APPLICATION OF GIS IN HYDROLOGICAL STUDIES FOR INFRASTRUCTURAL DEVELOPMENT ALONG TEMBOGA ROAD, BENIN CITY.

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CERTIFICATION

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DEDICATION

This work is dedicated to Almighty God, for His divine guidance and wisdom. To my amazing parents Engr.Surv. Ogiamien Cewuo Charles and Mrs. Joy Ogiamien for their unwavering love, support, and sacrifices.

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I extend my heartfelt gratitude to Almighty God for His divine guidance and wisdom. To my family, who has been a constant source of support and encouragement. My parents, in particular, Engr.Surv. Ogiamien Cewuo Charles and Mrs. Joy Ogiamien, have been instrumental in shaping my values, work ethic, and character. Their unwavering belief in me has been a driving force behind my success.

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ABSTRACT

Flooding, erosion, and inadequate drainage systems have continued to pose significant hydrological challenges affecting the durability and performance of road infrastructure in Benin City. One of the most impacted corridors is Temboga Road, situated within the Ikpoba-Okha Local Government Area. This study employs Geographic Information Systems (GIS) and Remote Sensing methods to evaluate the hydrological characteristics of the Temboga area and develop sustainable solutions for resilient hydraulic infrastructure design and planning. Digital Elevation Models (DEMs) sourced from the Shuttle Radar Topography Mission (SRTM/ USGS), combined with high-resolution UAV (Phantom 4) imagery and differential GNSS observations, were processed within ArcGIS Pro and Global Mapper environments to delineate watersheds, trace flow accumulation pathways, and identify flood-prone zones. The Rational Method was applied to estimate peak runoff, while GIS-based spatial were used to evaluate drainage and erosion-vulnerable locations.

Findings indicate that Temboga Road lies across multiple sub-catchments (eight in total) within the Ikpoba River basin characterized by low-lying topography, high rainfall intensity exceeding 2,400mm annually, and sandy-loam soils that are highly susceptible to erosion.

The integration of GIS and hydrological analysis proved instrumental for evidence-based decision-making, enabling engineers and planners to visualize water flow dynamics, mitigate flood risks, and design drainage systems that strengthen the resilience and sustainability of road infrastructures. Ultimately, this research demonstrates the value of spatial intelligence in transforming traditional hydrological assessments into proactive tools for sustainable infrastructural development along Temboga Road, Benin City.

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CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Infrastructure Development involves the planning, design, construction, improvement, and maintenance of essential physical systems that support societal and economic activities. In fast-growing urban environments, such as Benin City, the development of road networks, bridges, and drainage systems must be carried out with deliberate consideration of environmental and hydrological conditions. Persistent issues along Temboga Road including seasonal flooding, erosion, and inadequate drainage highlight the urgent need for improved environmental assessment and planning. These hydrological challenges not only compromise the integrity of the infrastructure but also disrupt transportation, escalate maintenance costs, and create safety concerns for the local population.

Hydrological studies help in understanding the distribution, movement, and behavior of both surface and subsurface water. Detailed assessments of rainfall intensity, runoff patterns, watershed characteristics, and flood pathways are essential in determining areas prone to water-related hazards. However, traditional hydrological methods often lack the spatial precision needed to capture the complexities of present-day infrastructural challenges. Geographic Information Systems (GIS) address this gap by providing an advanced spatial framework for analyzing hydrological variables across large and complex terrains.

Temboga Road intersects multiple sub-catchments within the Ikpoba River system and is vulnerable to flooding and erosion due to its low-lying terrain, intense rainfall patterns, and increasing impervious surfaces resulting from rapid urbanization. Using GIS tools, engineers and planners can delineate watersheds, identify natural drainage routes, map flood-susceptible areas, and study land use changes over time. Such analytical capabilities enable a broader and more comprehensive understanding of water, environment and infrastructure interactions. This approach supports the identification of high-risk zones, the design of appropriate mitigation measures such as culverts and retention basins, and the selection of suitable locations for infrastructural development that minimize exposure to hydrological risks.

1.2 STATEMENT OF THE PROBLEM

Temboga Road, which lies in close proximity to the Ikpoba River, is routinely affected by flooding and erosion due to its low elevation and exposure to heavy rainfall. Previous flood events have involved the overtopping of the riverbanks and the advancement of erosional features, threatening homes, road structures, and nearby communities. Without adequate hydrological planning, the area is vulnerable to pavement deterioration, water-induced structural failures, and displacement of residents.

