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SUSTAINABLE CATFISH FARMING AND SUPPLY CHAIN IN MUBI AND ITS ENVIRONS: A GIS-BASED APPROACH ADAMAWA STATE NIGERIA

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Abstract: *Aquaculture, specifically catfish (Ictalurus punctatus) farming, plays a vital role in addressing protein needs and supporting economic growth in Mubi, Nigeria. This study explores sustainable catfish farming practices and supply chain optimization through the application of Geographic Information System technology. Employing GIS permits a meticulous spatial analysis to aid strategic decisions, enhancing environmental, economic, and societal sustainability. The investigation begins by assessing current catfish farming methods in Mubi, such as stocking densities, feed regimens, and waste management. Sustainable approaches are also considered, spanning water resource management, environmental impact mitigation, and local community involvement. GIS mapping and analysis are central to the study, enabling visualization of farm locations, assessment of environmental sustainability factors, and refinement of the supply chain network.*

Data collection hinges on field surveys, interviews with farmers, and extraction from relevant databases. This encompasses production figures, environmental data, and supply chain particulars. A combination of statistical and spatial techniques is employed in analyzing the collected data to elucidate the intricate connections within the catfish farming ecosystem. The study's outcomes include identification of catfish farm spatial distributions, evaluations of environmental impacts, and suggestions for supply chain improvement. Concluding discussions reflect on these results and their bearings on sustainable practices, alongside the contemplation of potential challenges and the study's limitations.

Key words: Sustainability, Catfish, GIS, Remote Sensing, Supply Chain, Farming

Introduction

Recent years have seen significant changes in land use/land cover (LU/LC) in Mubi North Local Government Area, Adamawa State, Nigeria (Abdulwahab A. et al., 2019). Factors such as cultural, agricultural, political, historical, and economic considerations have driven these transformations globally. Urbanization, which surged to 54.5 percent in 2016 and is projected to reach 60 percent by 2030, directly impacts local environments and economies (Wang et al., 2018; Singh et al., 2017). As urban populations grow, the demand for food, including fish, increases due to its recognized health benefits (FAO, 2020). Aquaculture's contribution to the fish supply has grown from less than 1 percent in 1970 to over 7 percent in 1988, with farm-raised catfish particularly important in the southeastern United States (FAO, 2020).

This study aims to explore sustainable solutions to fish consumption, unemployment, and food insecurity in Mubi North. Following a 2014 terrorist attack, the area faced heightened unemployment and food insecurity. The research focuses on promoting catfish farming and optimizing its supply chain, aligning with global trends in aquaculture and addressing local challenges. Previous studies in Nigeria have shown favorable profitability for catfish farms, but a decline in production from 2015 to 2017 led to many farmers abandoning the practice due to high production costs and stagnant farm gate prices (Digun-Aweto and Oladele, 2017; Bassey et al., 2013; Kingsley et al., 2014; Sogbesan et al., 2015; Ume et al., 2016). Analyzing profitability based on operational scales is critical. This research integrates Geographic Information System (GIS) technology to provide a spatially informed perspective on catfish farming and supply chain dynamics in Mubi and its environs. By mapping the spatial distribution of farms and supply chain nodes, the study aims to offer valuable insights for sustainable catfish farming while addressing unemployment and food insecurity in the region.

Literature Review

Land Use/Land Cover Changes and Environmental Implications: Land use and land cover (LU/LC) transformations, influenced by cultural, political, historical, and economic factors, significantly impact global landscapes (Abdulwahab A. et al., 2019). Urbanization, a major driver, disrupts ecological balance and climatic conditions while altering economic dynamics (Wang et al., 2018; Singh et al., 2017). In Mubi North Local Government Area, Nigeria, post-2014 terrorist attack challenges highlight the necessity of nuanced LU/LC management for effective rehabilitation and sustainable development. Understanding these changes is crucial for informed decision-making and resilience building in affected communities.

Global Urbanization and Increasing Fish Consumption: Global urbanization has significantly altered population dynamics, with urban areas housing over half the global population in 2016 and projected to reach 60 percent by 2030 (The World’s Cities In 2016). This shift has increased demand for fishery products due to rising health awareness, particularly in urban centres prioritizing healthier diets. Aquaculture has become vital, contributing over 7 percent to the total fishery supply by 1988 (FAO, 2020). As urbanization continues, understanding its impact on food systems, especially fishery products, is essential for sustainable development. The proposed research in Mubi North Local Government Area aims to assess catfish farming's role in providing sustainable fish sources amidst changing urban trends and dietary patterns. This study seeks to explore the interactions between urbanization and food systems, offering insights for policymakers, food producers, and stakeholders in sustainable development initiatives.

Aquaculture Growth and the Role of Catfish Farming: The United States has experienced significant growth in aquaculture, highlighted by a 25 percent increase in per capita fishery product consumption during the 1980s (FAO, 2020). This increase reflects a greater recognition of fish's nutritional benefits, in line with global health trends. Aquaculture's contribution to the total fishery supply rose from less than 1 percent in 1970 to over 7 percent by 1988 (FAO, 2020). A major driver of this growth has been farm-raised catfish, particularly in the southeastern United States. This region has become a hub for catfish production, significantly boosting overall aquaculture output and farm gate value. Catfish farming's efficiency, adaptability to intensive farming, and consumer appeal have established it as a cornerstone of U.S. aquaculture, encouraging investment in the commercial production of various other fish species.

