EFFECTS OF LAND USE CHANGES ON CHANNEL MORPHOLOGY IN THE GINZO WATERSHED, NIGERIA

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EFFECTS OF LAND USE CHANGES ON CHANNEL MORPHOLOGY IN THE GINZO WATERSHED, NIGERIA

by

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LIST OF ABBREVIATIONS

ACLUMP	Australian Collaboration Land Use and Management Programme
CMT	Channel Migration Toolbox
ETM	Enhanced Thematic Mapper
ETM+	Enhanced Thematic Mapper Plus
FAO	Food and Agricultural Organisation
FGD	Focused Group Discussion
FLAASH	Fast Line of sight Atmospheric Analysis Hypercubes
GCP	Ground Control Point
GIS	Geographic Information System
GPS	Global Positioning System
MLC	Maximum Likelihood Classification
OLI	Operational Land Imager
TM	Thematic Mapper
UNICEF	United Nations International Children’s Emergency Fund
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
WGS	World Geodetic System

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KESAN PERUBAHAN GUNA TANAH TERHADAP MORFOLOGI SALURAN DI LEMBANGAN GINZO, NIGERIA

ABSTRAK

Kajian ini menganalisis perubahan guna tanah dan kesannya kepada morfologi saluran sungai di Lembangan Ginzo, Nigeria, dari tahun 1980 hingga 2020. Objektif kajian ialah untuk menyiasat perubahan guna tanah, menilai perubahan dalam morfologi saluran sungai, mengkaji kesan perubahan guna tanah kepada morfologi saluran sungai, dan membangunkan model ramalan tindak balas morfologi saluran sungai terhadap perubahan guna tanah. Imejan Landsat telah diperbetulkan kerana kekurangan geometri dan radiometrik, dikelaskan dan dianalisis menggunakan perisian ArcGIS untuk menilai perubahan dalam penggunaan tanah, kawasan saluran sungai, panjang, lebar, kawasan migrasi dan jarak migrasi. Kajian mendapati perubahan besar dalam penggunaan tanah dalam tempoh tersebut. Kawasan terbina, tanah kosong, dan badan air meningkat masing-masing sebanyak 21.9%, 27.7%, dan 1.1%, manakala tanah ladang dan hutan menurun sebanyak 11.1% dan 38.2%. Hasil selanjutnya menunjukkan perubahan dalam morfologi saluran sungai. Kawasan alur sungai, panjang dan lebarnya mempamerkan corak yang berubah-ubah, dengan garis tengahnya berhijrah ke arah timur di bahagian hulu dan tengah, manakala ke arah barat di bahagian hilir dengan jarak yang agak jauh. Kajian itu mengenal pasti kelas guna tanah utama yang menyumbang kepada perubahan ini. Hutan dan tanah kosong menyumbang 86% dan 14% daripada perubahan dalam kawasan saluran sungai. Tanah ladang, tanah kosong, kawasan binaan dan badan air menyumbang kepada perubahan panjang saluran masing-masing sebanyak 32.8%, 30.8%, 8.6% dan 27.8%. Perubahan lebar saluran sungai dipengaruhi oleh tanah ladang (70.9%) dan kawasan binaan

(29.1%). Kawasan dan jarak migrasi terutamanya dipengaruhi oleh hutan dan tanah ladang. Model ramalan menunjukkan bahawa kawasan saluran sungai meningkat dengan peningkatan 1% dalam kawasan binaan, tanah kosong, badan air, serta tanah ladang, dan berkurangan dengan penurunan 1% dalam hutan. Panjang saluran sungai meningkat dengan peningkatan 1% tanah kosong dan tanah ladang, dan berkurangan dengan pengurangan 1% di kawasan binaan, badan air dan hutan. Lebar saluran sungai akan bertambah dengan peningkatan 1% dalam kawasan binaan, tanah kosong, dan badan air serta mengecil dengan pengurangan 1% dalam tanah ladang dan hutan. Kawasan penghijrahan berkembang dengan peningkatan 1% dalam kawasan binaan dan tanah ladang, mengecil dengan penurunan 1% dalam tanah kosong, badan air dan hutan. Jarak migrasi meningkat dengan peningkatan 1% di kawasan binaan dan tanah ladang dan berkurangan dengan penurunan 1% di tanah kosong, badan air dan hutan. Kajian itu mengesyorkan keperluan untuk kepolisan hutan dan pengawalseliaan pertanian dalam koridor saluran.

