4.4 Alignment with STISA-2024 and Future Directions

The study aligns with the Science, Technology and Innovation Strategy for Africa (STISA-2024) by integrating innovative solutions that leverage natural processes for flood management. NBS contribute to STISA-2024's objectives of promoting sustainable development and addressing climate change impacts through adaptive strategies. Future research should focus on continuous monitoring and refining NBS approaches to enhance their effectiveness and scalability. Embracing NBS will support the African Union's post-STISA initiatives by fostering sustainable water resource management and improving community resilience to climate change.

5 Conclusion

This study underscores the critical role of sub-watersheds in shaping flood dynamics within the Magarya Catchment. Through detailed analysis and delineation, high-risk areas contributing disproportionately to flood events have been identified. These findings emphasize the urgency of implementing targeted flood management strategies to mitigate potential damages to infrastructure and enhance community resilience. To effectively manage flooding in the Magarya Catchment, prioritizing nature-based solutions alongside traditional infrastructure is recommended. Initiatives such as reforestation, wetland restoration, and the promotion of green infrastructure in urban planning should be integrated into flood risk management frameworks. Collaboration among stakeholders, including local communities and governmental bodies, is essential for the successful implementation and maintenance of NBS. Long-term monitoring and evaluation of NBS effectiveness are critical to adapting and refining strategies based on local conditions and evolving climate scenarios. Future research should focus on scaling up successful NBS interventions across similar catchments to assess their transferability and scalability. Investigating the socio-economic impacts of NBS adoption and evaluating community perceptions and engagement can provide valuable insights for enhancing resilience and adaptive capacity. Additionally, exploring synergies between NBS and traditional flood management approaches can optimize resource allocation and maximize flood resilience outcomes. By advancing knowledge in this field, future studies can contribute to more robust and sustainable flood risk management practices globally.

6 Acknowledgment

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Figures and Tables

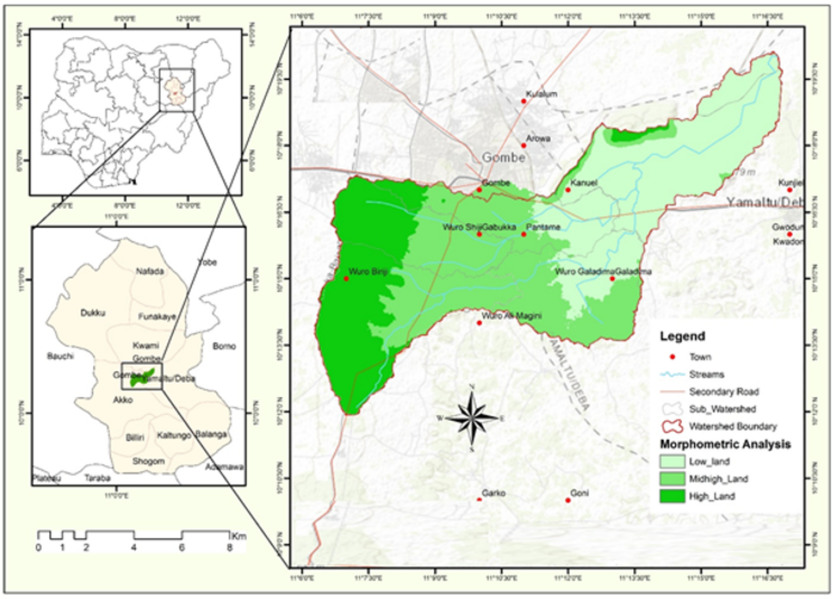

Figure 1: River Magarya Drainage Basin - Source; USGS Earth Explorer, 2023

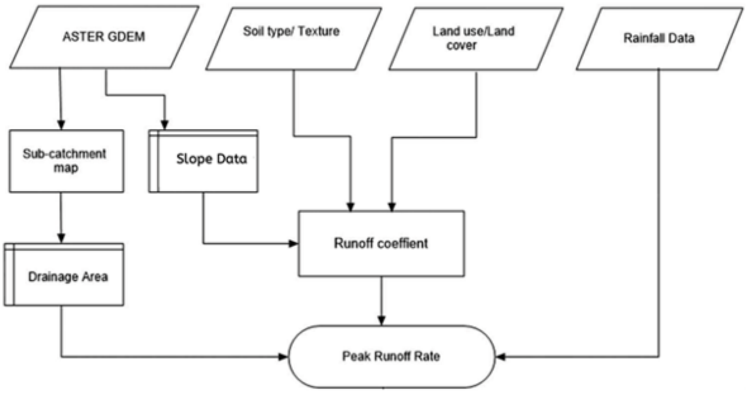

Figure 2: Modified modeling flow diagram for relational-rule-based flood assessment

Table 1: Rational method run-off coefficients by Land use, soil type and slope.

Soil Type	Sand		Loamy Sand		Sandy Loam		Sandy Clay	
Landuse/Slope	¡0.5	0.5 – 5	¡0.5	0.5 - 5	¡0.5	0.5 – 5	¡0.5	0.5 – 5
Grassland	0.13	0.17	0.17	0.21	0.20	0.24	0.43	0.47
Farmland	0.23	0.27	0.27	0.31	0.30	0.34	0.53	0.57
Bare land	0.33	0.37	0.37	0.41	0.40	0.44	0.63	0.67
Residential	0.37	0.43	0.41	0.47	0.44	0.50	0.67	0.73

Source:USDA, 2009

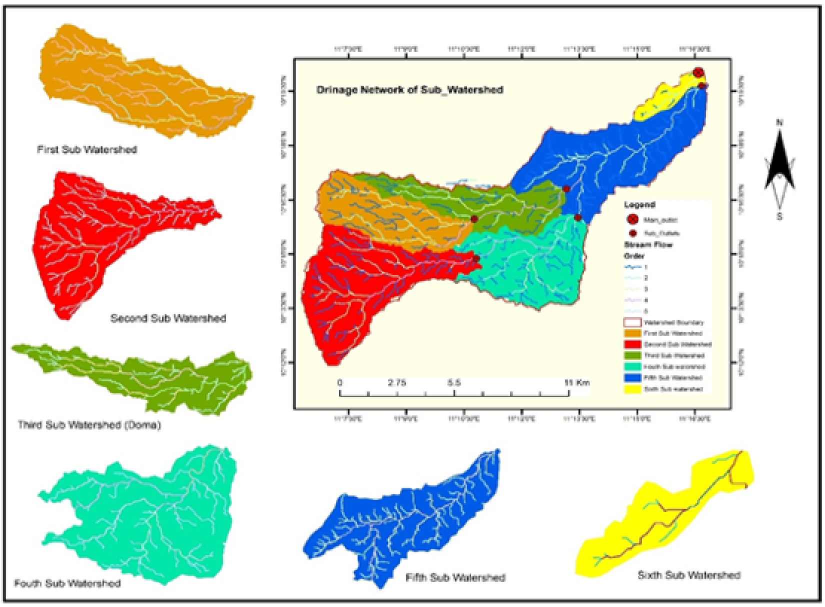

Figure 3: Sub-watersheds within Magarya River Basin Source; USGS Earth Explorer 2024

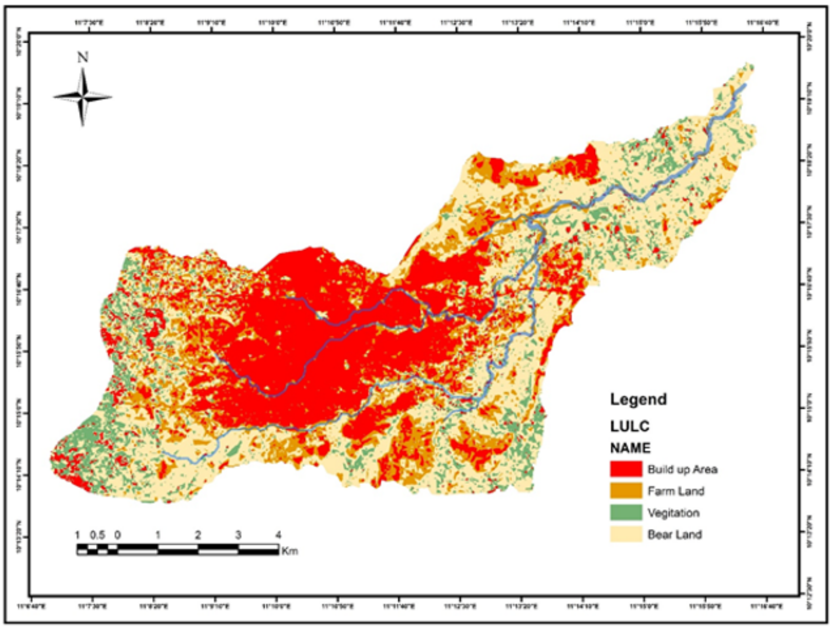

Figure 4: Land Use Land Cover Classes of Magarya Catchment.

Table 2: Composite Runoff Coefficient of Sub-watersheds

Sub-Watershed	Bare Land (km^2)	Built-up (km^2)	Grassland (km^2)	Farmlands (km^2)	Total Area (km^2)	Slope	CRE
SW 1	1.20	8.37	1.99	1.73	13.29	0.039	0.57
SW 2	3.82	5.61	5.84	7.19	22.46	0.034	0.37
SW 3	0.64	10.28	0.77	1.16	12.85	0.032	0.61
SW 4	7.16	2.83	3.49	3.19	16.64	0.031	0.40
SW 5	11.77	2.72	2.45	5.66	22.63	0.023	0.36
SW 6	0.61	0.26	0.59	1.10	2.56	0.011	0.31
Total	25.20	30.07	15.13	20.03	90.43	0.033	

CRE is Composite Runoff Coefficient

Table 3: Sub-catchment discharges based on August 2023 rainfall

Sub-Watershed	Area (km^2)	Runoff Coefficient (C)	Rainfall Intensity (mm/hr)	Peak Discharge (Q, m^3/s)
SW 1	13.29	0.57	18.92	143.41
SW 2	22.46	0.37	18.92	156.90
SW 3	12.85	0.61	18.92	148.15
SW 4	16.64	0.40	18.92	125.87
SW 5	22.63	0.36	18.92	153.75
SW 6	2.56	0.31	18.92	15.00

Table 4: Accumulated Peak Discharge

Sub-Watersheds	Area (km^2)	Outlet	Accumulated Discharge
SW1 & SW3	26.14	End of SW3	291.56
SW2 & SW4	39.10	End of SW4	282.77
SW1, 2, 3, 4, & 5	87.87	End of SW5	728.08
SW1, 2, 3, 4, 5, & 6	90.43	End of SW6	743.08

Developing A Participatory Decision Support Tool for Soil and Water Management in Kakia-Esamburmbur Catchment of Narok, Kenya

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Graphical Abstract

Developing A Participatory Decision Support Tool for Soil and Water Management in Kakia-Esamburmbur Catchment of Narok, Kenya

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Abstract

Soil and water management are crucial for sustainable agriculture and environmental conservation. This study developed a decision support tool for managing soil and water in the Kakia-Esamburmbur catchment, Narok, Kenya. Using experimental data, interviews, questionnaires, field measurements, and simulations, the study assessed runoff, soil loss, and sediment yield under different land management practices. The average annual sediment yield was 21.19 t/ha, soil loss was 37.02 t/ha, and runoff was 276.52 mm. The highest values were observed in farm 1, which had a fallow section and the steepest slope. The WEPP model's predictions were inaccurate due to limited soil loss measured data. Incorporating 15m forest/grass strips at 50-meter intervals or 30-meter forest strips at key locations was recommended for sustainable management. Although grass strips reduced soil loss slightly more, forest strips were better at reducing sediment yield. The study highlights the importance of the tool in managing resources but has limitations such as the lack of insufficient observed data for model calibration. This work supports UN SDGs 2, 6, and 15 and aligns with the Science, Technology, and Innovation Strategy for Africa (STISA-2024) by addressing critical environmental challenges and promoting sustainable development goals through innovative solutions. Future research should focus on improving data accuracy for model calibration.