Addressing Unemployment and Food Insecurity through Aquaculture: Following the 2014 terrorist attack, Mubi North Local Government Area faced severe socio-economic challenges, including heightened unemployment and food insecurity. In response, a comprehensive approach is urgently needed. Aquaculture, particularly catfish farming, offers economic opportunities and addresses protein deficiencies. Catfish farming is a viable solution for economic development in Mubi North due to its adaptability and rapid growth. The proposed study aims to optimize the catfish farming supply chain, enhancing local development and contributing to global sustainability efforts in aquaculture.

The Role of GIS in Sustainable Catfish Farming: Geographic Information System (GIS) technology is crucial for sustainable catfish farming, providing a spatially informed perspective. GIS integrates spatial data for comprehensive analysis, interpretation, and visualization, enhancing the optimization of catfish farming in Mubi and its environs. GIS maps the spatial distribution of catfish farms, identifying clusters, patterns, and areas for intervention or expansion. It analyzes environmental factors like water quality and topography, improving the precision of sustainable practices for environmental and economic viability. GIS visualization helps stakeholders understand complex spatial relationships. GIS-generated maps of farm distribution, environmental factors, and supply chain nodes support informed decision-making for researchers, policymakers, and farmers.

Aquaculture Practices and Site Selection

In contemporary African aquaculture, tilapias and carps remain prominent, while controlled breeding extends to ponds housing catfish and Tilapia lazera. Mollusc cultivation includes ten species across four genera-Crassostrea, Mytilus, Venerupis, and Pinctada though crustacean culture is still in its nascent stages on the continent. Emphasizing the crucial role of site selection in ensuring aquaculture success, recent guidelines have been outlined.

Site Selection Guidelines for Fish Ponds:

(i) Soil Quality: Optimal soil for fish ponds includes clay-loam or sandy-clay for water retention and an alkaline pH (7 and above) to mitigate acid-sulphate soil problems. Key soil attributes are:

Texture: Clay-loam or sandy-clay soils provide structural stability, good water retention, and adequate drainage, ideal for pond construction.

Water Retention: These soils maintain water levels, ensuring a stable aquatic environment and preventing stress on the fish.

Alkaline pH (7 and above): An alkaline pH counteracts acid-sulphate soil issues, creating a stable environment for fish culture.

(ii) Land Elevation and Tidal Characteristics: Optimal land elevation ensures ponds are watered by ordinary high tides and drained by ordinary low tides, with moderate tidal fluctuations (2-3 m). This balance prevents flooding and ensures effective drainage.

Vegetation: Avoid large tree stumps and thick vegetation to ease pond construction. Establish buffer zones in areas exposed to wave action to protect pond structures. Mangrove growth indicates productive soil.
Water Supply and Quality: Ensure a reliable supply of fresh and brackish water, free from pollution, with a pH of 7.8-8.5, throughout the year to maintain optimal pond conditions.
Accessibility: Select sites with easy access by land and water transport, proximity to input sources, markets, and communication facilities to streamline operations and reduce costs.
Availability of Manpower: Ensure skilled manpower for both construction and operation phases to build infrastructure and maintain daily activities efficiently.
Pond Layout:
The design and layout of fish ponds are vital for the efficiency, productivity, and sustainability of an aquaculture system. Key considerations include:
Species Requirements: Different fish species need varying space, water depth, and environmental conditions. The pond layout must suit these specific needs, ensuring optimal conditions for growth and well-being.
Area Size and Shape: The layout should maximize the use of available space, considering topography, soil composition, and water sources.
Number and Sizes of Ponds: The number and size of ponds depend on production goals and management strategies. Smaller ponds might be used for nurseries or breeding, while larger ones are for grow-out phases.
Water Canals and Gates: Proper layout of water canals and gates is crucial for maintaining water flow, nutrient distribution, and waste management.

Protein Requirements and Considerations
Protein requirements for catfish remain a subject of ongoing debate among fish nutritionists, influenced by factors such as water temperature, feed allowance, fish size and age, dietary protein to energy ratio, protein quality, natural food availability, and management practices (Craig & Edwin, 2022).

Proper Planning and Layout
A well-designed fish farm integrates water control structures, canals, and pond compartments in a mutually complementary manner (SCSP, 2020). A complete fish farm includes nursery, grow-out, and transition ponds, with proper proportions and positions (SCSP, 2020).

Milkfish Culture in Brackish Water Ponds
Milkfish culture in the Philippines adheres to traditional practices, incorporating nursery, transition, and rearing operations. Formation ponds may be used for additional growth or stunting of fingerlings before stocking in rearing ponds (Camacho and Lagua, 2021).