EFFECTS OF LAND USE CHANGES ON CHANNEL MORPHOLOGY IN THE GINZO WATERSHED, NIGERIA

ABSTRACT

Previous research on land use and river channel morphology in Northern Nigeria has largely emphasized urbanization while neglecting the influence of various land use types on channel adjustments. Moreover, limited understanding of the rate, magnitude, and drivers of land use-induced channel changes, stemming from complex biophysical and socio-economic interactions across different scales and variable river responses, creates uncertainty in potential channel adjustments. This underscores the need for accurate predictions to support effective policy and sustainable land management. This study analyzed the effects of land use changes on channel morphology in the Ginzo watershed from 1980 to 2020. The objectives were to investigate land use changes, assess changes in stream channel morphology, examine the impact of land use change on stream channel morphology, and develop a predictive model of the response of stream channel morphology to land use change. Landsat images were corrected for geometric and radiometric deficiencies, classified, and analyzed using ArcGIS software to evaluate changes in land use, river channel area, length, width, migration area, and migration distance. The study found significant changes in land use during this period. Built-up areas, bare land, and water bodies increased by 21.9%, 27.7%, and 1.1%, respectively, while farmland and forest decreased by 11.1% and 38.2%. The results further indicate changes in stream channel morphology. The river channel area, length, and width showed fluctuating patterns, with the centerline migrating eastward in the upstream and midstream sections, and westward in the downstream segment over a considerable distance. The study identified key land use classes contributing to these changes. Forest and bare land accounted for 86% and 14% of changes in river channel area, respectively. Farmland, bare land, built-up areas, and water bodies contributed to changes in channel length by 53%, 5.9%, 21.8%, and 19.5%, respectively. Changes in channel width were influenced by farmland (70.9%) and built-up areas (29.1%). Migration areas and distances were primarily influenced by forest and farmland. The predictive model indicates that river channel area increases with a 1% increase in built-up areas, bare land, water bodies, and farmland, and decreases with a 1% decrease in forest. Channel length increases with a 1% increase in bare land and farmland, and decreases with a 1% decrease in built-up areas, water bodies, and forests. Channel width will expand with a 1% increase in built-up areas, bare land, and water bodies, and contract with a 1% decrease in farmland and forest. The migration area enlarges with a 1% increase in built-up and farmland areas, and contracts with a 1% decrease in bare land, water bodies, and forests. Migration distance increases with a 1% increase in built-up area and farmland, and decreases with a 1% decrease in bare land, water bodies, and forests. The study recommends reforming land tenure by abolishing customary systems and simplifying governance laws to enhance land ownership clarity and efficiency.

CHAPTER 1

INTRODUCTION

1.1 Introduction to the Chapter

The chapter provides a preliminary overview of this study, including the background, a statement of the research problem, research questions, objectives, significance, scope of the study, and the structure of the thesis.

1.2 Background to the Study

Rivers and their surrounding ecosystem are central to the development of human activities within the landscape (Grabowski et al., 2022). However, changes in stream channel morphology threaten the economic, social, and biotic services of rivers through sedimentation, deterioration of water quality, habitat degradation, and infrastructural damage (Ekka et al., 2020; Kuriqi et al., 2021). River channel morphology is the outcome of the interaction between the channel bed and banks, water discharge, sediment flux, and vegetation (Bernard et al., 2018). Flow and sediment discharge are the major drivers of channel morphology, although their effects are fashioned by external controls, specifically climate, geology, tectonic adjustment, and land use change (Fryirs & Brierly, 2013).

The responses of river channels to the changes in watershed land use are well documented in different parts of the world (Apollonio et al., 2016; Cooper et al., 2013; Jin et al., 2019; Sajikumar & Remya, 2015; G. Zhao et al., 2016). Some authors characterized these responses as the river moving from low-angle stable vegetated banks to highly unstable and incised channels resulting from anthropogenic disturbances of urbanization, farming, construction, channelization, mining, and deforestation (Brierley et al., 2005; Knox, 2006). Urbanization creates impervious surfaces, which reduce infiltration and significantly increase runoff and sediment discharge, consequently increasing channel size. The term ‘urban syndrome’ has been consistently used to describe the effects of urbanization on stream ecosystems (Nabegu, 2014; Paul & Meyer, 2001). Moreover, empirical investigations have found that channel modifications are associated with farming activity. Blann et al. (2009) discovered that to boost agricultural production in the United States of America, 80% of some river catchments drain through sub-surface drain pipes and sub-surface ditches, and that natural channel portions were deepened and incised, with profound effects on channel morphology.

Furthermore, construction activities churn the soil, making it readily available for erosion and entrainment, with the consequential effects of increasing channel sediment load (Gregory, 2006). The effects of channelization on channel dynamics have garnered more attention in river channel research. Comparing 1874 to 2016 aerial photographs and remotely sensed collected data of Srivia River in Italy, Mandarino (2019) found many morphological adjustments ranging from increasing channel stability and narrow channel width to an increase in sediment deposition and bank widening, which are attributed to channelization and river bank protection. Additionally, several studies linked changes in channel morphology to instream sand mining. For example, Khaleghi and Surian (2019) observed that 19% to 73% of rivers in Iran undergo channel narrowing due to instream sand mining.

Moreover, a decrease in the forest canopy due to deforestation can have a notable influence on peak runoff flows, thereby augmenting the transport and redistribution of sediment within water channels. The recurrence of peak flow events contributes to significant modifications in the active channel (Eagle et al., 2021).

Investigations on the responses of river channels to the influence of land use change are critically needed for preventing the damaging consequences of floods, channel widening, infrastructure maintenance, and river ecosystem restoration. For instance, information on land use change and channel characteristics is required to prepare a critical flood risk map of a particular locality in the face of global climate change. Similarly, data on the land use history and consequent channel changes are needed for upstream erosion management to control sedimentation and stream water quality degradation. Furthermore, the provision of long-term remedies against river channel expansion, which frequently displaces riverine residents and promotes infrastructure failure, necessitates data on land use history and channel changes (Gregory, 2006; Maetens et al., 2015).

Studies on the effects of land use change on channel morphology in Nigeria have been well documented. However, the majority of these studies concentrated on the streams of the humid tropical areas of Southern Nigeria, notably Anya et al. (2017), Fashae and Olusola (2017), Jeje and Ikeazota (2002), Aziegbe (2006) and Ibitoye (2021). Few of these investigations have been extended to Northern Nigeria, a semi-arid region characterized by low-frequency high-magnitude rainfall, scanty vegetation cover, loose soils, and dominance of intermittent streams. These investigations, such as those carried out by Nabegu (2010), Iroye and Kabir (2016), and Butu et al. (2020), have addressed this research gap. However, their primary emphasis has been on examining the impact of urbanization on channel morphology, neglecting to explore the collective and individual contributions of diverse land use types in influencing channel adjustments. In addition, the results from the study cannot be extrapolated to reflect the responses of river channels to land use change in Northern Nigeria. The scarcity of available scholarly works in the region further restricts the possibility of drawing inferences from existing studies on the relationship between land use change and channel adjustment in Northern Nigeria.