The lack of a GIS-based hydrological framework limits the ability to accurately identify risk zones, predict flow behavior, and design long-lasting solutions. Flood-vulnerable areas, erosion-prone sites, and ineffective drainage channels remain largely unresolved. A GIS-supported hydrological study offers an efficient, cost-effective means of integrating multiple datasets to develop flood hazard maps, delineate watersheds, and assess potential risks. This study responds to the need for a spatially informed, data-driven approach to enhance sustainable infrastructure development along Temboga Road.

1.3 AIM AND OBJECTIVES

The aim of this study is to illustrate how Geographic Information Systems (GIS) can be applied to conduct hydrological analyses that support the planning, design, and implementation of resilient and sustainable infrastructure along Temboga Road in Benin City.

1.4 OBJECTIVES OF THE STUDY

The objectives of this project are to:

i. Develop detailed base maps of Temboga Road and its surrounding environment.

ii. Delineate watershed boundaries of the Ikpoba River and the sub-catchments influencing Temboga Road using DEM data.

iii. Collect, process, and analyze spatial and hydrological datasets using GIS software.

1.5 SCOPE AND LIMITATIONS OF THE STUDY

This research focuses on using GIS to conduct hydrological analysis in support of infrastructure development along Temboga Road. Key hydrological features evaluated include drainage patterns, elevation variations, land use, and rainfall distribution. The study applies GIS tools to delineate watersheds, identify flood-prone regions, and generate spatial outputs that facilitate informed decision-making regarding road design and drainage infrastructure.

However, the study has limitations. Access to high-resolution and up-to-date spatial data was constrained, making it necessary to rely on openly accessible datasets that may not fully represent current ground realities. Time constraints restricted the extent of field verification, meaning not all GIS outputs could be validated in situ. Furthermore, the study concentrates on road and drainage infrastructure and does not extend to utilities such as electricity, housing systems, or telecommunications.

1.6 JUSTIFICATION OF THE STUDY

Temboga Road has long been burdened by flooding, erosion, and poorly designed drainage systems problems that intensify during the rainy season. These challenges stem largely from insufficient hydrological evaluation during initial planning and construction phases. As human activities and development intensify along the corridor, understanding the interaction between natural terrain and water flow becomes increasingly essential.

This study is justified by the need to incorporate spatially robust analytical methods into infrastructural design. GIS enables the integration and analysis of multiple hydrological parameters including rainfall intensity, topography, soil characteristics, and drainage patterns in a unified system. This approach allows engineers and planners to identify vulnerable zones, optimize drainage layout, and develop long-term infrastructure solutions that improve safety, reduce maintenance costs, and enhance environmental sustainability.

CHAPTER TWO

LITERATURE REVIEW

2.1 GEOSPATIAL INTELLIGENCE AND URBAN HYDROLOGICAL RESILIENCE

Geographic Information Systems (GIS) have significantly transformed the field of hydrology by providing a platform for managing spatially distributed datasets and analyzing complex environmental dynamics. Traditionally, hydrologists relied on isolated point-based measurements such as rain gauges and stream-flow gauges, which did not provide sufficient spatial detail to capture basin-wide variations. However, GIS offers a multidimensional approach that integrates topographic, hydrological, climatic, and land-use information within a unified analytical framework, thereby improving the accuracy and efficiency of hydrological assessments.

GIS supports the extraction of key basin attributes including area, slope, drainage density, and terrain characteristics while enabling the combination of datasets such as rainfall, soil composition, and land-cover maps to produce sophisticated hydrological models. As emphasized by Zhou & Li (2020), advancements in geospatial techniques have enhanced researchers' ability to interpret the complexities of hydrological systems, particularly in data-scarce or ungauged basins. These improvements are attributed to the availability of high-resolution spatial data and enhanced computational tools.

Several core hydrological procedures have been greatly streamlined through GIS. Watershed delineation, which once required laborious manual mapping, can now be accomplished rapidly using DEMs. GIS also enables rainfall interpolation techniques such as IDW, kriging, and Thiessen polygon methods to convert discrete rainfall records into continuous spatial surfaces, ensuring that analyses reflect actual hydrometeorological variability. Additionally, GIS is compatible with a variety of hydrological modelling platforms, such as HEC-HMS, SWAT, and MIKE 11, allowing modelers to import spatial datasets and visualize outputs as thematic maps.