Keywords: Soil and water management; participatory decision support tool; WEPP model; land management practices; model simulations.

1 Introduction

Soil and water degradation is a pressing global concern, impacting agricultural productivity, ecosystem services, and human well-being. [1, 2]. In the Kakia-Esamburmbur catchment of Narok County, Kenya, these issues are particularly pronounced. The catchment experiences significant soil erosion, sediment yield, and runoff, leading to a decline in soil fertility, reduced water quality, and increased flood risks. This degradation poses a major threat to the livelihoods of local communities who depend on the land for agriculture, livestock grazing, and other economic activities. Addressing these challenges requires a comprehensive approach that involves sustainable land management practices and participatory decision-making. [3,4]. While various strategies for soil and water conservation exist, their implementation have ineffective and unsustainable outcomes. This highlights the need for a participatory decision support tool that can empower local communities to make informed choices regarding land management practices. This paper presents the development of such a decision support tool for the Kakia-Esamburmbur catchment. The tool is based on the widely recognized Water Erosion Prediction Project (WEPP) model, which allows for simulating soil loss, sediment yield, and runoff under different land management scenarios. The tool integrates participatory approaches, ensuring that local knowledge and perspectives are incorporated into the decision-making process. By combining scientific modeling with community engagement, this tool aims to provide a valuable platform for developing sustainable soil and water management strategies in the Kakia-Esamburmbur catchment. The initiative aligns with and supports the objectives of the Science, Technology, and Innovation Strategy for Africa (STISA-2024), which emphasizes the integration of science and technology for sustainable development. The potential impact of this tool extends to post-STISA initiatives by contributing to Africa's environmental and agricultural goals through innovative and practical solutions In Kenya, the Kakia-Esamburmbur catchment, like many other regions, experiences significant soil erosion and water runoff, leading to degraded land and compromised water resources [5]. Addressing this issue requires a holistic approach that integrates scientific understanding with local knowledge and participatory decision-making [6]. The Water Erosion Prediction Project (WEPP) model has been widely used for simulating soil erosion and runoff, providing valuable insights into the impact of land management practices [7, 8]. WEPP has been successfully applied in various regions to assess erosion rates, identify critical areas, and evaluate the effectiveness of conservation measures [9, 10]. However, effectively utilizing WEPP for decision-making requires integrating it with participatory approaches that actively involve local stakeholders in the modeling process [11, 12]. Participatory decision support tools (DSTs) have emerged as powerful instruments for facilitating collaborative decision-making in natural resource management [13]. By integrating scientific knowledge, local expertise, and stakeholder values, DSTs can empower communities to develop and implement sustainable solutions [14, 15]. Studies have demonstrated the effectiveness of participatory DSTs in promoting sustainable land use planning, water resource management, and biodiversity conservation [16, 17]. Integrating WEPP with participatory approaches has shown promising results [18, 19]. By involving local communities in the calibration, validation, and interpretation of WEPP simulations, researchers can ensure that the model outputs are relevant and actionable for local decision-making. This participatory approach fosters ownership and builds capacity within communities to effectively manage their natural resources [20]. The DST leveraged the predictive capabilities of WEPP while actively engaging local stakeholders in the modeling process, ensuring that the tool is tailored to their specific needs and priorities. Such a tool aligns with STISA-2024 objectives by promoting sustainable land management and advancing scientific and technological solutions for environmental challenges.

2 Methods

2.1 Methodology

This section outlines the methodology employed in developing the participatory decision support tool for soil and water management in the Kakia-Esamburmbur catchment. The methodology encompassed four key components: data collection, model calibration, stakeholder engagement, and running model simulations.

2.2 Data Collection

The study involved collecting various data essential for model calibration and analysis. These data included:

Soil Properties

This included data on soil type, texture, organic matter content, and infiltration rate. Soil samples were collected from different locations within the catchment, and laboratory analyses were conducted to determine the properties.

Rainfall Data

Historical rainfall data for the Kakia-Esamburmbur catchment was obtained from the Kenya Meteorological Department. This data was used to simulate rainfall patterns in the WEPP model.

Land Use and Land Cover

Through observations and interviews with farmers, the current and past land use and land cover patterns in the catchment were established. This information was used to define the different land management practices within the WEPP model.

Topographic Data

Digital Elevation Models (DEMs) were used to determine the slope, elevation, and aspect of the catchment. This information was crucial for simulating water flow and soil erosion in the WEPP model.

Socio-economic Data

Information on farming practices, land tenure, and community demographics was collected through surveys and interviews with local farmers and stakeholders. This data helped to understand the social and economic context of land management practices. The farmers also gave suggestions on future land use practices that they considered practical for model simulations.

2.3 Model Calibration

The Water Erosion Prediction Project (WEPP) model was selected as the primary tool for simulating soil loss, sediment yield, and runoff. The model was calibrated using the field-measured soil loss data.

2.4 Stakeholder Engagement

A participatory approach was adopted throughout the study, ensuring the involvement of local stakeholders in the decision-making process. This involved:

Workshops

Two workshops, one at the start of the study and one at the end of the study, were conducted with local farmers, community leaders, and government officials to discuss the objectives of the study, understand their perspectives on soil and water management, and solicit feedback on model simulations.

Field Visits

Field visits were conducted to collect data on the simulated farms and demonstrate the application of the WEPP model. This provided stakeholders with a hands-on understanding of the model's functionality.

Data Sharing

Model results and outputs were shared with stakeholders, facilitating a dialogue on the potential impacts of different land management practices.

Decision-Making

The decision support tool was designed to be user-friendly and accessible to local stakeholders, enabling them to explore different management scenarios and make informed decisions based on the simulation results.
This participatory approach aimed to ensure the relevance and applicability of the decision support tool to the specific needs and priorities of the Kakia-Esamburmbur community.

3 Results

This section presents the results of the WEPP model simulations, comparing soil loss, sediment yield, and runoff under different land management practices in the Kakia-Esamburmbur catchment. A land management practice was considered acceptable if it achieved soil loss below the permissible sediment yield of 10 t/ha/year and was acceptable by the locals (color-coded green as shown in the tables). The percentage of reduced soil loss and sediment yield are referenced on the current land management values for each farm (coded as S/No.1) to deduce the extent to which each simulated land management will reduce the current problem.

3.1 Farm 1 Simulation

From Table 1, the current land management (1) had the highest runoff, soil loss, and sediment yield values. The 30 meters of forest strips at the top, middle, and bottom of the farm resulted in the lowest soil loss and sediment yield rates among all practices. Replacing fallow land with forest significantly reduced soil loss and sediment yield, though not to acceptable levels as shown in Table 1 and Figure 1 below

Table 1: Land management treatments and their impacts.

S/No.	Length (m)	Slope (%)	Management	Treatment	Precipitation (mm/yr)	Runoff (mm/yr)	Runoff (%)	Soil loss (t/ha/yr)	Sediment yield (t/ha/yr)	Soil loss Reduction (%)	Sediment yield Reduction (%)	Land management Acceptable? (Y/N)
1	336	1 to 2.5	Maize-100m, Beans-50m, Maize-36m, Grazing-150m	None	1017.90	288.82	28.37	23.96	23.70	0.00	0.00	N
2				15m forest strips at 50m intervals	1017.90	228.21	22.42	19.11	12.11	20.24	48.91	N
3				Replace Maize with wheat	1017.90	266.94	26.22	20.16	20.16	15.86	14.93	N
4				30m forest strips at the top, middle, and bottom of the farm	1017.90	228.25	22.42	14.00	5.61	41.57	76.35	Y
5				15m grass strips at 50m intervals	1017.90	228.38	22.44	18.89	13.36	21.16	43.65	N

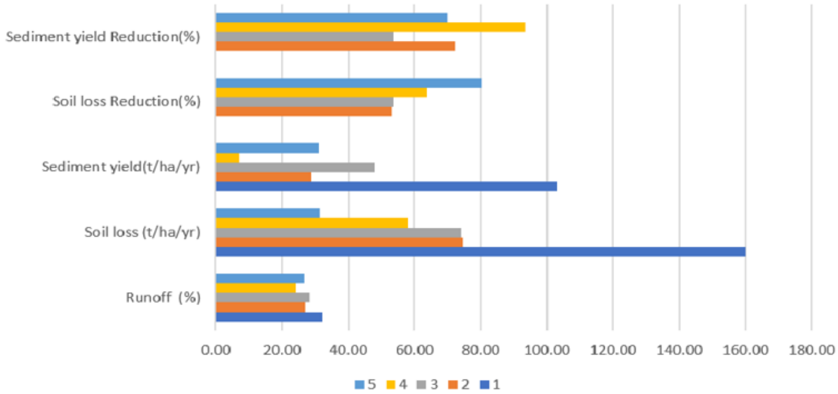

Figure 1: Farm 1 Results Analysis

3.2 Farm 2 Simulation

All sediment yield rates in Table 2 below are higher than 10 t/ha/yr except for the 30-meter forest strip. Wheat outperformed maize in reducing runoff, soil loss, and sediment yield from Figure 2 below. The 15-meter forest strips had less sediment yield and runoff but slightly higher soil loss compared to grass strips as per Table 2 below.

Table 2: Land management treatments and their impacts.

S/No.	Length (m)	Slope (%)	Management	Treatment	Precipitation (mm/yr)	Runoff (mm/yr)	Runoff (%)	Soil loss (t/ha/yr)	Sediment yield (t/ha/yr)	Soil loss Reduction (%)	Sediment yield Reduction (%)	Land management Acceptable? (Y/N)
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2				15m forest strips at 50m intervals	1017.90	228.21	22.42	19.11	12.11	20.24	48.91	N
3				Replace Maize with wheat	1017.90	266.94	26.22	20.16	20.16	15.86	14.93	N
4				30m forest strips at the top, middle, and bottom of the farm	1017.90	228.25	22.42	14.00	5.61	41.57	76.35	Y
5				15m grass strips at 50m intervals	1017.90	228.38	22.44	18.89	13.36	21.16	43.65	N

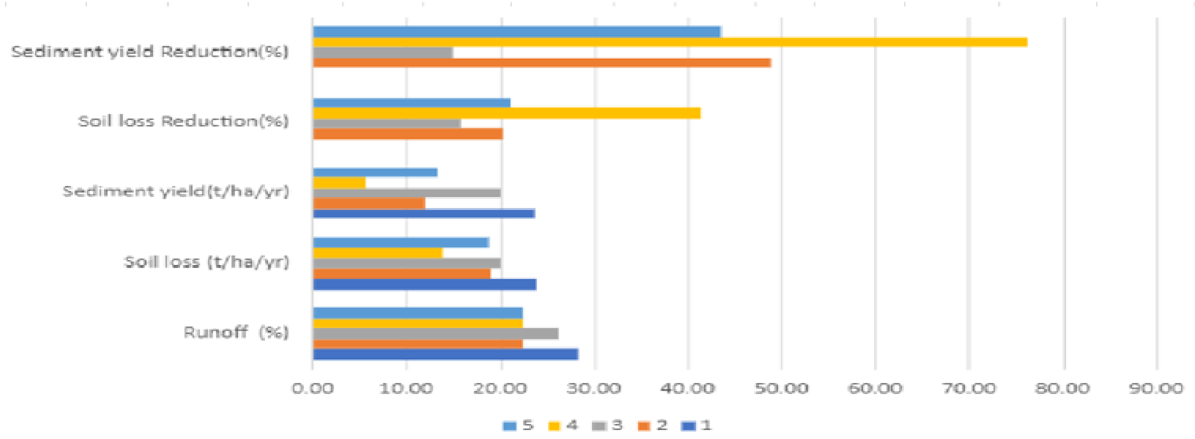

Figure 2: Farm 2 Results Analysis

3.3 Farm 3 Simulation

Based on Table 3 below, three land management practices met the criterion for maximum allowable sediment yield. Increasing the forest to 56m resulted in lower soil loss rates compared to the 30-meter forest strips, which recorded the lowest sediment yield rate. Replacing maize with wheat led to slightly reduced soil loss and sediment yield rates, with barley performing better than maize but not as well as wheat as depicted in Figure 3 below.