The limited body of empirical research on the impacts of land use change on ephemeral and intermittent streams poses a challenge in effectively managing stormwater impacts in the Northern part of Nigeria. Instances such as floods have resulted in significant consequences, including loss of lives and properties, farmland destruction, infrastructure collapse, and water quality issues. UNICEF Nigeria (2022) reported that the November floods claimed 612 lives and displaced 423,300 people across Northern Nigeria. Preventing these problems requires knowledge of the relationship between land use change and resultant channel adjustments. Hence the need for this research which will focus on the Ginzo watershed as the study area.

1.3 Statement of Research Problem

The Ginzo watershed, where the city of Katsina is situated, witnessed significant population growth following the designation of Katsina town as the administrative headquarters of Katsina state in 1987. The population of this city grew from 151,000 to 505,000 between 1987 and 2022, leading to rapid changes in the watershed's land use as a result of large-scale forest clearance for building construction, farming, and increasing demand for fuel energy (Ibrahim et al., 2022).

Before urban development in Katsina city, the surface of the watershed encouraged infiltration. However, impervious surfaces imposed by buildings and tarred surfaces became dominant in the early 1980s, marking the beginning of notable social and economic development in the state. Consequently, this development reduced infiltration and increased runoff discharge into the channel, with profound effects on channel widening. Additionally, a recent reconnaissance survey in 2022 showed that intensive crop production is taking place along the channel banks of the study river. This may induce erosion, sediment transfer, and siltation of the river channel (Kusimi, 2008).

Similarly, the increasing demand for fuelwood resulted in massive vegetation clearance along the river channel corridors, exposing the channel banks to the direct effects of shear flow, erosion, and bank widening. Moreover, sand mining at the downstream part of the river rapidly regrades the channel slope, resulting in serious effects on bank stability. Other modifications to the channel include bank protection, channel strengthening, and channelization at the upstream reaches, which reduced the channel width and increased its vulnerability to overbank flows.

Understanding the long-term changes in land use and channel morphology will provide policymakers with a framework to mitigate problems resulting from poor watershed management, which has rendered Ginzo River a corridor of flooding, channel widening, and infrastructural damage in the city. For example, IOM (2022) reported that floods in the Ginzo watershed displaced about 24,294 persons. Besides, Hamisu (2013) observed a significant reduction in the suspended sediment discharge into the river and cautioned on the effects of clear water on channel bed and bank degradation. Despite the aforesaid, research conducted on the study watershed concentrated on urbanization and channel morphology (Iroye and Kabir, 2016), analysis of irrigation water (Safana & Rilwanu, 2018), anthropogenic activities, and water quality (Badamasi, 2019; Oyewumi et al., 2019; Aliyu & Ibrahim, 2022; Osuji et al., 2023), heavy metals and crop cultivation (Alhassan & Dajal, 2023; Jafar et.al; 2023), identification of microbial species (Badamasi et.al; 2019), wastewater bio-remediation (Badamasi et al., 2018) and Algae species and Biodiesel production (Umar et al., 2021).

Moreover, the rate, magnitude, and controlling factors of land use-driven channel modifications remain poorly understood. This knowledge gap arises from the complex interactions between biophysical and socio-economic factors across various spatial and temporal scales and the diverse responses of river channels to these influences. The variability in these responses introduces uncertainty regarding the potential river channel adjustment in reaction to land use changes within the watershed. Therefore, predicting future channel responses to land use changes is crucial for informed policymaking and sustainable land management.

It is clear from the preceding that information on the channel responses to land-use change is grossly inadequate. It further highlights the scarcity of data regarding the potential responses of river channels to future land-use changes within the watershed. Such information is necessary for river channel rehabilitation measures against flooding, erosion, channel widening, and infrastructure collapse. This prompted this research to investigate the effects of land-use change on the channel morphology of the watershed to understand channel response to land-use change.

The study employed remotely sensed data in conjunction with Geographic Information System (GIS)-based spatial analysis tools to examine changes in both land use and channel morphology, a methodology commonly used by numerous scholars in the field (Bhuiyan & Kumamoto, 2014; Kong et al., 2019; Ibitoye, 2021; Kang & Kanniah, 2022; Ibitoye et al., 2023). Remote sensing proves to be a valuable instrument in monitoring changes in land use owing to its superior temporal resolution and cost-effectiveness relative to conventional methodologies (Hegazy & Kaloop, 2015). Moreover, the utilization of remote sensing provides several advantages, including widespread ground coverage, access to multiple spectral information, and the incorporation of digital image formats (Abou Samra & El-Barbary, 2018).

1.4 Research Questions (RQ)

The study is expected to provide answers to the following questions.

RQ1. Is there any change in land use within the Ginzo watershed from 1980 to 2020?

RQ2. What changes have occurred in Ginzo stream channel morphology from 1980 to 2020?

RQ3. What are the impacts of the land use change on Ginzo stream channel morphology from 1980 to 2020?

RQ4. How would Ginzo stream channel morphology respond to land use change within the Ginzo watershed in the future?

1.5 Research Objectives (RO)

The general objective of this study is to investigate land use change and its impact on channel morphology of Ginzo watershed, Nigeria. The specific objectives are to:

RO1. Investigate the change in land use within the Ginzo watershed from 1980 to 2020.

RO1. Assess changes in the Ginzo stream channel morphology from 1980 to 2020.

RO3. Examine the impacts of the land use change on the Ginzo stream channel morphology from 1980 to 2020.

RO4. Develop a predictive model of the response of the Ginzo stream channel morphology to land use change.