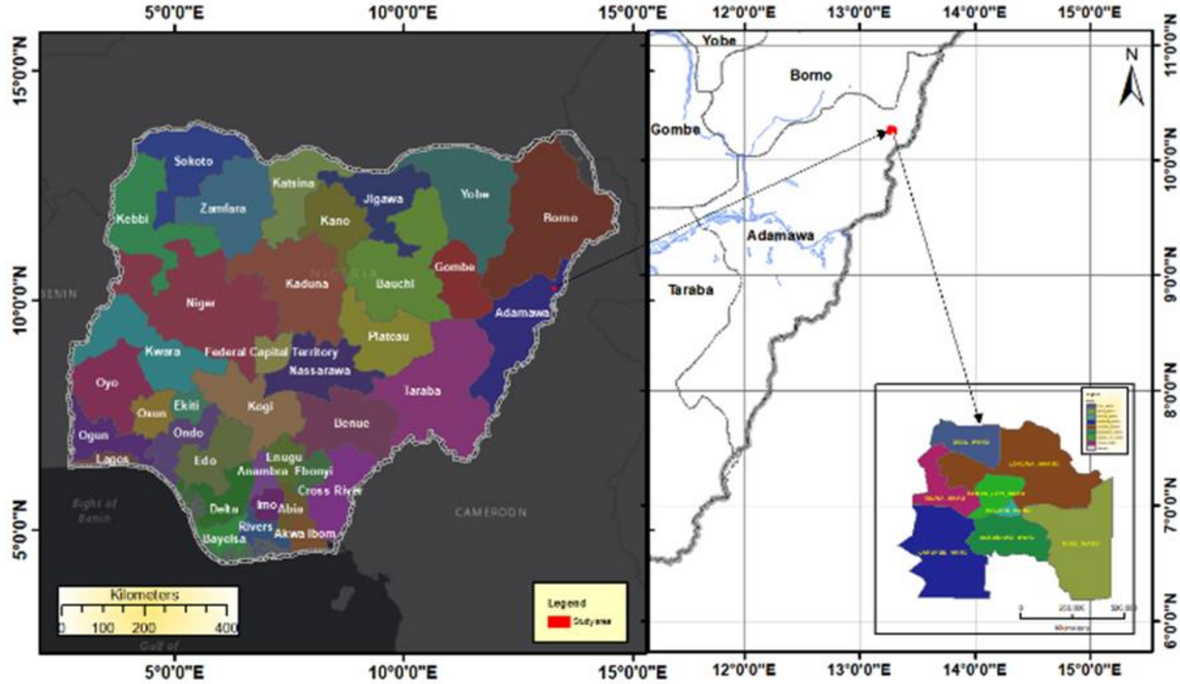
Statement of the problem
The lack of maps and information on the geospatial distribution and dynamics of catfish demand and supply in Mubi has highlighted the need for this project. This gap makes it difficult to visualize the relationship between catfish consumption and demographic influences on the supply chain. Thus, the project aims to graphically and statistically describe catfish demand, supply, farms, and vendor patterns in Mubi, Adamawa State. To date, no such analysis using statistical methods and Geospatial Science exists for this region.2.2.7 Aims and Objectives

1. Assess Current Catfish Farming Practices:
2. Implement Sustainable Measures:

The Study Area

The study area for the proposed research on sustainable catfish farming and supply chain is Mubi North Local Government Area in Adamawa State, Nigeria. Mubi metropolis, comprising Mubi North and Mubi South, lies between latitudes 10°05' and 10°30'N and longitudes 13°12' and 13°19'E. Covering 192,307 km², it has a population of 260,009 (National Population Census 2006). The area borders Maiha L.G.A to the south, Hong L.G.A to the west, Michika L.G.A, and the Cameroon Republic to the east (Adebayo 2004), as shown in Figure 1.

Figure 01: Map of Nigeria Showing the Study Area Mubi



Source: Surveying and Geoinformatics Federal Polytechnic Mubi

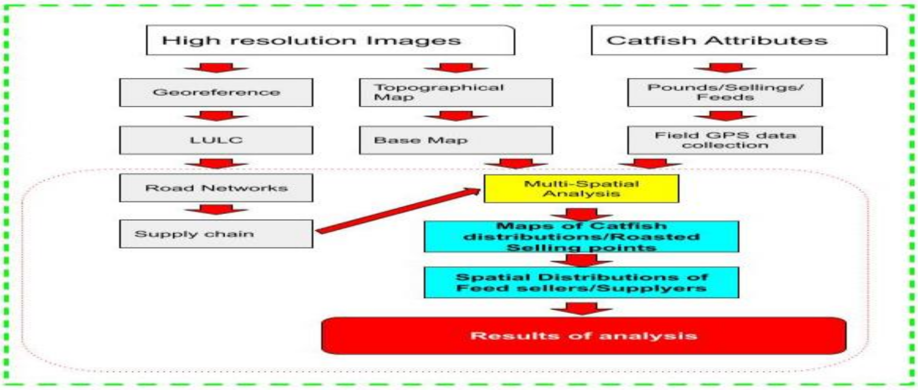
Materials and Methods

Method of Data Collection and Analysis: The research employs a comprehensive methodology that includes data collection through surveys, interviews with farmers, and extraction from existing databases. The collected data covers aspects of catfish production statistics, environmental parameters, and supply chain dynamics. Sustainable measures are applied to assess water management, environmental impact, and community engagement. Geographic Information System (GIS) tools are utilized for mapping and analyzing spatial data to visualize the distribution of catfish farms, identify environmental factors affecting sustainability, and optimize supply chain nodes. Statistical and spatial analysis methods are employed to interpret the multifaceted relationships within the catfish farming system.