Table 3: Land management treatments and their impacts.

S/No.	Length (m)	Slope (%)	Management	Treatment	Precipitation (mm/yr)	Runoff (mm/yr)	Runoff (%)	Soil loss (t/ha/yr)	Sediment yield (t/ha/yr)	Soil loss Reduction (%)	Sediment yield Reduction (%)	Land management Acceptable? (Y/N)
1	131	1.5 to 6.8	Maize-45m, Grassland-20m, Forest-36m, Beans-30m	None	1017.90	297.92	29.27	24.98	11.88	0.00	0.00	N
2				Replace Maize with barley	1017.90	290.56	28.55	10.52	10.28	57.89	13.46	N
3				30m forest strips at the top, middle, and bottom of the farm	1017.90	225.13	22.12	16.97	3.06	32.07	74.25	Y
4				Replace Maize with wheat	1017.90	288.15	28.31	10.09	10.01	59.61	15.71	N
5				15m forest strips at 50m intervals	1017.90	258.84	25.43	20.47	3.06	18.05	74.25	Y
6				Replace grassland with forest	1017.90	285.04	28.00	14.90	7.93	40.35	33.25	Y

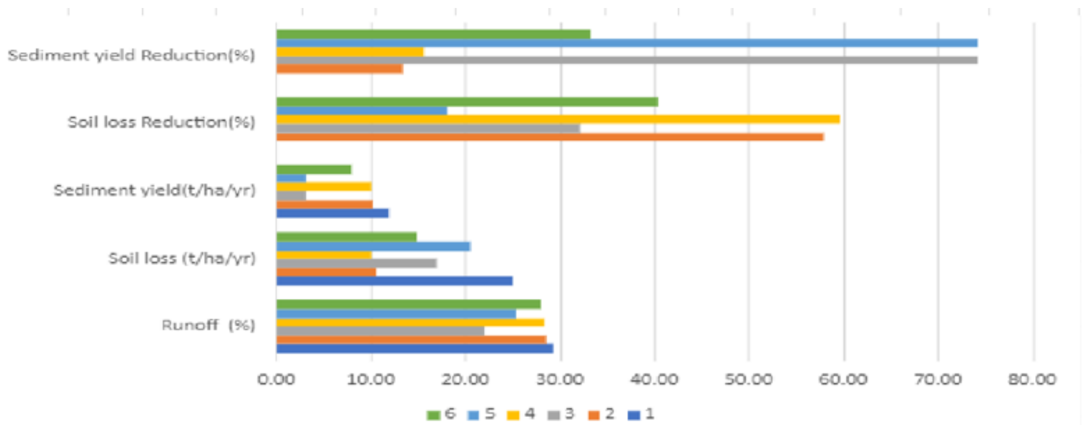

Figure 3: Farm 3 Results Analysis

3.4 Calibration Results

The WEPP model was calibrated using measured soil loss data collected from the study area. However, due to limitations in accurately measuring soil loss in the simulated farms, the model exhibited a poor performance in predicting soil loss as shown in Figure 4 below.

Table 4: Comparison of Simulated and Measured Soil Loss for Different Farms.

Farm	Simulated Soil Loss (t/ha/yr)	Measured Soil Loss (t/ha/yr)
1	79.65	19.78
1	159.97	1.099
2	19.22	17.20
2	23.96	0.956
3	16.32	3.62
3	24.98	0.403

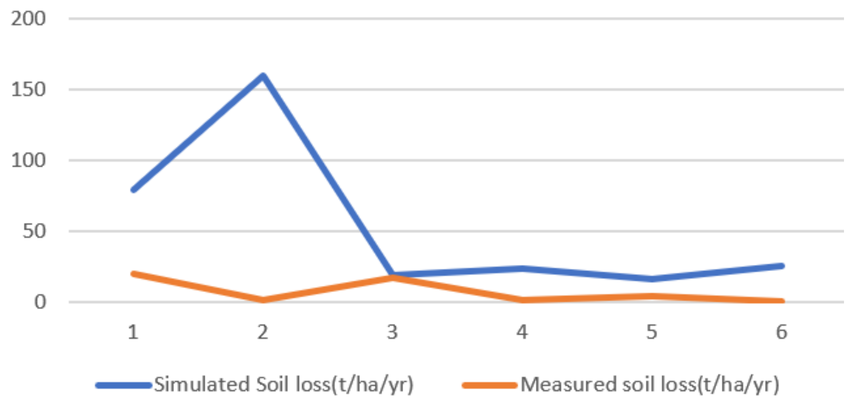

Figure 4: A graph of Simulated vs Measured Soil loss

3.5 Decision Support Tool

The decision support tool, Table 4, below combines simulation results from three farms. Planting 30m forest strips at the top, middle, and bottom of the farm results in acceptable soil loss and sediment yield rates. The tool shows that 15m grass and forest strips can manage soil loss and sediment yield and may be acceptable in some cases.

4 Discussion

4.1 Discussion

The results of the WEPP model simulations demonstrate the potential of the proposed land management practices to address soil erosion and water runoff challenges in the

Table 5: Land management treatments and their impacts.

S/No.	Length (m)	Slope (%)	Current Management	Modification	Precipitation (mm/yr)	Runoff (mm/yr)	Runoff (%)	Soil loss (t/ha/yr)	Sediment yield (t/ha/yr)	Soil loss Reduction (%)	Sediment yield Reduction (%)	Sediment yield Acceptable? (Y/N)
1	336	1 to 2.5	Maize-100m, beans-50m, maize-36m, Grazing-150m	None	1017.90	288.82	28.37	23.96	23.70	0.00	0.00	N
2				15m forest strips at 50m intervals	1017.90	228.21	22.42	19.11	12.11	20.24	48.91	N
3				Replace Maize with wheat	1017.90	266.94	26.22	20.16	20.16	15.86	14.93	N
4				30m forest strips at the top, middle, and bottom of the farm	1017.90	228.25	22.42	14.00	5.61	41.57	76.35	Y
5				15m grass strips at 50m intervals	1017.90	228.38	22.44	18.89	13.36	21.16	43.65	N
6	131	1.5 to 6.8	Maize-45m, Grassland-20m, Forest-36m, Beans-30m	None	1017.90	297.92	29.27	24.98	11.88	0.00	0.00	N
7				Replace Maize with barley	1017.90	290.56	28.55	10.52	10.28	57.89	13.46	N
8				30m forest strips at the top, middle, and bottom of the farm	1017.90	225.13	22.12	16.97	3.06	32.07	74.25	Y
9				Replace Maize with wheat	1017.90	288.15	28.31	10.09	10.01	59.61	15.71	N
10				15m forest strips at 50m intervals	1017.90	258.84	25.43	20.47	3.06	18.05	74.25	Y
11				Replace grassland with forest	1017.90	329.31	32.35	159.97	103.13	0.00	0.00	N
12	195	2.5 to 10	Beans-100m, Fallow-25m, Maize-50m, Maize/beans-20m (Current)	None	1017.90	274.19	26.94	74.72	28.84	53.29	72.03	N
13				15m grass strips at 50m intervals	1017.90	274.19	26.94	74.72	28.84	53.29	72.03	N
14				Replace fallow land with forest	1017.90	287.04	28.20	74.18	47.74	53.63	53.71	N
15				30m forest strips at the top, middle, and bottom of the farm	1017.90	245.59	24.13	57.85	6.98	63.84	70.53	Y

Kakia-Esamburmbur catchment. Land management practices with soil loss values below 10 but higher sediment yield values show the ability to minimize soil detachment but the inability to trap and contain the soil quantities that are detached due to insufficient sediment-trapping mechanisms.

4.2 Farm 1

The current land management had the highest runoff, soil loss, and sediment yield values due to inadequate ground cover and poor soil conservation practices.
15-meter grass strips at 50-meter intervals as in Figure 1 significantly reduced soil loss because grass provides a good ground cover and resistance to soil detachment, but they have higher sediment yield because grass lacks the ability to trap and stop detached sediments.30-meter forest strips at the top, middle, and bottom of the farm result in the lowest soil loss and sediment yield rates because forests effectively intercept runoff and trap detached soil. Replacing fallow land with forest significantly reduces soil loss and sediment yield, but not to acceptable rates, because the forest strip is too small to substantially overcome soil detachment and sediment yield. Wheat performs better than maize by reducing soil loss and sediment yield because wheat's size and spacing provide better ground cover and act as filters for runoff.

4.3 Farm 2

All the sediment yield rates in Table 2 are higher than 10 t/ha/yr except for the 30-meter forest strip, which effectively traps and deposits detached soil.
Wheat outperformed maize slightly regarding reduced runoff, soil loss, and sediment yield due to better ground cover. The 15-meter forest strips had less sediment yield and runoff but a slightly higher soil loss rate compared to grass strips due to better interception and trapping capabilities. The 30-meter forest strips resulted in the lowest and acceptable soil loss and sediment yield rates. Both the 15-meter grass and forest strips need contour terraces to manage soil loss and sediment yield effectively, as they lack sufficient trapping mechanisms.

4.4 Farm 3

Three land management practices met the criterion for the maximum allowable sediment yield because the forest strip already existed in the current land management. Increasing the forest to 56m resulted in lower soil loss rates compared to the 30-meter forest strips, which recorded the lowest sediment yield rate. Replacing maize with wheat led to slightly reduced soil loss and sediment yield rates due to better ground cover. Barley performed slightly better than maize but was outperformed by wheat in reducing soil loss and sediment yield. Barley reduces soil loss as much as twice as maize, but the difference in reducing sediment is negligible. Wheat performs slightly better than barley because small-leaved and short crops provide better ground cover. Forest strips outperform all other land management practices in reducing sediment yield due to their robust structure to trap and deposit detached soil. (Table 3)
The findings of this study align with previous research, confirming the significant role of steep slopes, high rainfall intensity, and sparse vegetation cover in driving soil erosion and sediment yield [19,20,]. The study, however, provides a more detailed analysis of sediment yield, soil loss, and runoff in Kakia-Esamburmbur by developing a decision support tool for soil and water management. This tool can be used to evaluate the effectiveness of different management strategies, promote informed decision-making, and ensure the long-term sustainability of soil and water resources in the catchment.

5 Conclusions and future research

5.1 Conclusion

The participatory decision support tool developed in this study provides a valuable platform for informed decision-making in soil and water management in the Kakia-Esamburmbur catchment. The proposed land management practices are incorporating 15m forest or grass strips at 50-meter intervals, and 30m forest strips at the top, middle, and bottom of the farms. These practices significantly reduce soil loss, sediment yield, and runoff, with the 30m forest strips being the most effective, making them viable options for sustainable soil and water management in the Kakia-Esamburmbur catchment. The tool integrates scientific modeling with local knowledge and stakeholder engagement, ensuring the relevance and applicability of the proposed land management practices.
The study contributes to several United Nations Sustainable Development Goals (SDGs), including SDG 2 (Zero Hunger), SDG 6 (Clean Water and Sanitation), and SDG 15 (Life

on Land), and aligns with the Science, Technology, and Innovation Strategy for Africa (STISA-2024) by addressing environmental challenges and promoting sustainable development through innovative solutions. The lack of sufficient observation data limited the accuracy of the WEPP model simulations. The study did not consider socio-economic factors that could influence the adoption of the proposed land management practices. Future studies should focus on collecting more comprehensive data and incorporating socio-economic factors to enhance the model's accuracy and relevance.