1.6 Significance of the Study

A review of the existing literature revealed that there is no current research on the effects of land use changes on the channel morphology in the Ginzo watershed, despite the necessity of this information for effective watershed management. Therefore, the contribution of this study can be utilized for policy-making, as well as theoretical and practical applications that serve national interests in reducing risks and enhancing community adaptation to river hazards. Consequently, the study provides the following contributions;

The contribution of the study's findings to policy-making is evident in the documented land use changes within the watershed over the study period, which show an expansion of built-up areas, bare land, and water bodies, at the expense of farmland and forest area. These trends should be taken into account by policymakers in Katsina State when reviewing land use policies, to reduce the vulnerability of the Ginzo watershed to disturbances.

The practical contribution of this study is reflected in its findings on river channel morphology changes over the study period, which are intended to serve as baseline data for rehabilitation efforts focused on the Ginzo stream channel. These findings are particularly relevant for the potential integration of the channel into the World Bank-supported Nigeria Erosion and Watershed Management Project (NEWMAP), aimed at enhancing the physical development of the watershed. Additionally, these results should be considered in flood risk mapping activities within the Katsina Metropolis, coordinated by the United Nations Children's Emergency Fund (UNICEF), especially for flood control strategies. Moreover, the findings hold relevance for the development of an early warning system aimed at effectively reducing the negative impacts of flooding.

Furthermore, the results of the predictive model on river channel morphological changes in response to land use changes within the Ginzo watershed highlight the influence of different land use types on variations in channel morphology parameters throughout the study period. These findings are intended to provide a framework for promoting sustainable land use practices within the watershed, to facilitate appropriate morphological adjustments of the river channel, and specifically address the mitigation of hazards such as erosion, channel widening, migration, flooding, and damage to infrastructure.

The theoretical contribution of this study lies in its identification of deviations from the established channel evolution model proposed by Schumm et al. (1984), thereby offering a valuable addition to the existing body of academic literature on this widely recognized framework. In Section II of the Ginzo stream channel, an incision beyond the critical bank height occurred, leading to the induction of mass wasting phenomena. Subsequently, this section advanced to stage III, undergoing a widening process, contrary to the description of section II in the model, which is characterized as slightly incised but stable. This finding implies that policymakers should consider employing a unique framework tailored to the specific characteristics of the Ginzo watershed for channel rehabilitation rather than adopting rehabilitation strategies proposed in the existing model.

1.7 Scope of the Study

The study is on the stream channel in the Ginzo watershed in Nigeria. The scope of this study is confined to the longitudinal stretch of the river. Concerning the river channel morphology, the research is limited to investigating the changes of channel morphology in the Ginzo watershed. It is restricted to parameters of channel area and length, channel width, channel centre line migration area, and distance representing both bank full and planform morphology parameters.

The land use of the study watershed was studied for 40 years, from 1980 to 2020. The land use classes are restricted to the United States Geological Survey Anderson et al. (2007) land use classification system, which was adjusted and reduced to built-up areas, water bodies, forests, farmlands, and bare land, reflecting the dominant land use in the study river. Therefore, land use changes before the state's significant socio-economic development, specifically before the 1980s, are beyond the scope of this study. The study further emphasizes that the watershed land cover was not considered as a variable, given that the river landscape is intrinsically a component of land cover, and its changes may be driven by changes in land use patterns. Furthermore, land cover was also excluded from the land use analysis because it is not entirely a product of human purpose or intent and, as such, may not adequately reflect the influence of human activities on river channel adjustments. Therefore, the land cover within the watershed does not influence the overall findings on watershed land use change.

1.8 Structure of the thesis

The thesis consists of six chapters, a bibliography, and an appendix. Chapter One provides a preliminary overview of this study, including the background of the study, statement of the research problem, research questions, objectives, significance, scope of the study, and the structure of the thesis.

Chapter Two presents a comprehensive literature review addressing key thematic areas relevant to the study. These include land use and land cover, river channel, river channel morphological change, land use and river channel morphology studies in Nigeria, river channel geomorphic response, and impacts of land use changes on river channel morphology. Other sub-themes discussed encompass river channel morphology changes prediction, and commonly used data and techniques for analyzing land use and river channel morphological changes. Consequently, the chapter identifies certain gaps in the existing literature, emphasizing the need for this research.

The chapter also discusses the theoretical framework, elucidating foundational theories that inform this research, including geomorphic threshold theory, equilibrium theory, and the channel evolution model. Building upon these theoretical foundations, the study's conceptual framework integrates key land use classes, specifically urbanization, bare land, forest cover, agricultural land, and water bodies, along with critical river channel morphology parameters (area, length, width, migration area, and migration distance). Schematic representations of this theoretical framework and conceptual relationships are provided to facilitate understanding.

Chapter Three describes the study area, including its location and size, climate, geology, relief and drainage, soils, and vegetation. It also outlines the land use and environmental policies aimed at promoting sustainable land and water resource management. Additionally, maps, figures, and plates are included to enhance understanding of the study area. The chapter further elucidates the research methodology, detailing the research framework, sampling procedures, research design, and methods of data collection and analysis. Diagrams and maps are included to refine the sampling procedures, research framework, and methodological workflow.

Chapter Four offers the findings on land use changes within the Ginzo watershed from 1980 to 2020. The land use was classified based on the major land use, considering the mixed land use system in the watershed, and the accuracy of the land use classification was also presented. The trends in land use changes are illustrated through tables, maps, and bar graphs. The chapter also presented findings on the changes in river channel morphology, the impact of land use changes on river channel morphology, and the impact of land use changes on river channel morphology models. The spatial and temporal pattern of the changes in river channel morphology parameters such as channel area, length, channel width, migration area, and distance were presented in tables, maps, bar and line graphs.

Chapter Five discusses the reasons for changes in the various land use categories within the watershed, including urbanization, bareland, farmland, forest, and water bodies, between 1980 and 2020. The chapter also explains the changes in river channel morphology parameters such as channel area, length, width, migration area, and distance. The impacts of land use changes on river channel morphology parameters are detailed. Additionally, the effects of land use changes on river channel morphology models are interpreted to support evidence-based decision-making in land and water resource management.