Urban environments, especially those in developing nations like Nigeria, face increasing hydrological stress due to rapid urbanization, population growth, and inadequate infrastructures. Flooding events in Benin City illustrate how environmental change and unplanned urban development can intensify hydrological risks. For instance, frequent flood events around Temboga Road and Ikpoba Hill demonstrate the interaction between changing land-use patterns and strained drainage systems. As conventional engineering measures alone are insufficient to address these challenges, GIS-based geospatial intelligence provides a proactive strategy for understanding and mitigating hydrological risks. Through accurate mapping, predictive modelling, and scenario analysis, GIS strengthens decision-making in urban planning and disaster management.

This literature review examines the evolving contributions of GIS to hydrological studies, emphasizing its relevance to flood-prone urban corridors such as Temboga Road. It discusses how remote sensing, terrain modelling, and GIS-based hydrological techniques can support resilient infrastructure planning within the Temboga–Ikpoba catchment.

2.2 URBAN HYDROLOGY AND FLOOD RISK IN DEVELOPING CITIES

Urban hydrology investigates the movement and distribution of water within urban spaces. Unlike natural landscapes, urban areas are characterized by impervious surfaces such as asphalt, concrete, and rooftops that greatly reduce infiltration and amplify surface runoff. Reduced infiltration leads to diminished groundwater recharge and increased susceptibility to flash flooding.

In Nigeria, flooding has become one of the most prevalent natural hazards, frequently disrupting livelihoods, transportation systems, and urban economies. Studies conducted in Benin City reveal that heavy rainfall and ineffective drainage systems account for the majority of flood events reported by residents (Chioma O.C. et al., 2019). The city's geomorphology featuring low-lying terrains and high water-table levels combined with inadequate waste management practices often results in blocked drains and prolonged inundation.

Temboga Road exemplifies these hydrological challenges. Positioned close to the Ikpoba River, the road receives runoff from surrounding elevations and serves as a natural drainage path. During peak rainfall, the river expands beyond its channel, inundating adjacent communities and compromising road users' safety. The absence of engineered drainage channels in some sections further exacerbates the problem, causing rapid erosion, surface washouts, and localized flooding.

The implications of flooding extend beyond road deterioration. Transportation delays, increased road maintenance costs, and disruption of economic activities are common consequences of hydrological failures in urban environments. A case study published by MDPI emphasizes that flood events in Benin City disrupt internal trade by damaging transport routes, thereby affecting the city's overall economic resilience. These findings underscore the importance of incorporating hydrological foresight into infrastructure planning, particularly in areas that exhibit strong rainfall-runoff interactions.

2.3 GULLY EROSION AND WATERSHED MANAGEMENT IN EDO STATE

In addition to flooding, Benin City and the wider Edo State region are highly susceptible to gully erosion; a phenomenon driven by concentrated surface runoff and weak soil structures.

Sandy soils within the Benin Formation erode rapidly when exposed, especially during intense rainfall events. The Iwogban–Uteh area near Temboga Road is a notable example, where uncontrolled runoff previously developed into a major gully that endangered lives and property and disrupted transportation networks.

Watershed management has been identified as an effective strategy for erosion mitigation. By delineating catchment boundaries, understanding soil behavior, and analyzing slope gradients, planners can identify erosion-prone zones and recommend appropriate interventions. GIS enhances watershed management by providing tools for overlaying soil maps, vegetation cover, topography, and land-use patterns to map erosion susceptibility. Localized studies in Nigerian towns such as Anyigba and Auchi have demonstrated a strong correlation between inadequate drainage networks and gully progression.

Furthermore, the Ikpoba River itself shapes the hydrological and erosional patterns in the Temboga corridor. Although the river serves as a natural outlet for runoff, its seasonal fluctuations contribute to periodic flooding and bank erosion. Regulatory guidelines recommend setback buffers along major rivers, but weak enforcement has led to encroachment and increased vulnerability for residents living within these zones. Previous research conducted along the Ikpoba River by Oyetunji et al. (2019) demonstrated the utility of GIS in identifying vulnerable buildings and categorizing them into risk clusters, reinforcing the importance of spatial analysis in urban erosion studies.