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Climate change ameliaration and enhancing food security through agriculture in Northern Nigeria

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Graphical Abstract

Climate change ameliaration and enhancing food security through agriculture in Northern Nigeria

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Abstract

The climate of northern Nigeria change more significantly during the twenty-first century in terms of temperature, precipitation, storms, and sea levels. This presents a serious threat to the region's agricultural output and food security. Northern Nigeria is the most populous region in the nation and has a majority of its rural residents being agrarians. Much of this can be ascribed to the harsher climate that regions are experiencing. When droughts persist, rainfall is rarely consistent for a long time. A further challenge to the region's agricultural economy was desertification and the removal of vegetation. Agriculture is still stagnant or perhaps declining despite government efforts to supply all agricultural inputs. In Nigeria, poor crop yield and livestock production, desertification, flooding, insect and disease infestation, and weed infestation are all consequences of climate change in agricultural output. The agribusiness entrepreneur is prompted by these challenges to play adaptive roles in mitigating these effects. These roles include agroforestry, harvesting and storing water, managing farm finances, vertical integration with pertinent agencies, and providing timely information for preventive measures. Moreover, agribusiness initiatives in Northern Nigeria contribute to the United Nations Sustainable Development Goals (SDGs) by creating jobs, increasing farmers' incomes, and promoting rural development. These initiatives combat hunger, create decent work opportunities, mitigate climate change effects, and preserve terrestrial ecosystems. The initiative aligns with the Science, Technology, and Innovation Strategy for Africa (STISA-2024), aiming to address socio-economic challenges in Africa. The success of these initiatives can serve as a model for other regions, promoting broader food security and climate improve food security and mitigate these issues, this study looks into how agribusiness to these changes evaluates the present effects of climate change on agriculture in northern Nigeria and looks at methods for advancing resilient food systems and sustainable farming practices

Keywords: Northern Nigeria, Climate change, Amelioration, Agribusiness, Food security and Sustainable Development Goals

1 Introduction

Nigeria's agriculture industry faces serious threats from climate change. Rain-fed agriculture, which is extremely vulnerable to climatic changes and can result in a variety of negative effects like rising temperatures, irregular rainfall patterns, and extreme weather events, is the main cause of the impact in areas like northern Nigeria. In the end, these variables endanger the livelihoods of millions of smallholder farmers and undermine the food security of the entire population by hurting agricultural yields and livestock production. According to Lal (2018), smallholder farmers in developing nations who depend on agriculture for a living are especially vulnerable to the negative effects of climate change on global food security. These farmers are especially susceptible to the effects of climate change because they frequently lack the means and technology to adjust to it (Niang et al., 2014). Climate change can have direct consequences on agricultural output, but it can also increase the frequency and intensity of extreme weather events like storms, floods, and droughts. These events can cause crop failures, livestock losses, and infrastructure damage (Lobell et al., 2019). Smallholder farmers may suffer greatly as a result, falling even deeper into poverty and food insecurity in terms of their income and food security (Lal, 2018; Lobell et al., 2019). Agribusiness, which includes farming, processing, marketing, and distribution, becomes an essential means of accomplishing these goals. Agribusiness may significantly contribute to reducing the effects of climate change on agriculture by incorporating climate-smart practices and technologies such as enhanced irrigation systems, resilient crop varieties, and sustainable land management strategies (FAO, 2019; Ahmed et al., 2020). Through an analysis of Nigeria's current agribusiness situation and the identification of growth prospects and obstacles, plans may be devised to advance environmentally conscious practices and sustainable agricultural development within the nation. Smallholder farmers can become more resilient with the support of adaptation techniques including encouraging crop types that are resistant to climate change, putting water conservation measures into place, and expanding their sources of income. Furthermore, improving the adaptive ability of agricultural systems and guaranteeing sustainable food production in Nigeria depend heavily on investments in climate-smart agriculture practices, such as agroforestry, conservation agriculture, and integrated water management. To increase the agriculture sector's total capacity for adaptation and to help smallholder farmers become more resilient, effective policies and interventions are needed. This could entail encouraging climate-smart farming methods, including investments in environmentally friendly water management, enhancing public access to weather data and early warning systems, and encouraging the creation and use of resilient crop kinds and breeds (Yusuf, 2017). Moreover, addressing the socioeconomic, institutional, and governance components of climate change adaptation should be a part of initiatives to strengthen the agricultural sector's adaptive potential. Increasing the ability of agricultural extension services, encouraging democratic and participatory decision-making procedures, and offering smallholder farmer's financial and technical support to put adaptation measures into place are a few ways to do this (Nkonya, 2015).

Agroforestry is a dynamic, ecologically grounded method of managing natural resources that incorporates trees into agricultural landscapes to increase output diversity and sustainability while providing more social, economic, and environmental advantages for land users at different levels. They contend that we should support farming methods or farming systems that put environmental quality first in addition to guaranteeing food security. There can be negative effects from neglecting to address environmental changes and from not developing farming systems that offer options for alternate livelihoods. As a result, quick action is needed to lessen the negative effects of these environmental changes (Alao & Shuaibu, 2013). The broad objective of the study is to examine the climate change amelioration and enhancing food security through agribusiness while the specific objectives are to;

- Implement sustainable agricultural practices to reduce greenhouse gas emissions and enhance carbon sequestration.
- Increase agricultural productivity and resilience to climate change to ensure a stable and sufficient food supply.
- Support the development of eco-friendly agribusinesses that utilize renewable resources and minimize environmental degradation.
- Advocate for policies that support climate-resilient agriculture and provide incentives for sustainable agribusiness practices.

2 Impacts of Climate Change on Agriculture in Northern Nigeria

Nigeria's agriculture faces serious obstacles from climate change, which might make the nation's overall levels of poverty and food insecurity worse. The significant effects of climate change on agricultural production have been the subject of numerous studies, which predict significant drops in crop yields due to changes in temperature and precipitation patterns (Udoh, Etim, & Etim, 2020). The bulk of the people in Nigeria still relies on agriculture as their main source of income, hence these developments will have a big impact on the country's primarily agrarian economy. Nigeria's agricultural economy is primarily dependent on smallholder farmers, who are especially sensitive to the negative effects of climate change. They are more vulnerable to dangers associated with climate change because they have restricted access to resources such as land, water, and inputs, as well as a lack of credit and financial support (Adefolalu et al. 2018).

Additionally, smallholder farmers are more vulnerable to the effects of climate change because of their substantial reliance on rain-fed agriculture, which makes them extremely susceptible to variations in seasonal rainfall patterns. In addition, the frequency and intensity of extreme weather events, like storms, floods, and droughts, have increased due to climate change. These occurrences represent serious threats to food security and agricultural productivity (Nzeadibe & Egbule, 2019). Extreme weather events have the potential to cause crop failure, animal losses, and infrastructure damage, which can upend livelihoods and worsen food shortages in the impacted areas. The problems faced by Nigerian farmers are further made worse by the compounding effects of climate change on the deterioration of natural resources, such as soil erosion, deforestation, and biodiversity loss. Addressing the complex interplay between climate change, agriculture, and food security requires coordinated efforts from policymakers, researchers, and agricultural practitioners. The impacts of climate change on agriculture in Nigeria are already being felt, with changes in crop phenology, increased incidence of pests and diseases, and reduced availability of water for irrigation posing significant challenges for farmers (Oluwaseun, 2018). It has been indicated in Fig. 1 below that northern Nigeria has great negative impact of climate change and these impacts not only threaten food production and livelihoods but also exacerbate poverty and food insecurity in the country.

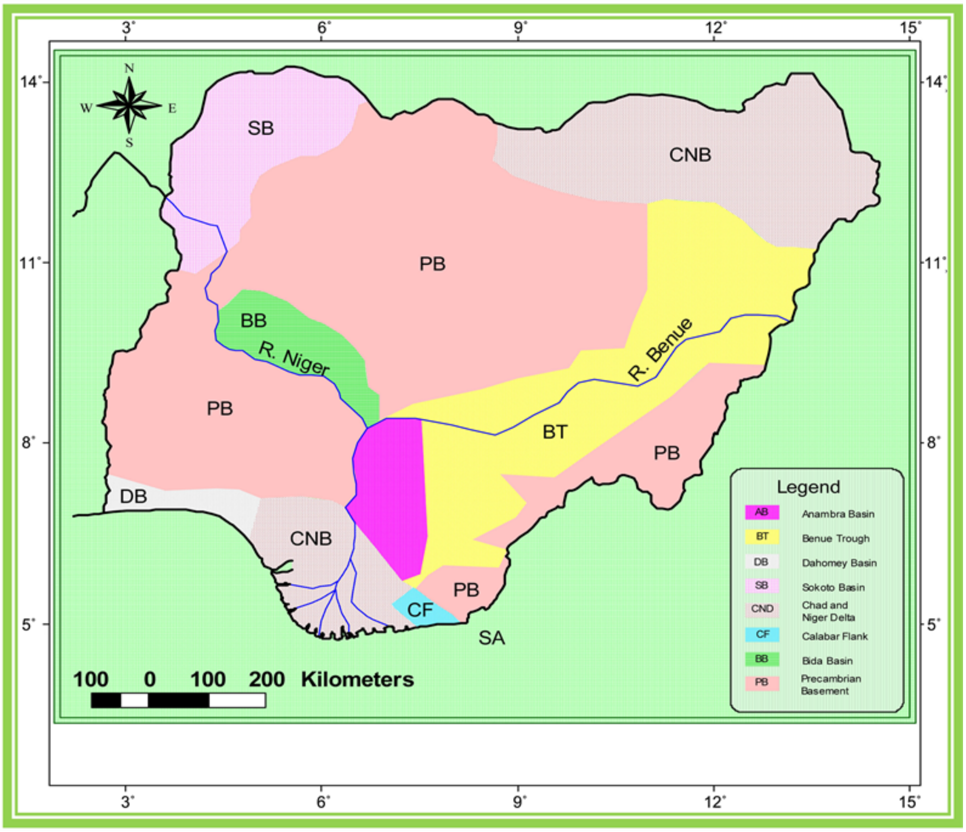

Figure 1: Map of Nigeria showing impact of climate change.

3 Effect of Climate Change on Agricultural Production in Nigeria

The study involved collecting various data essential for model calibration and analysis. These data included:

- **Desertification:** Based on government geological data, sand dunes are expected to rise 400 percent over the next 20 years. Rural residents have long engaged in the regular and widespread practice of continuously felling trees without planting new ones. In Nigeria, overcultivation and deforestation are common practices that encourage the encroachment of the desert (Umeghalu and Okonkwo, 2012).
- **Poor crop and animal yields:** Drought has plagued several northern Nigerian regions since the early 1970s, causing agricultural yields to vary greatly from year to year and from one place to another. This has upset the typical pattern of seasonal water availability (Ekphoh, 2010). The majority of droughts also show signs of false start, late start, sharp breaks during the rainy season, and early end to the rains. These features cause significant changes in the seasonal rainfall distribution pattern, which in turn results in low agricultural yields (Anyanwole, 2007).
- **Flooding (hydrological cycle):** According to hydrological modeling, more than 11,000 square miles of coastal land would be submerged in a 1.5-foot rise in sea level (Onofeghara, 1990). Soil degradation, flooding, and erosion are likely to happen. These are unfavorable signs for fields that could be destroyed by flooding and crops (Umeghalu and Okonkwo, 2012).
- **Pest, diseases, and weeds:** Rainfall would increase due to global warming, lengthening the rainy season and increasing air humidity. When combined with

rising temperatures, this would promote the growth of fungi-related illnesses. Agriculture involving both crops and animals is greatly impacted by this. Trypanosomiasis has a devastating effect on the livestock business in the Nigerian rainforest region, where pasture is plentiful. In the same way, higher humidity and temperatures may result in more insects and disease-carrying organisms exerting pressure. The poultry outbreak in western portions of Nigeria was linked to rising temperatures because of the related heat stress (Adefalolu, 2004).