Chapter Six highlights the main findings of this study and its contribution. It also addresses the study's limitations and suggested some recommendations to assist reduce vulnerability to Ginzo watershed disturbances.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter presents a comprehensive literature review addressing key thematic areas relevant to the study. These include land use and land cover, river channel, river channel morphological change, land use and river channel morphology studies in Nigeria, river channel geomorphic response, and impacts of land use changes on river channel morphology. Other sub-themes discussed encompass river channel morphology changes prediction, and commonly used data and techniques for analyzing land use and river channel morphological changes. Consequently, the study identifies certain gaps in the existing literature, emphasizing the need for this research.

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2.2 Land Use and Land Cover

Historically, the differentiation between land use and land cover was contentious, generating ongoing discussion and disagreements among different fields of study (Mustaphi et al., 2019; Loconto et al., 2020). Ecologists defined land use as modifications to terrestrial ecosystems resulting from human activities and disturbances (Root-Bernstein & Ladle, 2019). Anthropologists have conceptualized land use as the dynamic process of emergence and coevolution between domesticated species and agricultural societies, framed within theoretical frameworks such as niche construction, cultural evolution, and the stretched evolutionary synthesis (Zeder, 2018). Land system scientists defined land use as the purposes and activities through which humans engage with the land and terrestrial ecosystems (Meyfroidt et al., 2018).

However, in general terms, Ren et al. (2019) defined land use as modification of the biophysical characteristics of land, and the specific objectives or purposes driving such changes. Văculișteanu et al. (2022) further, clarify that land use pertains to how humans interact with and manage a particular land-cover type. It represents the organization of outputs from gross primary production, which is shaped by the combined influence of various socio-economic factors. According to the Food and Agricultural Organisation (FAO, 2020), land use refers to human activities undertaken for economic production, environmental management, and the restoration of ecological functions. However, Land Use Consultants and GHK consulting (UK Environmental Agency, 2009) defined land use as the designated purpose for which a particular land area is employed rather than the specific management practices carried out on that land. While previous definitions defined land use from a resource perspective as a "resource use" to satisfy human needs, Briassoulis (2019) describe land use from the urban and regional perspective by emphasizing the use of land surface for the location of human activities. Therefore, improper utilization of land surfaces can significantly impact rivers, leading to changes in runoff patterns, river flow dynamics, and channel morphology.

Land cover refers to the biophysical attributes of the land surface. In other words, it represents the physical state of the earth's surface (Hasmadi et al., 2009). It encompasses various types such as cropland, wasteland, water bodies, build-up areas, range land, and bare soil (Ge et al., 2020). Similarly, land cover refers to the physical and biotic attributes of the land surface, including vegetation, asphalt, and soil (Vali et al., 2020). The term "land cover" was originally used to describe the vegetation covering the earth's surface. However, its definition has since expanded to encompass physical features, including soil, surface and groundwater, biodiversity, and human-made structures such as buildings and infrastructure (Venter et al., 2022).

Based on the preceding discussion, it can be inferred that the term "land cover" refers to the biological, physical, or chemical classification of the Earth's surface, encompassing attributes such as vegetation, paved surfaces, groundwater, bare soils, wetlands, and croplands. This classification does not account for the human purposes associated with land use, such as agriculture, construction, and industrialization, which can induce changes in land cover. This distinction underscores the concept that land use drives changes in land cover. Furthermore, it highlights the susceptibility of land cover attributes, such as river ecosystems, to human-induced changes, emphasizing the need to examine the impacts of land use on river landscapes.

2.3 Land Use Changes

The increasing need for improving decision-making processes in environmental management necessitated monitoring land use and land cover changes. As a result, land use changes have been a subject of research for several decades. On a global scale, Winkler et al. (2019) estimated the dynamics of land use changes from 1960 to 2019. They claimed that land use changes affected 32% of the globe and identified agricultural production as one of the major drivers in the accelerating and decelerating phases of land use change. Potapov et al. (2022) conducted a comprehensive analysis of global land cover and land use changes, highlighting the expansion of cropland and settlements at the expense of tree cover, along with region-specific shifts in land management practices. The study also identified regional variations in surface water changes, primarily driven by hydropower projects and the depletion of lakes. Additionally, it documented a significant decline in snow and ice cover, largely attributed to climate change. In a global analysis of the response of amphibians and reptiles to land-use changes, Cordier et al. (2021) found that land-use changes negatively impact amphibians and reptiles to varying degrees, with disturbed conditions limiting species richness recovery over time, particularly affecting the richest communities, with responses differing by biome. Cao et al. (2023) evaluated the impact of future land use changes on terrestrial ecosystem carbon fool evolution under SDG scenarios. The study revealed that by 2030, land use change and carbon stocks will vary across four SDG scenarios, with the ENV scenario mitigating forest loss, the GRA scenario slowing the reduction in cultivated land, and the ECO scenario inducing the highest carbon losses due to urban expansion.

On a regional scale, Alqurashi and Kumar (2019) quantified the effect of land use changes and urbanization in some Saudi Arabian cities between 1985 and 2004. They discovered that urban areas had the most changed land cover. Cahya et al. (2018) examined the impacts of urbanization on land use changes in the Ciawi urban area of Jakarta. They found that urbanization reduced farmland and wetlands by 4% and 2.51%, respectively, due to the increasing demand for land for hotels and resort development by 3%. Recently, Santra et al. (2018) studied the effects of urbanization on land use changes in Agartala city, India, from 1901 to 2013 and found that the city experienced a low growth rate of 7.94 km^2 from 1901 to 1981, which slightly increased by 5.08 km^2 between 1981 and 2001 before rapidly increasing to 60.484 km^2 from 2001 to 2013. Furthermore, Liu et al. (2021) investigated the impacts of urbanization on urban green space in Shangai City, China. They observed a reduction in green space from 84.4% to 61.9% between 1990 and 2005, while the built-up area expanded from 15.0% to 36.5%, and attributed the changes to urban sprawl.