Primary Data Source: Fieldwork involved the utilization of GPS (Global Positioning System) technology to collect primary data. Precise coordinates, encompassing eastings, northings, or latitude and longitude, were gathered for pivotal locations, including catfish farms, Catfish selling spots, and catfish feeds selling stores within the study area. These coordinates were then superimposed onto a georeferenced High-resolution image of the research region, facilitating visual interpretation and geographical analysis of catfish availability and supply chain.

Secondary Data Source: The secondary data predominantly originated from the catfish farmers, sellers, feed suppliers and consumers. This encompassed variables such as production rates, water quality parameters, growth rates, and other relevant metrics. A comprehensive database was analysed within the ArcGIS 10.8 environment, providing a structured foundation for systematic data retrieval and analysis. The data collection process unfolded through six distinct stages. Commencing with primary data collection, subsequent steps involved the georeferencing of the raster dataset and digitization of spatial information. Key elements such as catfish farms, water bodies, access points, and more were delineated. The fifth stage cantered on the creation and mapping of a database tailored to the intricacies of catfish farming. The flowchart of the process is presented in figure 2.

Figure 02: Methodological flowchart of the Analysis



Criteria for Sustainable Catfish Farming in Mubi Metropolis: The assessing the viability of sustainable catfish farming in Mubi Metropolis, a tailored set of criteria has been developed. Inspired by successful practices in analogous regions and adapted to Mubi's specifics, these criteria serve as essential benchmarks for evaluating the area's suitability for enduring catfish farming operations. The first criterion, "Soil Suitability for Ponds," examines soil compatibility for pond construction, considering topography and manageability crucial for smooth farm operations. The second criterion, "Soil Suitability for Levees," evaluates soil appropriateness for levee construction, vital for maintaining water levels and facilitating harvest. Lastly, the fifth criterion, "Soil Suitability for Heavy Equipment," assesses soil resilience and support for heavy equipment essential in various catfish farming tasks like feeding, harvesting, and maintenance. Data from localized soil surveys and Mubi-specific assessments inform the categorization of each criterion, considering potential limitations from "slight" to "moderate" and "severe." These detailed evaluations offer insights into the distinct challenges and advantages of different soil types in the metropolis. Numerical ratings, factoring in limitations associated with each soil type, are assigned to each criterion. Overall suitability scores for general soil map units are then determined by aggregating scores across individual criteria. Additionally, factors like relief, slope, and susceptibility to flooding are considered to establish a final suitability rating for sustainable catfish farming in Mubi Metropolis.

Coastal and Marine Ecosystems in the Context of Sustainable Catfish Farming in Mubi and Its Environs: Within the realm of sustainable catfish farming in Mubi and its environs, the significance of coastal and marine ecosystems cannot be overstated. While Mubi is situated inland, understanding the broader implications of sustainable aquaculture requires a contextual examination of coastal and marine ecosystems globally. In the Association of Southeast Asian Nations (ASEAN) region, where millions of registered fishers rely on fishing for their basic livelihoods, the interconnectedness of aquatic environments and human well-being becomes evident. Similarly, in the Coral Triangle countries, millions are employed directly in fisheries, emphasizing the socio-economic.

Results and Discussion

The study's results focus on key findings regarding spatial patterns of catfish farms, environmental impacts, and supply chain optimization, emphasizing their implications for promoting sustainability and supply chain efficiency. Data collected through field surveys were converted into shapefile format using Global Mapper software, recognized for its compatibility with GIS platforms. The Universal Transverse Mercator (UTM) projection system with the World Geodetic System 1984 (WGS84) datum, specifically Zone 33, was employed for precise spatial referencing. Ground control points (GCPs) obtained via handheld GPS receivers enhanced spatial data accuracy. Through field survey data collection, shapefile conversion, and integration of georeferenced imagery, the research produced comprehensive mapping of catfish farm spatial distribution. These outcomes serve as a robust basis for discussing catfish farming patterns, supply chains, and sustainable resource management strategies. Figure 3a and 3b depict the spatial distribution of roads, wards, catfish farms, and selling points, offering insights into their relationships within the context of catfish farming in Mubi metropolis.

Figure 03a: General Spatial Distributions

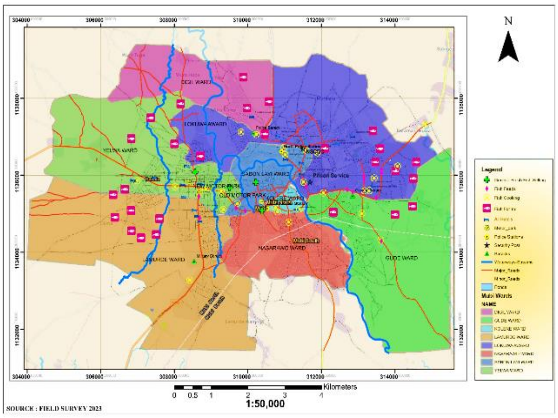
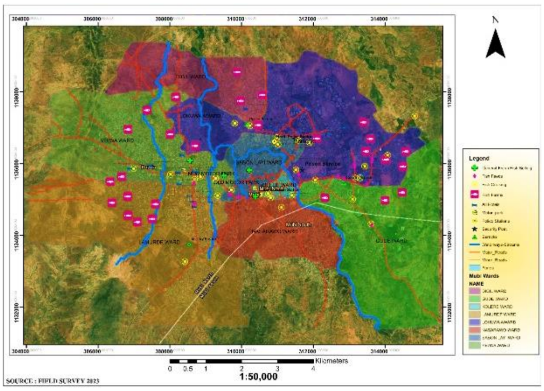