4 Agribusiness, value chain development and Agri-logistics

Low agricultural productivity in recent decades due to a lack of investment in the agri-food sector has been a severe obstacle to value chain development. The productivity of agriculture is severely hampered by a lack of quality inputs and a basic understanding of effective agricultural techniques. Nonetheless, there is a significant (and unfulfilled) need for food in many parts of Nigeria, especially in the vicinity of major centers. In local markets, the greatest demand is still for inexpensive food, but in urban areas, up-scale specialty markets are expanding. To increase production efficiency (producing more output per unit of input) and generate a sufficient surplus for the processing industry, any investment in processing agribusinesses should be accompanied by investments in agricultural productivity (mostly through the combination of offering extension, tailored advice, quality seed, and inputs). Concentrated power in cartels and entrenched interests are characteristics of some value chains. It is challenging for an outsider to invest due to corruption, fragmented value chains, and a lack of market knowledge. Strengthening the short-value chains (fruit and vegetables) that can cater to the local peri-urban markets is advised instead. This might be achieved by improving the training that several TVETs receive in vegetable farming and by making Dutch training modules and materials on vegetable value chains available. Additionally, the development of these value chains may be aided by Dutch expertise and the supply of enhanced vegetable seeds. The emphasis on enhancing particular value chains that are being suggested fits in nicely with the Nigerian Agricultural Promotion Policy (APP), which lists enterprise development support in various commodities value chains as one of its top priorities (FMARD 2016).

5 Climate Change Adaptation

Nigeria's food system is predicted to suffer greatly as a result of climate change, and initial effects are already being seen (FMIC, 2016; Nugent, 2018). It is predicted that temperatures will rise and precipitation will become increasingly erratic. While more severe rainfall that could cause floods is predicted for Nigeria's southern region, the country's northern region is predicted to see less consistent and more unpredictable rainfall (WUR/BZ, 2018). In the meanwhile, both farmers and extension agencies lack fundamental expertise in climate wise agriculture. The majority of farmers in Nigeria can only cultivate their crops during the rainy season because very little of the country's cropland is irrigated. Additionally, this makes communities who lack access to food and farmers vulnerable to the unpredictable and shifting climate. Climate change is expected to have a significant negative impact on Nigeria's food system, with some effects already being felt

(FMIC, 2016; Nugent, 2018). Temperatures are expected to climb, while precipitation is expected to become more unpredictable. Nigeria's northern region is expected to experience less steady and more erratic rainfall, while the country's southern part is expected to experience more severe rainfall that could result in floods (WUR/BZ, 2018). Meanwhile, fundamental knowledge on climate-smart agriculture is lacking for both farmers and extension organizations. Because so little of Nigeria's agriculture is irrigated, most farmers are only able to grow their crops during the rainy season. This also leaves farmers and communities without access to food exposed to an uncertain and changing climate. The identified leverage point is the sharing of data and information (and know-how) on climate change impacts and adaptation strategies for value chain actors, including regional scenarios for climate change impact. This should be combined with the following leverage points:

- Provision of quality inputs (e.g. drought-resistant varieties).
- Technical training on climate change adaptation in value chains (production, processing, storage).
- Strengthen land rights; integrated masterplan on the use of contested natural resources agreed upon with stakeholders.
- Promote low-cost small-scale irrigation and climate-smart agriculture in prioritized sub-sectors.

6 Amelioration of Greenhouse Gas Emissions through Agroforestry and Enhancing Food Security

Agroforestry systems, according to Kiptot and Franzel (2012), not only boost crop yields and food production, but they also significantly improve food security by offering communities more diversified diets and better nutritional outcomes. Agroforestry systems can alleviate hunger and food insecurity by increasing the availability of fruits, nuts, and other nutrient-dense food products through the integration of trees with food crops. Furthermore, agroforestry techniques like alley cropping and intercropping can enhance soil fertility and create resilient and sustainable food production systems (Garrity et al., 2010). It has been demonstrated in Fig. 2 below that agroforestry techniques reduce greenhouse gas emissions by growing trees and crops on the same piece of land. The incorporation of trees into agricultural land contributes to the reduction of greenhouse gas emissions, including nitrous oxide and methane, which are key causes of climate change. Using nitrogen-fixing trees is one method that agroforestry reduces emissions. By helping the soil meet its nitrogen needs, these trees can lessen the need for artificial fertilizers that release nitrous oxide into the atmosphere (van Noordwijk et al., 2014).

Furthermore, by increasing soil fertility and lowering the need for chemical inputs, the agroforestry practice of alley cropping helps to reduce greenhouse gas emissions. Alley cropping lessens emissions related to pesticide manufacture and use by controlling soil health and utilizing organic matter from tree leaves and other organic material. It has been demonstrated that agroforestry techniques reduce greenhouse gas emissions. The incorporation of trees into agricultural land contributes to the reduction of greenhouse gas emissions, including nitrous oxide and methane, which are key causes of climate change. Using nitrogen-fixing trees is one method that agroforestry reduces emissions. These trees can supplement the nitrogen needs of the soil, reducing the reliance on synthetic fertilizers that result in nitrous oxide emissions (van Noordwijk et al., 2014).

Figure 2: Agroforestry practice.

7 Strategies for Climate Change Amelioration through Agribusiness

1. **Sustainable Agricultural Practice:** Crop rotation, agroforestry, and conservation agriculture are examples of sustainable agricultural methods that can improve soil health and climate change resilience. According to FAO (2019), these methods enhance water retention, lessen soil erosion, and boost biodiversity.
2. **Irrigation Systems:** Reducing reliance on rainfall can be achieved through the development of effective irrigation systems. For Kano State, solar-powered pumps and drip irrigation are practical solutions that will minimize water waste and provide a steady supply of water (Ahmed et al., 2020).
3. **Climate-smart Agriculture:** CSA, or climate-smart agriculture, is the adoption of methods that lower greenhouse gas emissions, boost resilience, and increase productivity. CSA methods include integrating livestock with crop production, choosing crop varieties resistant to drought, and scheduling plantings according to the best dates (Mbow et al., 2019).
4. **Agro-processing and Value Addition:** Promoting these two activities can enhance food security by lowering post-harvest losses. Both farmers and consumers profit when agricultural produce is processed into finished items because it extends its shelf life and raises its market value (Adeniji et al., 2018).

8 Adaptive Roles by Nigerian Agribusiness Entrepreneurs to cushion the effect of climate change

- **Improved and more organized techniques of agricultural production:** Owners of agribusinesses must utilize improved animal and crop varieties. Some

Nigerian farmers have diversified their crop farming by planting a range of crops on their farmlands; crops that could be long-duration crops and short-duration to lessen the effects of climate change. Across the country, farmers are also engaged in early farming and produce harvesting (Akor, 2012). Using compost and farm yard waste in conjunction with sustainable agricultural practices is another strategy used by Nigerian farmers to boost yields and avoid farm failures. Crop diversification, or crop substitution, addresses the financial risks and alterations to the environment associated with climate change.

- **Water harvesting and storage:** The majority of farmers need to have access to this technology to preserve the nation's food security. Agribusiness entrepreneurs harvest and store water. In Nigeria, this is also an adaptation strategy; the water is conserved and used for home gardening and other uses (Akor, 2012; Ijeoma, 2012).
- **Farm finance management:** Agribusiness entrepreneurs can use farm-level adaptation options, such as government-backed and private farm income methods, to lower the risk of income loss due to climate change (Smith and Skinner, 2002). In the case of sponsored programs, insurance spreads public exposure to climate-related risks while also reducing revenue loss from reduced crop yields due to droughts, floods, and other climate-related disasters (Smit et al. 1989). In Nigeria, buying insurance to lessen the possibility of income loss due to climate change is not yet common.
- **Vertical integration with pertinent agencies:** To mitigate the effects of climate change, the agribusiness entrepreneur teams up with pertinent organizations. These agencies, which are in charge of coordinating their policy and research-related activities, are the National Emergency Management Agency (NEMA), the Nigerian Meteorological Agency, the National Environmental Standards and Regulations Enforcement Agency, the National Institute for Fresh-water Fisheries Research, the National Water Resources Institute, Kaduna, and the National Center for Arid Zone Studies, Maiduguri (Sayne, 2011).
- **Current information to take preventative action:** An extensive evaluation of all available facts regarding probable climate change impacts and related conflict risks is conducted by the agribusiness entrepreneur. Entrepreneurs in the agribusiness sector who achieve success create a participatory, multidisciplinary assessment process that starts with analyzing resource constraints, secondary effects, and conflict risks related to climate change. Next, they evaluate the viability and affordability of specific adaptation strategies (Sayne, 2011). For future adjustment options to be valuable, the impact of drought on agricultural yields is analyzed along with an assessment of farmers' current reactions to drought (IPCC, 2007).

9 Contribution to United Nations Sustainable Development Goals (SDGs)

- **SDG 1: No Poverty** Agribusiness initiatives in Northern Nigeria reduce poverty by creating jobs, increasing farmers' incomes, and promoting rural development. These initiatives help smallholder farmers increase productivity and profitability, economically empowering them and reducing poverty levels (FAO, 2020).
- **SDG 2: Zero Hunger** Enhancing food security through agribusiness directly combats hunger. Sustainable agricultural practices increase food production and

supply, ensuring food security. Promoting diverse and nutritious crops also improves nutrition and food availability (UN, 2020).

- **SDG 8: Decent Work and Economic Growth** Climate-smart agribusiness creates decent work opportunities in agriculture. Integrating modern technology and sustainable practices attracts investments, promotes entrepreneurship, and stimulates economic growth in rural areas (ILO, 2018).
- **SDG 13: Climate Action** Climate change amelioration strategies in agribusiness mitigate adverse climate effects. Practices like sustainable land management, water conservation, and renewable energy in agriculture reduce greenhouse gas emissions and enhance climate resilience (IPCC, 2019).
- **SDG 15: Life on Land** Sustainable agribusiness preserves terrestrial ecosystems by promoting biodiversity and reducing land degradation. Techniques such as agroforestry, organic farming, and conservation agriculture contribute to healthier ecosystems and improved soil quality (FAO, 2020).

10 Coordination with Science, Technology, and Innovation Strategy for Africa (STISA-2024)

The Science, Technology, and Innovation Strategy for Africa (STISA-2024) aims to harness science, technology, and innovation to address Africa's socio-economic challenges. The initiative on climate change amelioration and food security in Northern Nigeria aligns with several STISA-2024 objectives:

10.1 Priority Area 1: Eradication of Hunger and Ensuring Food and Nutrition Security

By leveraging agribusiness to enhance food security, the initiative supports eradicating hunger and ensuring food and nutrition security. Innovative agricultural practices and technologies increase food production and improve nutrition (AU, 2014).

10.2 Priority Area 2: Prevention and Control of Diseases

Agribusiness initiatives can include cultivating medicinal plants and producing nutritious foods that boost immunity, contributing to disease prevention and control. Healthier agricultural practices reduce harmful pesticide use, promoting better health outcomes (WHO, 2020).

10.3 Priority Area 3: Communication (Physical and Intellectual Mobility)

The initiative can promote the dissemination of agricultural innovations and best practices through digital platforms and farmer networks. Improved communication and knowledge sharing enhance farmers' capacity to adopt sustainable practices (AU, 2014).