One study on conjectural drivers of land use changes in a Brazilian pampa biome conducted by Esteves et al. (2017) discovered a 26% reduction in natural pastures connected with the high growth rate of cultivated forest and temporary crops. In analyzing the relationship between agricultural productivity, land use, and land cover changes in India, Hinz et al. (2020) predicted that agricultural lands will expand by 2030, resulting in biodiversity loss. FAO (2012) assessed the effects of livestock farming on global land use change and conclusively showed that around 13 billion hectares of land are committed to animal feed production annually, with negative consequences for biodiversity. In an attempt to detect changes in land use in the northwestern highlands of Ethiopia, Worku et al. (2020) observed that plantation cover expanded by 16% at the expense of cultivated land, wetlands, natural forests, and bare lands.

Yurui Li et al. (2010) studied the impact of industrial development on land use in Changshu, China. They discovered that industrial development in the region is marked by replacing agricultural land with forested and built lands, urban and rural settlements, and artificial ponds. Similarly, a detailed examination of rural land use change induced by industrialization in the Fengzhuan village in China, Yin et al. (2020) revealed informality in land use where rural areas that are legally designated as residential zones are, in effect, utilized for industrial activities. Additionally, a diachronic analysis of the driving forces of land use and land cover change in the peri-urban Ploeiesti city of Romania undertaken by Gavrilidis et al. (2015) revealed that the city undergoes a series of evolution in land use changes as a result of its oil-based industrial activities. Another major study discovered a link between biofuel energy and land use change, observing that at least 1% of global land is now utilized for growing biofuel crops (Popp et al., 2016).

While different studies (Gavrilidis et al., 2015; Esteves et al., 2017; Hinz et al., 2020) focused on the factors causing land use change, others are more concerned with the impacts of land use changes on the environment. To determine whether land use changes affect soil physicochemical properties in North Western Cameroon, Tellen and Yerima (2018) found that organic carbon, organic matter, total nitrogen, exchangeable basis, PH, and Cation Exchange Capacity (CEC) were reduced as a result of the conversion of savanna forests to farmlands. In a study aimed at evaluating the effect of land use and cover change on the surface temperature in Lokoja town, Nigeria, Oluseyi et al. (2009) reported an association between land use types and temperature variations. A recent study conducted by Victor et al. (2021) assessed the impact of land use change on riparian vegetation in Osun state, Nigeria, and found that areas covered by riparian forest decreased from 6.40% to 2.01% between 1986 and 2016 and pointed to human activities of farming, construction, grazing, and logging as the prime suspects in driving the land use change. In a similar study, Ladan (2014) associated the disappearance of vegetation in the Katsina Metropolis with the high rate of urbanization. Recently, Ibrahim et al. (2022) examined urbanization's impacts on topography in the Katsina Metropolis and found a rapid increase in the built-up area and a reduction in bare land surfaces.

Based on the preceding pieces of evidence, it seems that scholarly works on land use change are generally geared towards identifying changes in the rate of urbanization, agricultural and industrial activities, and the effects of these activities on the environment. However, these exposed the nature of a few existing research on the effects of land use changes on the environment in the Ginzo watershed. Therefore, research of this type will fill the gap in the existing literature.

2.4 River Channel

A river channel is a morphological element within a river system functioning as a conduit for transporting water flow and sediment discharge. It is characterized by riverbeds, banks, overall shape, and geometric characteristics (Richards, 2024). River channels play a role in facilitating the movement of water and sediment across the landscape, functioning as lateral corridors that connect terrestrial and marine ecosystems and serving as essential habitats for aquatic species, thus, supporting biodiversity and ecological processes (Hudson, 2021). However, human activities have altered the ecological functions of river channels. For example, Dethier et al. (2022), observed that dams have considerably reduced sediment flow in the northern regions of the globe, while land use changes have led to an increase in sediment flow in the Global South. Modifications of sediment flux can significantly impact the morphology and behaviour of river channels (Vázquez-Tarrío et al., 2024a).

River channel morphology, behaviour, and pattern vary in response to changes in water and sediment discharge (Nádudvari et al., 2023). This necessitates the classification of river channels to enhance the understanding of their response to fluvial dynamics and to support sustainable management practices. Thus, river channels are classified based on their source, geomorphological characteristics, age, and stream order (Kamboj et al. 2020). According to the source, rivers can be classified into three main types: mountain rivers, subsurface streams, and seasonal or ephemeral streams. Mountain rivers originate from mountainous regions, commonly called glacier-fed or ephemeral rivers. Subsurface rivers, on the other hand, flow beneath the surface, typically under ice sheets, glaciers, and within caves, and are prevalent in limestone geological formations. Seasonal or ephemeral rivers are primarily influenced by regional rainfall patterns, flowing only for a few months of a year while remaining dry for the rest of the year. These rivers are characteristic of semi-arid climatic regions. From a geomorphological perspective, rivers are categorized into alluvial and bedrock channels. Alluvial channels develop through the erosion of unconsolidated sediments in subaerial environments. These channels typically exhibit parabolic or trapezoidal cross-sections and are accompanied by horizontal floodplains, susceptible to inundation during overbank flows. The classification of alluvial rivers is based on the sinuosity index and geomorphological characteristics (Charlton, 2007). The sinuosity index quantifies the meandering nature of a river channel and is calculated by dividing the average channel length by the direct channel length from the source to the basin mouth, as illustrated in Figure 2.1. This index can be determined using the formula proposed by Leopold et al. (2020).