Figure 03b: General Spatial distributions



Constraints in the Mubi Study Area

In assessing suitable areas for fish pond farming in the Mubi study area, "constraint areas" were identified, including protected areas, water bodies, and major urban centres. Data on these constraints were sourced from OpenStreetMap (OSM). Water bodies were excluded due to their insignificance at the high-resolution image overlay level. Major urban centres, identified by population size, were pinpointed using OSM and high-resolution images. Within these metropolitan and ward zones, a feature layer for constraints was established by extracting fish farm density maps. Densely populated catfish farm areas were considered very suitable for aquaculture, as shown in Figure 4a, assuming higher economic costs and population density. Additionally, the catfish roasting/feeds location density was analyzed and identified in Figures 4b and 4c, respectively (https://www.fao.org/3/W5268E/W5268E01.htm).

Figure 4a1: Catfish Farm Density Distributions

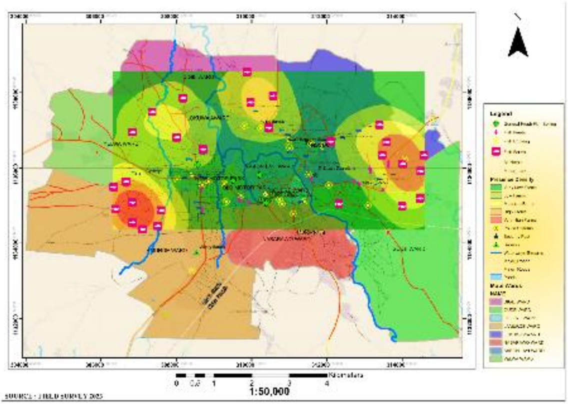


Figure 4a2: Catfish Farm Density Dis.

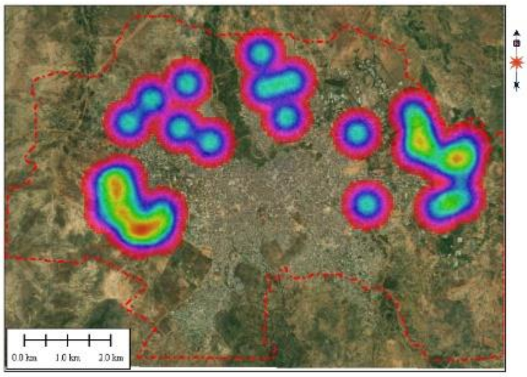
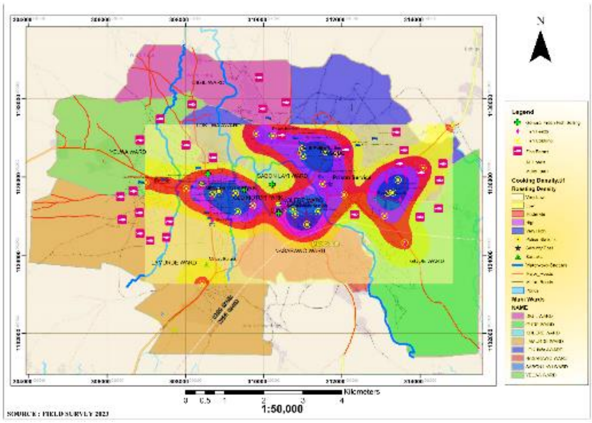


Figure 4b1: Catfish Roasting Location Densit Figure 4b2: Catfish Roasting Location Density Distributions within the metropolis



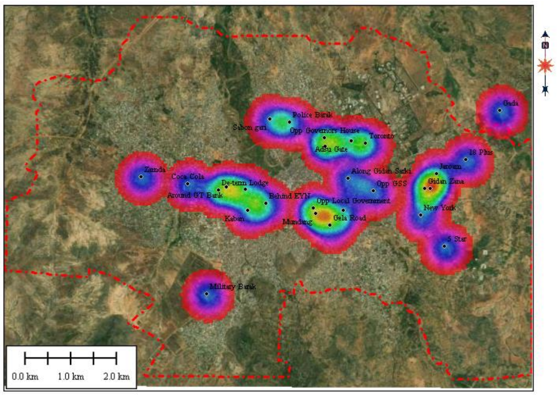
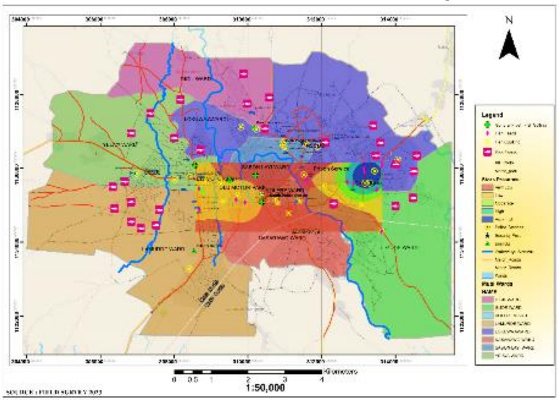
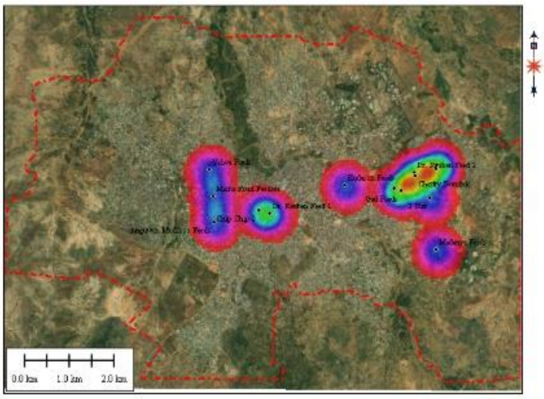