10.4 Priority Area 4: Protection of our Space

Sustainable agribusiness practices contribute to environmental protection by reducing carbon footprints, conserving biodiversity, and preventing land degradation. This aligns with broader goals of environmental protection and sustainable resource management (AU, 2014).

11 Potential Impact on Post-STISA Initiatives by the African Union

The success of climate change amelioration and food security initiatives in Northern Nigeria can serve as a model for other regions in Africa. Key potential impacts include:

11.1 Scaling Up Innovations

Successful agribusiness models and climate-smart practices can be scaled up and replicated across Africa, contributing to broader food security and climate resilience efforts.

11.2 Socio-economic Data

Information on farming practices, land tenure, and community demographics was collected through surveys and interviews with local farmers and stakeholders. This data helped to understand the social and economic context of land management practices. The farmers also gave suggestions on future land use practices that they considered practical for model simulations.

11.3 Socio-economic Data

Positive outcomes from these initiatives can inform policy decisions and encourage the adoption of supportive policies at national and continental levels, promoting sustainable agriculture and climate action (AU, 2014).

11.4 Policy Influence

Information on farming practices, land tenure, and community demographics was collected through surveys and interviews with local farmers and stakeholders. This data helped to understand the social and economic context of land management practices. The farmers also gave suggestions on future land use practices that they considered practical for model simulations.

11.5 Capacity Building

Building the capacity of farmers and agribusinesses through training and knowledge transfer creates a skilled agricultural workforce, ready to implement innovative and sustainable practices (AU, 2014).

11.6 Regional Cooperation

The initiative can foster regional cooperation by sharing best practices, technologies, and resources among African countries, strengthening collective efforts towards achieving the SDGs and STISA-2024 goals (AU, 2024).

12 Conclusion

Climate change poses significant threats to Nigeria's agriculture industry, particularly in northern Nigeria, where rain-fed agriculture is highly vulnerable. This vulnerability leads to rising temperatures, irregular rainfall patterns, and extreme weather events, endangering the livelihoods of millions of smallholder farmers and undermining food security. Agribusiness, including farming, processing, marketing, and distribution, can contribute to reducing climate change's effects by incorporating climate-smart practices and technologies. Investments in climate-smart agriculture practices, such as agroforestry, conservation agriculture, and integrated water management, are crucial for improving agricultural systems and ensuring sustainable food production in Nigeria. Effective policies and interventions are needed to increase the agriculture sector's capacity for adaptation and help smallholder farmers become more resilient. Agroforestry systems can improve crop yields, and food security, and reduce greenhouse gas emissions. Nigerian agribusiness entrepreneurs can mitigate the effects of climate change by utilizing improved animal and crop varieties, water harvesting and storage, farm finance management, and vertical integration with relevant agencies.

13 Recommendation

- Develop a comprehensive stakeholder engagement plan that includes local communities, government agencies, private sector partners, and international organizations. This will ensure broad support and collaboration, enhancing the initiative's effectiveness and sustainability.
- Incorporate Local Knowledge and Practices by integrating indigenous knowledge and traditional agricultural practices with modern techniques to create context-specific solutions. This approach respects local cultures and enhances the relevance and acceptance of the initiative.
- Monitor and Evaluate Impact This can be done by establishing robust monitoring and evaluation frameworks to assess the impact of agribusiness practices on food security and climate resilience. Use data-driven insights to continuously improve strategies and demonstrate progress to stakeholders.
- Ensure that the initiative promotes gender equality by providing equal opportunities for women in agribusiness. Implement targeted programs to support female farmers and entrepreneurs, addressing specific barriers they face.
- Facilitate access to financial services for smallholder farmers and agribusinesses. Provide training on financial literacy and develop innovative financing models to support investments in sustainable agriculture.
- Strengthen Infrastructure by investing in rural infrastructure such as roads, storage facilities, and irrigation systems. Improved infrastructure will enhance market access, reduce post-harvest losses, and increase the efficiency of agricultural value

chains.

- Foster Research and Development by supporting research and development in climate-resilient crops, sustainable farming techniques, and agribusiness innovations. Collaborate with research institutions and universities to drive scientific advancements that benefit agriculture.
- Advocate for supportive policies that promote sustainable agriculture and climate action. Engage with policymakers to ensure that regulations and incentives align with the goals of the initiative.

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Heat, Harm, and Hope: Ghana's Savanna Ecosystem Services in a Fiery Climate

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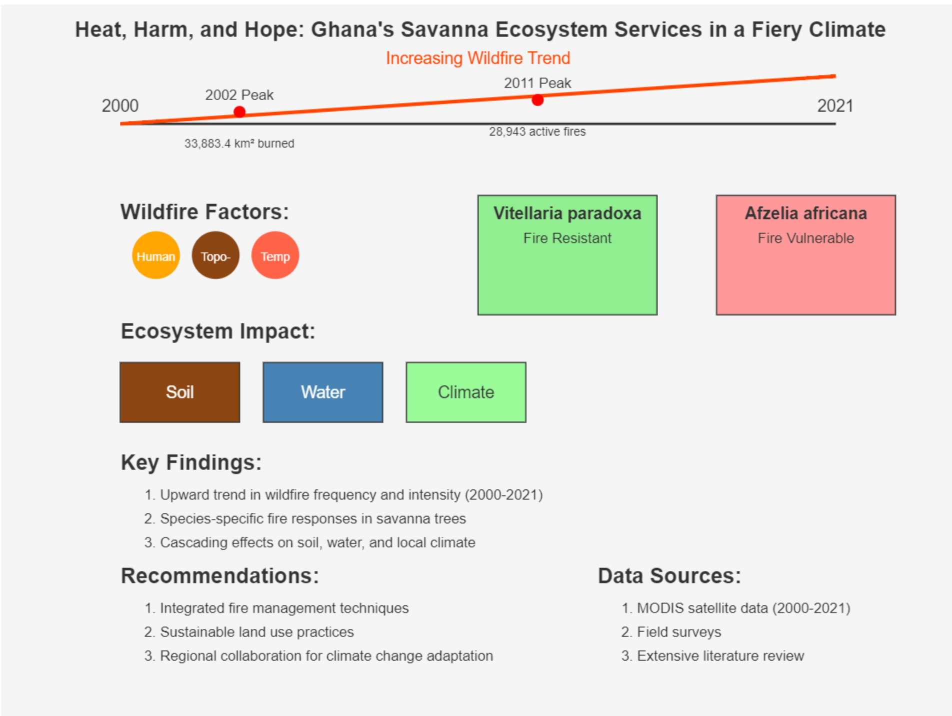
Graphical Abstract



Heat, Harm, and Hope: Ghana's Savanna Ecosystem Services in a Fiery Climate

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Abstract

This study investigates the link between wildfires and ecosystem services within Ghana's northern savanna through an integrative approach combining satellite data analysis, field surveys, and an extensive literature review. Analysis of MODIS data from 2000 to 2021 reveals an upward trend in both the frequency and intensity of wildfires, with notable peaks in 2011 (28,943 active fires) and 2002 (33,883.4 km^2 of burned area). Key factors influencing wildfire dynamics were identified as proximity to human settlements, topographical features, and maximum temperature. Field surveys highlighted species-specific responses, with Vitellaria paradoxa demonstrating significant fire resistance, in contrast to the vulnerability observed in Afzelia africana. The research further elucidates the cascading effects of wildfires on soil properties, water quality, and local climate regulation. The study emphasizes the need for integrated fire management techniques that prioritize prevention and mitigation above suppression. Addressing the wildfire issue requires sustainable land use practices, climate change adaptation, and regional collaboration.

Keywords: Wildfires, Ecosystem services, Savanna, Ghana, Climate change, Conservation

1 Introduction

The northern savanna of Ghana is a significant ecosystem consisting of expansive grassland with scattered trees and plays a crucial role in providing various services that are needed for both human well-being and environmental sustainability (Paterson et al., 1998). The savanna's impact on local economies, through activities including agriculture, cattle grazing, and the extraction of non-timber forest products, highlights its significance to Ghana's socio-economic structure. The ecosystem services are facing a greater risk due to the rising occurrence and severity of wildfires, which are worsened by climate change and changing land-use patterns. Given the increasing pace of climate change and the expanding scope of human activities, it is imperative to comprehend the intricate relationships between wildfires and ecosystem services to develop efficient strategies for managing and conserving these ecosystems (Hurteau et al., 2014). Ghana has seen numerous problems in recent years (2021-2023), including the ongoing recovery from the COVID-19 pandemic and a rise in wildfire occurrences in the northern savanna region. Although not approaching the extraordinary magnitudes observed in Australia (2019-2020) or the United States (2020), Ghana's wildfire situation has nonetheless raised concerns. Over the past two decades, the frequency and intensity of wildfires in the northern savanna have increased significantly, posing substantial risks to biodiversity, ecosystem functions, and human livelihoods. The aftermath was characterized by substantial economic losses, extensive loss of species and habitat, as well as a significant rise in land degradation. The intricate interaction of fire, climate, and human activity poses an urgent issue for the management of ecosystems and conservation endeavors (Kugbe et al., 2012). This study seeks to analyze the diverse consequences of wildfires on ecosystem services in the northern savanna of Ghana. It attempts to explore both the direct and indirect effects of wildfires on the provision, regulation, cultural, and supporting services offered by the ecosystem. In addition, possible management methods would help reduce the impact of wildfires and protect the valuable ecological services of the region (Appiah et al., 2010). Four(4) objectives were proposed to facilitate the attainment of the purpose of this work:

1. Assessing the occurrence and pattern of wildfires in the northern savanna region between 2000 and 2021 by utilizing MODIS data.
2. Analyzing the key drivers of wildfires.
3. Assessing wildfires' direct and indirect effects on the provision, regulation, culture, and supporting ecosystem services.
4. Suggesting management and mitigation strategies to protect the region's valuable ecosystem services from rising wildfire risks.

Through this analysis, the study aims to contribute valuable insights for policymakers, land managers, and stakeholders working towards sustainable management of Ghana's savanna ecosystems in an increasingly fire-prone environment.

2 Methods

2.1 Study Area

Figure 1 is the geographic location of the study area showing the five main regions in Northern Ghana. The study concentrates on the Northern Savannah ecological zone of Ghana which covers the bulk of the northern part of the country with an area of about 99,182 km 2 (41% of the total land area) but only 17.1% of the population. It lies between latitudes 8°N and 11°N and has a land area of 97702 km^2. It comprises the Upper West, Upper East, Savannah, North-East, and Northern regions and is the most sparsely inhabited.

The region has a tropical continental climate classified as Köppen's Aw, with a strong seasonal rainfall pattern characterized by distinct wet and dry seasons (Ahmad & Wanah, 2024). Precipitation is concentrated from May to September, peaking in August (Amos, Ahmad, Abashiya, & Abaje, 2015; Ahmad & Wanah, 2023). The average annual precipitation is about 863.2 mm.

Hydrologically, the region is located in the Gongora Basin, part of the Upper Benue Trough Plain in northeastern Nigeria. The inhabitants are primarily engaged in agriculture, raising livestock and cultivating crops for subsistence and export. The most important crops for domestic and international markets include rice, maize, and beans (Ahmad & Wanah, 2023).