$$SI = \frac{\text{stream channel length}}{\text{Direct length of the river}} \tag{2.1}$$

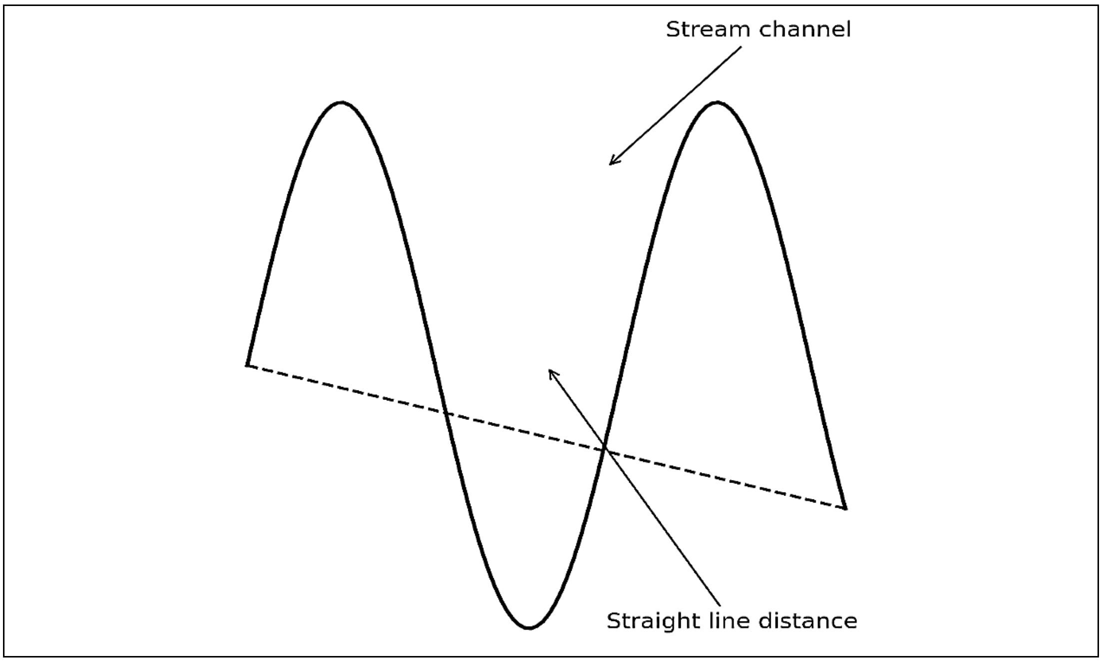

Figure 2.1 Procedure for estimating the sinuosity index

Based on the sinuosity index, alluvial rivers can be classified into three categories: straight, sinuous, and meandering channels. A channel is considered straight when the sinuosity index is less than 1.05. It is classified as a sinuous channel if the sinuosity index falls between 1.05 and 1.50. However, when the sinuosity index exceeds 1.50, the channel is categorized as meandering, as shown in Table 2.1.

Table 2.1 Types of alluvial rivers based on sinuosity index

Type of river	**Sinuosity index**	**Pattern**
Straight channel	< 1.05	
Sinuous channel	1.05 to 1.50	
Meandering channel	> 1.50	

Alluvial rivers are also classified into braided and anabranching channels based on their geomorphological characteristics. Braided channels are typically shallow and wide, exhibiting a network of separations and confluences around vegetation, islands, and sediment bars as shown in Figure 2.2. The morphological appearance of these rivers varies in response to flow conditions. During high flows, bars become inundated, resulting in a single, widened channel, whereas low flows cause the channel to divide around extensive bars. In contrast, anabranching channels consist of multiple separate channels that are interrupted by floodplains, leading to the formation of large, stable, and often vegetated islands. These channels are distinguished by minimal lateral migration.

Bedrock channels are formed when a stream flows through unconsolidated sediments that are underlain by solid bedrock. The morphology of these channels is primarily influenced by the characteristics of the underlying rock, such as bedding planes, joints, and stratification. These geological features play a significant role in shaping the channel's form, developing straight and meandering channel patterns.