Figure 4c1: Catfish Feeds Selling Location Density Figure 4c1: Catfish Feeds Selling Location Density Distributions within the metropolis

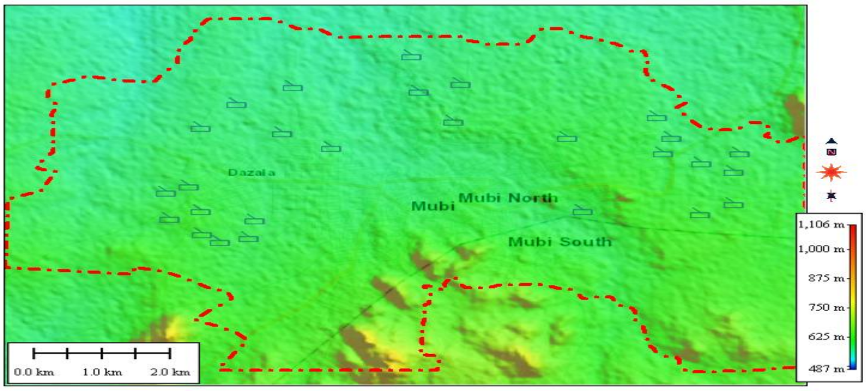




Digital Elevation Model (DEM)

The Digital Elevation Model (DEM) is a critical component of our research, providing a three-dimensional representation of the topography in the Mubi study area. It is a numerical representation of the Earth's surface, capturing variations in elevation and terrain. Utilizing remote sensing data and geographic information system (GIS) technology, as in figure 5.

Figure 05: Digital Elevation Mode of the Study Area



Water Availability Assessment

Assessing water availability for sustainable catfish farming in Mubi is a key component of our research methodology. Our approach integrates multiple strategies considering critical factors for efficient aquaculture practices. We identify and map surface water bodies, utilizing the Planetary-scale surface water detection from space (Figure 6c) to evaluate groundwater resources. Historical rainfall patterns (Figures 6a and 6b) from 2010 to 2023 add a temporal dimension to our assessment. Donchyts et al. (2018) discuss automated techniques for surface water detection from satellite imagery, introducing new algorithms for accurate monitoring of changes (Figure 6c).

Figure 6a: HISTORICAL RAINFALL PATTERNS from 2010-2023

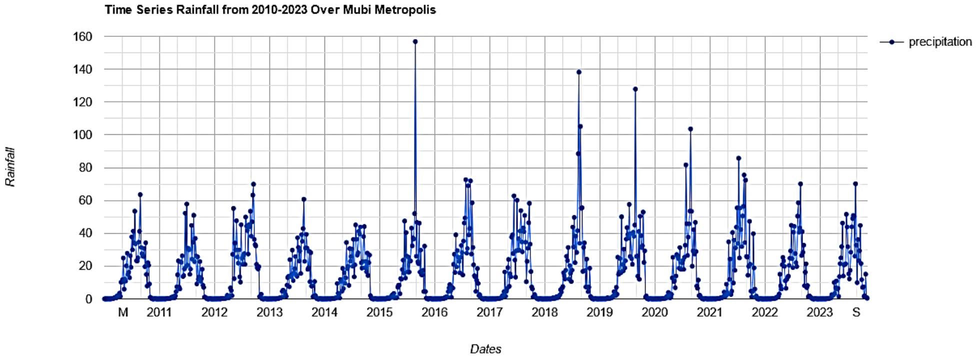
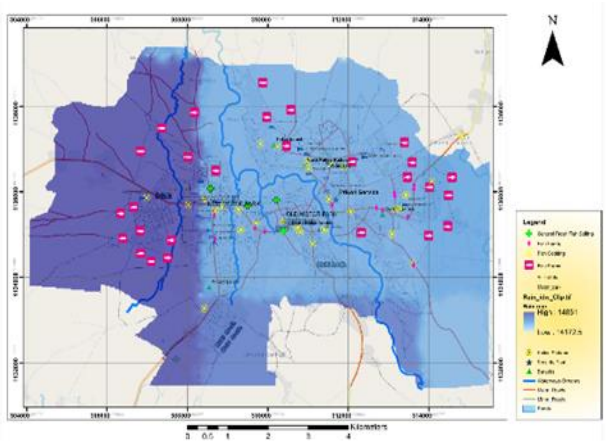
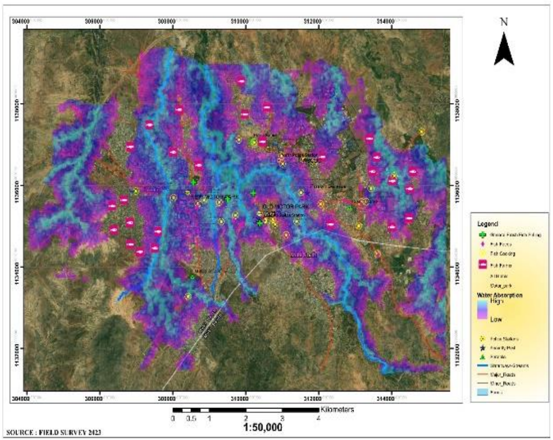