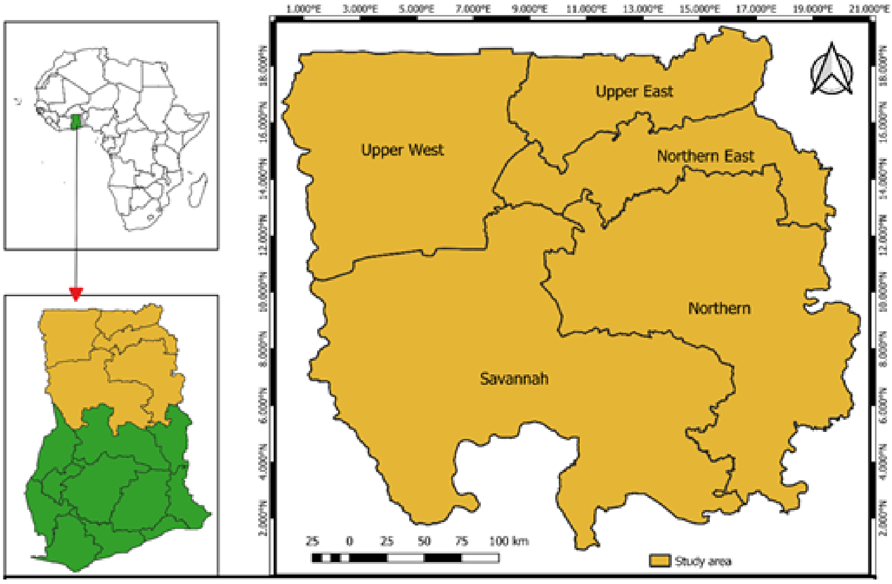

Figure 1: Study Area Map with the 5 regions where data was collected from.

2.2 Climate, Ecological, and Soil Characteristics of the study area

The northern savanna of Ghana is characterized by a semi-arid climate, primarily influenced by two distinct air masses: the hot, dry, and dusty North-East Trade Winds (Harmattan) from the Sahara Desert, and the cold, moist South-West Monsoon winds from the Atlantic Ocean (Incoom et al., 2020). This region hosts the largest vegetation types in Ghana, comprising the Guinea savannah and Sudan savannah. Important tree species include baobab, dawadawa, and shea nut trees, which are mostly scattered throughout the landscape.

The study area experiences a mono-modal rainy season with an annual mean rainfall of approximately 1250 mm to 1750 mm and a mean temperature ranging from 27°C to 36°C (Incoom et al., 2020). These climatic conditions make the area suitable for agriculture, with most inhabitants predominantly engaged in farming. Over three-quarters of households in these areas participate in subsistence agriculture (Acheampong et al., 2021). Consequently, agriculture remains the dominant land-use activity, with several small farm fields visible during the rainy season. Major crops cultivated include maize, sorghum, millet, groundnut, and yam.

Table 1: Summary of Characteristics of the Study Area

Characteristics	**Savannah Ecological zone**
Climate	Semi-Arid
Rainfall Patterns	Mono-modal
Major Average period	May to September
Annual Average Rainfall	1250-1750 mm
Monthly Average Temperature	$25°C$ and $36°C$
Soil Types	Savannah ochrosols
Socio-economic activities	Agriculture, shea butter processing

2.3 Data Collection

This study relied on a combination of field observations, literature review, and analysis of the wildfire and some vegetation data. This study, conducted for 21 years (2000 to 2021) involved annual fire data downloaded at the peak of the seasonal evolution of wildfire (December) for each year. The wildfire occurrence in the Savannah eco-zone of Ghana were assessed using the Collection 6 (C6) wildfire data of the Moderate Resolution Imaging Spectroradiometer (MODIS). Specifically, collection 6 MODIS Global Burned Area Product (MCD64A1) (https://ladsweb.modaps.eosdis.nasa.gov/search/order/) which provides daily global 500m resolution summarized in monthly data was utilized to map the annual fire occurrence (Annual Burn Area) (Giglio et al., 2018). In addition to the fire data, this study used various exploratory variables including climatic data (daily 30-year climate data retrieved from the NOAA National Climatic Data Center online data retrieval tool (https://www.ncdc.noaa.gov/cdo-web/search)); i.e., precipitation, relative humidity, maximum temperature, and wind speed. Based on MODIS data that was overlayed in the zone and based on the frequency of occurrences of wildfire provided by the MODIS data, five risk categories were identified, i.e. very high, high, medium, low and very low. A simple random sampling approach was used in selecting the locations from the categorized areas totaling 30 sampling sites A single rectangular plot measuring 30 m x 30 m was established to conduct a phytosociological inventory of the woody, regeneration, and herbaceous species components (Toko & Sinsin, 2011). The corners of the plot were georeferenced using a handheld GPS device with an accuracy of ±3 m

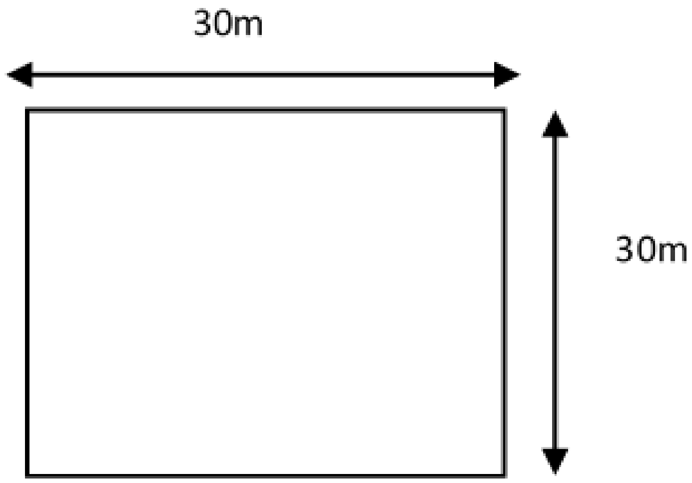

Figure 2: Plot measurement for phytosociological inventory of tree species.

All woody plants with a diameter at breast height (DBH) $\geq$ 5 cm were measured for physical parameters such as height and crown diameter, with a particular focus on frequently burnt life forms to assess regeneration dynamics. Human disturbance factors, including fire, farming, cutting, and pasture, were recorded through field observations along with the geographical coordinates. Additionally, soil types were observed as part of the data collection process (Fousseni et al., 2011).

2.4 Data Analysis and Processing

Using the "Kendall" package in "R", the Mann-Kendall test was employed to analyze the trend of wildfires over a 21-year period, tested at a significance level of $\alpha = 0.05$. This non-parametric trend test is a refinement of the original test developed by Mann (1945) and later adopted by Kendall (1975). The Mann-Kendall test is used to detect the existence of a single overall trend within a time series. A positive Kendall's tau indicates an increasing trend, while a negative tau indicates a decreasing trend.
A multiple regression analysis was carried out to predict fire resistance species based on various factors such as the degree of damage sustained in a fire (Dependent variable) and the plant height, bark thickness and resprouting ability, and soil type (Independent variables). This was carried out using, the 'lm' function in "R". Descriptive statistics (Minimum and Maximum values) were used to present findings on fire frequency, burned areas, and species distribution whilst incorporating the findings from previous research to provide context and support for their observations, particularly in discussing the indirect effects of wildfires and potential management strategies. Bar charts for frequency and time series plots for trends were used to visualize the data analyzed.

2.5 Overview of Ecosystem Services in Ghana's Northern Savanna

Ghana's northern savanna offers an array of ecosystem services that are crucial for both local communities and the wider environment. The Millennium Ecosystem Assessment (MEA, 2005) highlighted four main categories of ecosystem services: provisioning, regulating, cultural, and supporting services.

- Provisioning services include food derived from cropping or animal/livestock farming, fuel wood, medicinal plants, and construction materials (Antwi et al., 2014). The many endemic plant species that the savanna hosts contribute essential local income and food for families.
- Regulating services encompass carbon sequestration, water purification and regulation, as well as flood and erosion management (Jo et al., 2024). Although minute, these services can significantly reduce climate change impacts and maintain environmental stability.
- Cultural services provided by the northern savanna include spirituality, traditional knowledge, and ecotourism (Campion & Acheampong, 2014). These services are vital to local culture and tradition.
- Supporting services such as nutrient cycling, soil formation, and primary production underpin all ecosystem services (Attuaquayefio & Folib, 2009). They are fundamental to the long-term sustainability of the savanna ecosystem and its ability to provide other services.

3 Data Analysis and Discussions

3.1 Wildfire Patterns in the Northern Savanna-Frequency and Seasonality

In Ghana's northern savanna, wildfires happen all the time, but they have clear trends when it comes to how often they happen when they happen, and what causes them. To figure out how these trends affect ecosystem services, you need to understand them. Historical trends indicate a gradual increase in wildfire frequency and intensity over the past decades, due to climate change and changing land-use patterns (Dwomoh et al., 2019). This trend has significant effects on how long ecosystem services will be sustainable in the region. Wildfires in the northern savanna typically occur during the dry season, which spans from November to April (Dwomoh & Wimberly, 2017). Data was derived from MODIS from 2000-2021 to determine the seasonality and establish a relationship between active fires and burn areas.

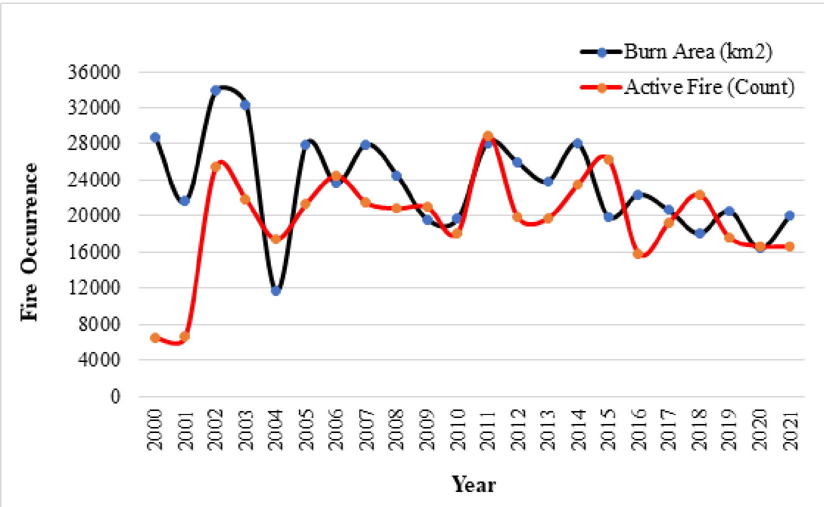

Figure 3: Burn area and active fire occurrence in Ghana's northern savanna zone from 2000 to 2021.

The analysis revealed a total count of 432,153 active fires, which burned a total landmass of 515,822.7 km2 of vegetation in the Savanna Zone. As shown in Figure 1, the highest wildfire occurrence was recorded in 2011, with 28,943 fire detections representing 6.7 percent of active fire counts whereas, the highest burn area happened in 2002 with 33883.4 km2 signifying 34.8 percent of the entire savanna zone. Conversely, the lowest occurrence of active fires was recorded in 2000 with 6501 active fire detections representing 1.5 percent of the total active fires from 2000 to 2021 while the lowest burn area was observed in 2004 occupying an area of 11,687.5 km2 signifying 12.0 percent of the entire savanna zone (Figure 1). Archibald et al. (2010) also used satellite data analysis to show that some areas experience annual burning, while others burn less frequently, creating a mosaic of fire regimes across the savanna landscape. Wildfires in this region have both natural and anthropogenic origins. Lightning strikes can ignite fires, particularly at the onset of the rainy season. However, human activities land clearing and preparation for agricultural practices, flushing out game animals during hunting, burning by pastoralists to promote new grass growth for livestock and indiscriminate disposal of cigarettes are the predominant causes of wildfires (Amoako & Gambiza, 2022).