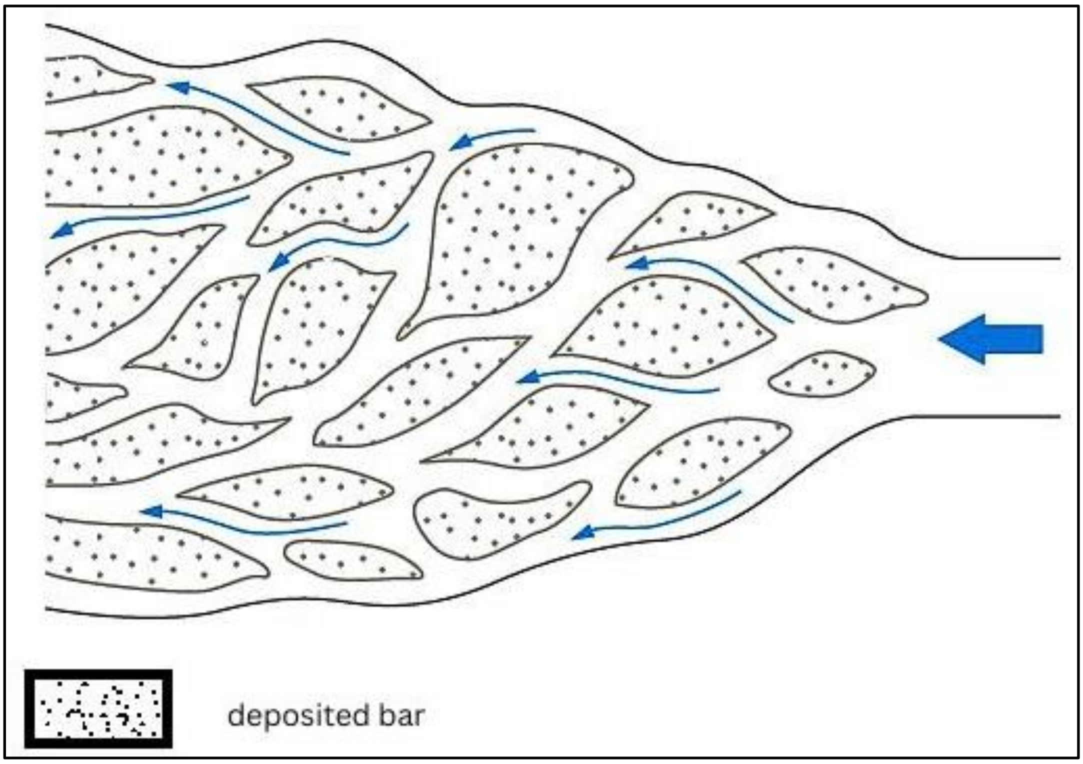

Figure 2.2 The Diagram of the Braided Channel

Also, William Morris Davis (1899, as cited in Birot, 2022) categorized rivers based on their developmental stages into youthful, mature, and old. In the youthful stage, rivers exhibit significant depth, steep gradients, limited tributaries, and rapid flow, with erosion being the dominant geomorphic process. As the river progresses to the mature stage, it develops a more moderate gradient, with transportation becoming the primary process. In the old stage, the river is characterized by reduced energy and velocity, leading to extensive floodplain deposition due to its low gradient.

Additionally, Strahler (1957) developed a classification system for river channels based on stream order. In this system, the smallest tributaries, known as fingertip streams, are classified as first-order streams. When two first-order streams converge, they form a second-order stream. Similarly, the confluence of two second-order streams forms a third-order stream. However, if a stream of a lower order merges with a stream of a higher order, the order of the higher-order stream remains unchanged as indicated in Figure 2.3.

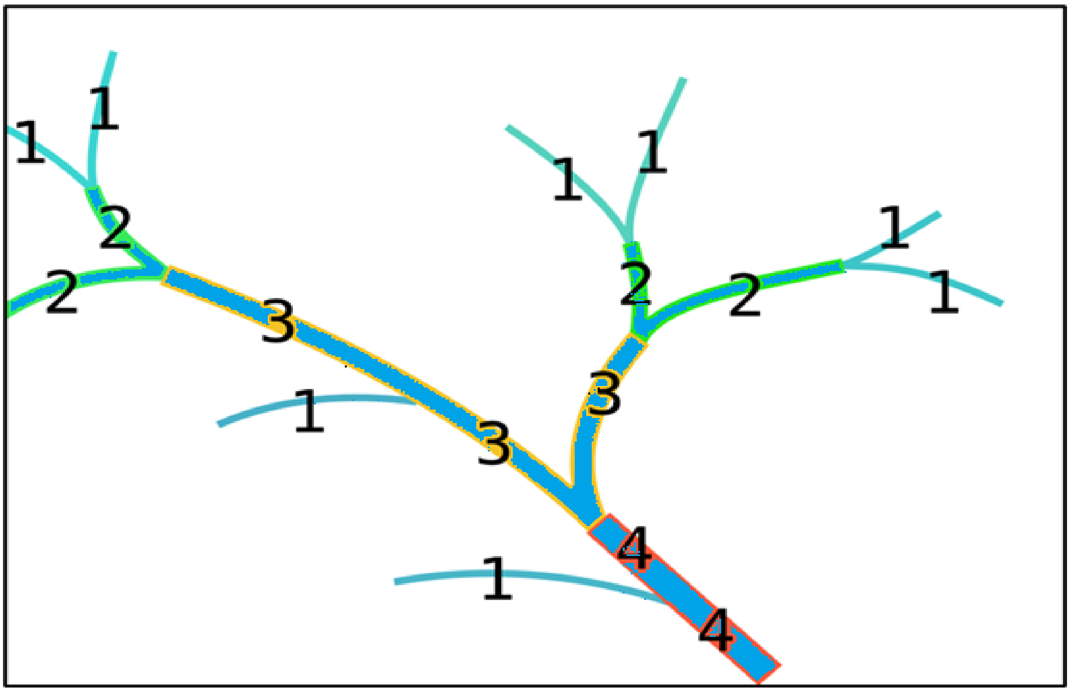

Figure 2.3 Strahler's Stream Ordering System

The previous discussion explored the characteristics, functions, and classification of river channels, essential for understanding their diverse responses to changes imposed by the intricate interaction among physical and socio-economic factors within the riverscape environment.

2.5 River Channel Morphological Change

The river channel morphological change is intricately connected to the concept of channel sensitivity. The sensitivity refers to the system's capacity to respond to disturbances compared to the degree of the disturbance force (Fryirs, 2017). The reasons necessitating the assessment of sensitivity to disturbance are outlined by Downs and Gregory (2014), including the potential changes in river channel, which depends on the equilibrium between the driving and resisting forces acting within the fluvial systems. If the driving force exceed the resisting force, the likelihood of change increases, prompting adjustments in the river planform as a response to the characteristics associated with the disturbances. For example, the width of a river channel might expand in response to an increase in water and sediment discharge occurring during high-flow events.

The second reason for sensitivity assessment relates to the likelihood of significant river change. This is associated with the proximity of the fluvial system to a critical threshold that dictates the nature of ensuing morphological changes. An evident instance is the impact of previous disturbance events, which may have accelerated morphological responses, rendering the river more sensitive to future morphological changes. The third rationale concerns the potential for river recovery. This examines whether the changes witnessed within the system are reversible and, if