Figure 6c: Surface water detection from using Google earth engine

Figure 6b Rainfall Patterns

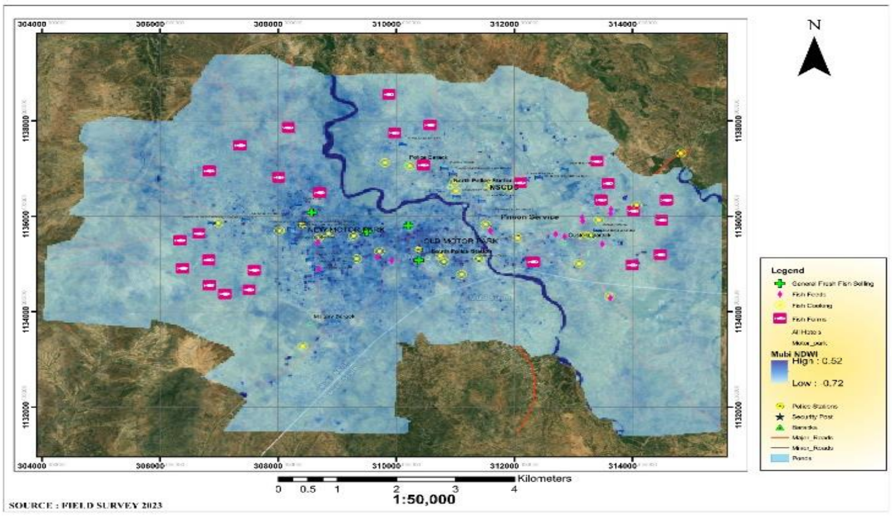




Normalize Difference Water Index

The Normalized Difference Water Index (NDWI) serves as a pivotal tool in the research's methodology, specifically designed to assess water content in the Mubi study area using satellite imagery. NDWI relies on the spectral reflectance differences between visible and near-infrared bands to effectively highlight the presence of water bodies in figure 7. This calculation allows for the creation of detailed maps and identification of surface water features.

Figure 07: Normalized Difference Water Index (Ndwi) of the Study Area



Slope Map

In our research methodology, the Slope Map is instrumental in evaluating the topographical characteristics of the Mubi study area. Derived from the Digital Elevation Model (DEM), it visually represents terrain steepness or incline. Analyzing slope variations provides insights into areas suitable for catfish farming. Flat or gently sloping areas are preferred for pond construction, ensuring efficient water management and farm sustainability. The analysis reveals higher slopes in the southeastern part due to Lamurde hill presence and along Gella Road. This information informs decisions on pond placement and infrastructure development, uiding strategic planning for sustainable catfish farming practices in the region, as depicted in Figure 08 .

Figure 08: Slope Map of the Study Area

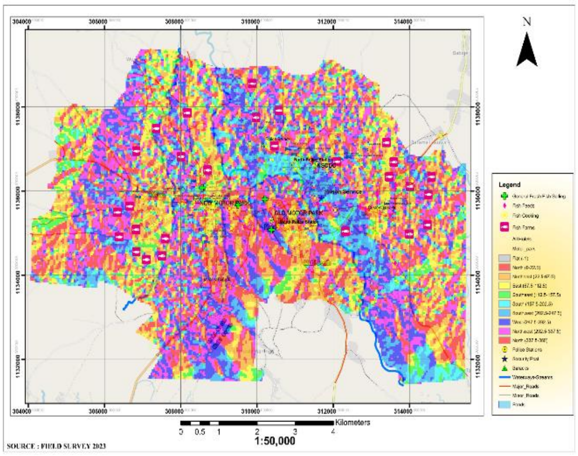
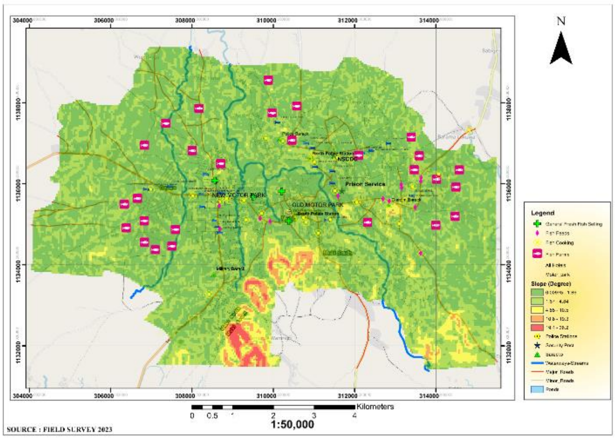