3.2 Drivers of wildfires

Although climate is considered a primary driver of wildfire activity through its influence on weather conditions and fuel availability, the analysis (Figure 4) shows that the best predictors of wildfire occurrence are a combination of various variables; distance to settlements, slope, distance to road, maximum temperature and elevation was found to have a relatively higher performance. According to studies, fires occur more frequently near towns than farther away (Elliott et al., 2009). This is likely due to increased human activity and ignition sources near populated areas. Literature also points out the fact that areas more than 500m farther away from settlements experience more frequent fires as compared to areas closer to settlements (Elliott et al., 2009). Also, distance to roads influences fire patterns, affecting both ignition sources (e.g., discarded cigarettes) but may have higher ignition rates but potentially quicker response times for fire suppression. The additional fires in areas farther from settlements tend to occur late in the dry season, likely due to less effective fire management and suppression efforts in remote areas away from settlements. Studies show that maximum temperatures significantly impact wildfire occurrence. Higher temperatures, combined with a lack of precipitation, increase fuel dryness and flammability, leading to more frequent and intense wildfires (Abatzoglou & Williams, 2016; Turco et al., 2016). Temperature is the most important factor in wildfires. High concentrations of wildfire hotspots are found in regions like West Gonja, North Gonja, Mamprugu Moagduri, Sissala East, and Saboba, attributed to moist semi-deciduous high forest vegetation and steep slopes.

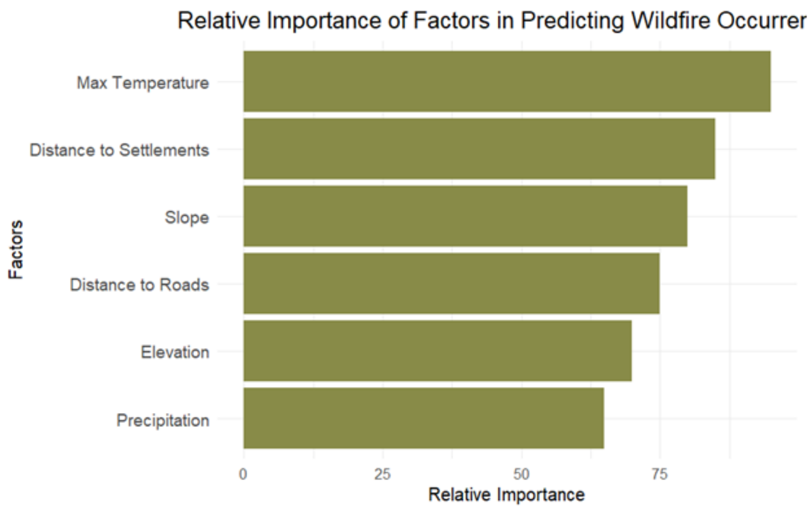

Figure 4: Factors contributing to the occurrence of wildfires in northern savannah zone of Ghana

3.3 Direct Effects of Wildfires on Ecosystem Services in Northern Ghana's Savanna

The savanna ecosystem provides numerous ecological and economic benefits. It supports a rich biodiversity, including many endemic plant and animal species. Economically, the savanna is crucial for livestock grazing, fuelwood collection, and the harvesting of non-timber forest products such as shea nuts and dawadawa fruits. Agriculture is also a significant land use, with crops like millet, sorghum, and maize being widely cultivated.

Wildfires dramatically alter vegetation structure and composition, affecting both provisioning and supporting services. Intense fires can kill mature trees, reducing woody biomass and altering habitat structures (Cardoso et al., 2018). This loss of biodiversity can disrupt pollination services and reduce the availability of medicinal plants and other non-timber forest products (Tom-Dery et al., 2014). These savannas are part of the larger Sudanian savanna belt that stretches across West Africa and are broadly classified into two main types: the Guinea savanna and the Sudan savanna. This ecosystem is characterized by a higher tree density and diversity compared to the Sudan savanna. Common tree species in this zone include Vitellaria paradoxa (shea), Parkia biglobosa (dawadawa), Adansonia digitata (baobab), and various Combretum and Terminalia species. Species composition and diversity were carried out on 30 plots of 30x30 meter land within the study area. Figure 5 illustrates the dominance of Vitellaria paradoxa among fire-resistant species in the surveyed areas followed by Parkia Biglobosa with 20 species. Piliostigma thonningii was the least with 2 trees identified. However, there was also Acacia Senegal, Combretum molle and Burkea Africana. The species listed above had regenerative potential and the ability to withstand wildfires and are considered fire-adapted. A similar analysis was carried out for tree species that are highly vulnerable to wildfire. Out of these Afzelia africana (Vulnerable), Khaya senegalensis(Vulnerable) and Pterocarpus erinaceus - Endangered (EN) were found on the IUCN list of endangered and vulnerable species (IUCN, 2024). Adansonia digitata and Khaya senegalensis were also seen as highly vulnerable to fire especially at their younger stages of growth as a result of their slow growth rates that make recovery from fire damage difficult, thin bark that provides inadequate protection against resprouting ability after fire damage, sensitivity to fire at seedling or sapling stage, even if adults are more resistant and lastly, specific habitat requirements that may be altered by frequent fires.

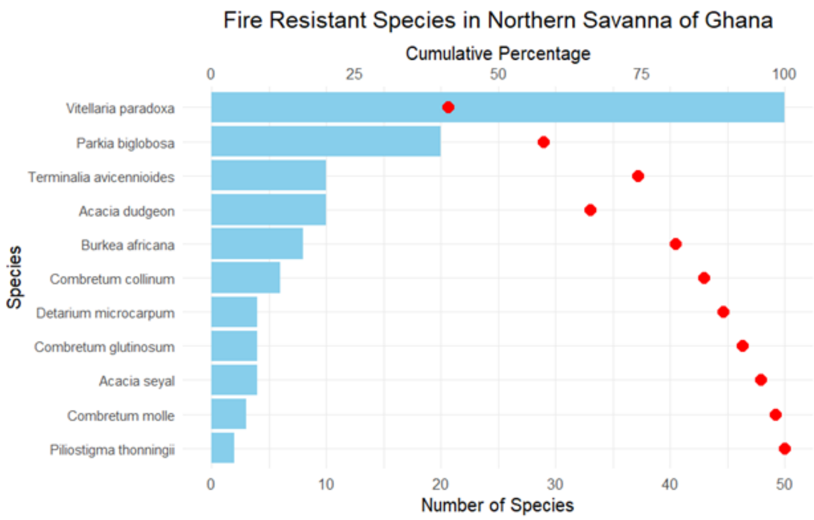

Figure 5: Distribution of fire-resistant savanna tree species identified in the field survey with red dotted points showing the cumulative percentage. Vitellaria paradoxa (shea) was the most prevalent, followed by Parkia biglobosa (dawadawa).

3.4 The Indirect Effects of Wildfires on Ecosystem Services

Wildfires are powerful ecological disturbances that can have far-reaching consequences beyond their immediate impact. While the direct effects of fire are often visually dramatic and well-documented, the indirect effects on provisioning, regulating, cultural and supporting services can be equally significant and long-lasting. These indirect effects ripple through various ecological processes, such as on soil properties and processes as a result of the increase in soil erosion, increased erosion and ash deposition impacting water quality. Air quality is another ecosystem service indirectly affected by wildfires from various literature. Smoke and particulate matter can travel long distances, impacting air quality far beyond the immediate fire area. This can have significant health implications for human populations, particularly for vulnerable groups such as children, the elderly, and those with respiratory conditions (Reid et al., 2016). This report found some interesting links between Landscape-level changes induced by wildfires and cascading effects on various ecosystem services. For instance, altered vegetation patterns can impact habitat connectivity, affect water retention and soil stability, and change the aesthetic and recreational value of landscapes. These changes can also influence the resilience of ecosystems to future disturbances, potentially altering their capacity to provide services in the face of climate change and other stressors. This finding was backed by (Turner, 2010) article which argued that ecosystems may exhibit non-linear responses to disturbances, with potential threshold effects leading to rapid and sometimes irreversible changes. In addition, the study also concluded that wildfires indirectly affect climatic conditions and hence likely to alter vegetation cover which could intend alter temperatures and rainfall patterns. These climatic changes can have implications for various ecosystem processes, including plant growth, decomposition rates, and species interactions (Holden et al., 2018). Biodiversity is another ecosystem service indirectly impacted by wildfires. While some species are adapted to fire-prone ecosystems, large-scale or high-intensity fires can lead to significant shifts in species composition and abundance. In some cases, wildfires can create opportunities for invasive species to establish, potentially leading to long-term changes in ecosystem structure and function (Bowman et al., 2009).

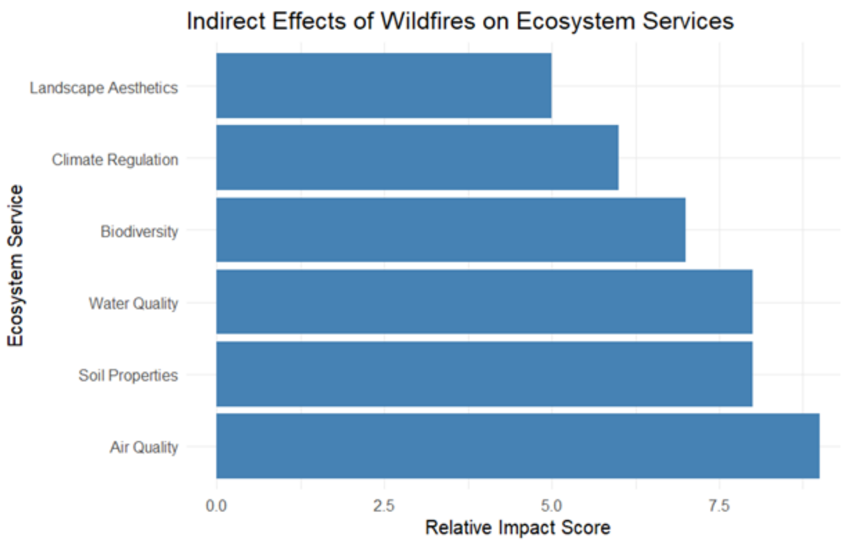

Figure 6: The indirect effects of wildfires on ecosystem services based on various literatures

3.5 Measures to reduce wildfires occurrences in the northern savanna zone of Ghana

The increasing frequency and severity of wildfires, as well as the catastrophic effects they have on ecosystems and human life, necessitate decisive action on all fronts. What follows are critical steps in creating and executing effective measures to lessen the likelihood of wildfires and lessen the severity of their effects while minimizing the financial and material losses that may result from them. Wildfire management strategies should encompass risk mitigation, prevention, suppression, and recovery plans. Sustainable, integrated planning at the landscape level is crucial. Cost-effective preventive and mitigation approaches have received less attention than repression in the savannas of Northern Ghana. Increased funding for mitigation must match upstream prevention. In addition, addressing wildfire drivers like climate change, and unsustainable land use practices is crucial for reducing their frequency and severity and should be integrated into national development strategies, including climate change adaptation and biodiversity conservation. Sufficient investment and budget should support these plans. Prioritizing fire mitigation and prevention, such as Integrated Fire Management (IFM) which seeks to combine traditional knowledge with modern techniques is essential at both national and local levels. Another measure could be developing and implementing advanced fire detection and warning systems such as using real-time satellite data to detect hotspots and predict fire spread and also create a system to send SMS alerts to local communities about high-fire risk periods. Collaborative virtual private networks (VNCs) with neighboring nations such as Burkina Faso, Togo and Ivory Coast can help combat forest fires and advance climate action.

4 Conclusion

The study reveals a growing trend of increasing wildfire frequency and intensity in Ghana's northern savanna, highlighting the need for enhanced fire management strategies. The study also highlights the complex interplay of climate, human, and topographical factors driving wildfire occurrences. Maximum temperature is a significant predictor of future fire regimes, while human factors, such as proximity to settlements and roads, have nuanced effects on fire patterns. Differential impacts of wildfires on savanna tree species and ecosystem services are also highlighted. The findings support an Integrated Fire Management approach that combines traditional ecological knowledge with modern scientific techniques, prioritizing prevention and mitigation strategies over reactive suppression efforts. Further investigation is needed to understand the long-term impacts of changing fire regimes on biodiversity and the effectiveness of fire management strategies.

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