Figure 08: The Aspect Map of the Study Area



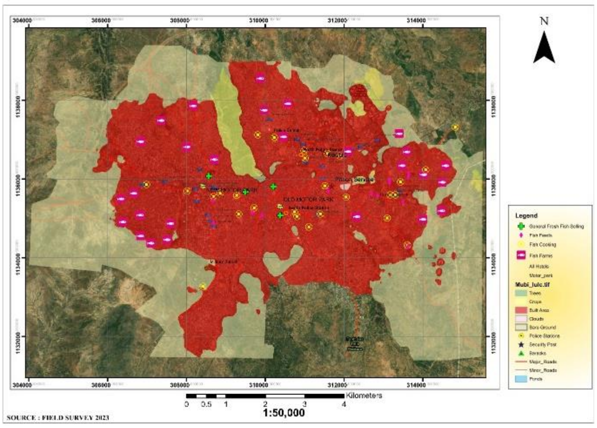
Aspect Map

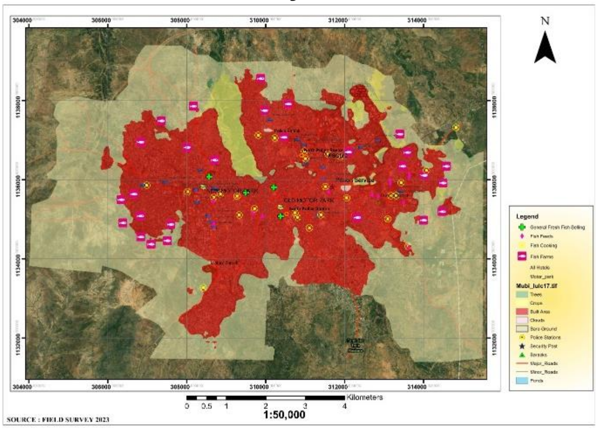
The Aspect Map is a significant component of our research methodology, derived from the Digital Elevation Model (DEM) data in the Mubi study area. This map provides valuable information about the orientation or direction of the terrain slopes. Aspect, representing the compass direction a slope faces, plays a crucial role in understanding sunlight exposure and potential microclimates across the landscape. In the context of catfish farming, it helps identify areas with optimal sunlight exposure for pond management and overall environmental conditions as shown in figure 9.

Land Use/Land Cover (LULC)

Land Use/Land Cover (LULC) analysis is integral to understanding sustainable catfish farming in Mubi and its surroundings. It identifies and categorizes different land uses and covers, offering a foundational grasp of the current landscape. Derived from satellite imagery, LULC data illuminates urbanization, agricultural practices, and natural features in the study area. In our research, LULC serves as a fundamental tool for assessing how human activities have shaped the land over time, reflecting changes influenced by cultural, political, historical, and economic factors. Additionally, it helps gauge the environmental impact of impervious growth and its implications for climate and economics. Understanding the evolving LULC patterns between 2017 and 2023 is crucial for planning and implementing sustainable catfish farming practices, as depicted in Figure 10a and 10b.

Figure 10a: Land Use/Land Cover (LULC) 2023 Figure 10b: Land Use/Land Cover (LULC) 2017 of the study are





Conclusion

In conclusion, this research underscores the importance of sustainable catfish farming and supply chain optimization in Mubi. Leveraging Geographic Information System (GIS) technology has provided insights into the spatial distribution of farms, environmental impacts, and opportunities for enhancing aquaculture sustainability. Our study demonstrates GIS's potential to inform decision-making for environmental, economic, and social sustainability in catfish farming. By analyzing spatial data and supply chain dynamics, we identified key factors influencing efficiency and resilience in Mubi's aquaculture practices. Integrating sustainable measures, data-driven approaches, and community engagement is crucial for promoting responsible aquaculture and ensuring food security. Assessing soil quality, water supply, and urbanization trends has laid a foundation for localized, sustainable catfish farming tailored to Mubi's needs. Strategic integration of sustainable farming practices, supply chain optimization, and spatial analyses is essential for the success and resilience of catfish farming in Mubi. This study provides a blueprint for revitalizing the local economy and contributes to sustainable aquaculture practices. Ongoing research, collaboration, and innovation will be key to advancing sustainable catfish farming and fostering a thriving industry in Mubi. Embracing technology, best practices, and stakeholder engagement can pave the way for a more sustainable and prosperous future for catfish farming in the region.

This study serves as a roadmap towards a more sustainable, efficient, and resilient catfish farming industry in Mubi, guided by environmental stewardship, economic viability, and social responsibility.

CRediT authorship contribution statement

Aminu Abdulwahab: Conceptualization, Methodology, Writing – original draft, Formal analysis, Data curation, Writing – review & editing. **Aminu Abdulwahab:** Conceptualization, Methodology, Writing – review & editing.

Declaration of Competing Interest

Aminu Abdulwahab reports financial support, administrative support, and travel were provided by the TETFUND institutional based Research (IBR)

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