2.4 GEOGRAPHIC INFORMATION SYSTEMS: CAPABILITIES AND RELEVANCE

GIS is a computer-based tool that captures, stores, analyses, and visualizes spatial and geographic data. Unlike traditional mapping techniques, GIS allows for the integration of multiple data layers; topography, hydrology, land-use, and infrastructure to assess complex environmental systems. In hydrological studies, GIS enables the modelling of drainage networks, watershed boundaries, flow-accumulation zones, and flood-prone areas. (neliti.com)

What makes GIS especially powerful is its adaptability to different scales and contexts. In urban settings like Benin City, GIS supports micro-level infrastructure planning (where to install culverts, how to align roads to avoid low-lying flood-zones) while also enabling macro-level watershed analysis. The strength of GIS lies in its ability to reveal patterns and relationships that are not immediately visible through conventional engineering assessments.

2.5 GIS TOOLS AND TECHNIQUES IN HYDROLOGICAL MODELLING

2.5.1 Digital Elevation Models (DEMs) and Terrain Analysis

At the heart of any hydrological GIS workflow is the Digital Elevation Model (DEM), a raster-based representation of terrain elevation. DEMs serve as the foundational input for extracting slope, aspect, flow direction, and accumulation which are critical parameters in hydrological modelling. (neliti.com)

In the Temboga Road context, elevation plays a pivotal role in determining flood-susceptibility. The terrain around the Ikpoba River includes both elevated and low-lying areas, with water naturally funneled into the riverbed and surrounding plains. Using software like Global Mapper (a powerful GIS tool known for its DEM-processing capabilities), researchers can delineate watersheds, simulate surface-runoff patterns, and identify natural water pathways. This is essential for positioning culverts, drains and embankments to ensure that road infrastructure remains stable and accessible during storm events.

2.5.2 Data Integration and Spatial Analysis

The strength of GIS lies not just in modelling, but in data integration. Hydrological studies rely on diverse datasets: rainfall records, land-use maps, soil types, stream gauge data and satellite imagery. GIS provides a framework to harmonize these inputs into a single analytical environment. (Scientific Research Publishing)

For Temboga Road, this integration is essential. Rainfall data from the Nigerian Meteorological Agency (NiMet), combined with soil-texture maps from the Ministry of Agriculture and recent drone imagery from field surveys, can be layered within a GIS platform to build a detailed hydrological profile. This comprehensive view allows planners to understand where runoff is generated, how it travels and where it accumulates key insights for resilient infrastructure design

2.6 PRACTICAL APPLICATIONS OF GIS IN HYDROLOGICAL STUDIES

2.6.1 Watershed Delineation and Drainage Network Modelling

Watershed delineation defines areas that drain into a common outlet, such as a river or drainage channel. This process is fundamental for understanding hydrological behavior within a region. Using DEMs and GIS tools, flow paths can be mapped and catchment boundaries accurately generated.

For Temboga Road, this analysis identifies the extent of upstream runoff contributing to observed drainage challenges and assists engineers in determining appropriate locations for culverts, drainage channels, and water diversion structures.

2.6.2 Flood Risk Assessment and Scenario Simulation

Flood-risk assessment is one of the most critical applications of GIS in urban hydrology. It involves identifying flood-prone areas, estimating the extent and depth of flooding, and evaluating the exposure of infrastructure and populations. In the case of Temboga Road, such an assessment is indispensable due to the seasonal variability in Ikpoba River discharge and the area's history of localized flooding. GIS facilitates the simulation of different rainfall scenarios, using historical precipitation records and runoff coefficients derived from land-use and soil-data. Through this process, planners can visualize flood extents under varying storm intensities (e.g., 5-year, 10-year, 50-year return periods). These models help determine which segments of Temboga Road are most vulnerable and guide the prioritization of mitigation interventions. For instance, using ArcGIS's HEC-GeoHMS and HEC-RAS integration, engineers can simulate channel overflow conditions, assess the performance of proposed drainage structures, and even test the effectiveness of levees or retention ponds. Such simulations move beyond theoretical planning and provide actionable insights for adaptive infrastructure development. (ScienceDirect)

2.6.3 Remote Sensing Integration in Hydrological Analysis

Remote sensing; the use of satellite or aerial imagery to collect data on the Earth's surface—is a powerful complement to GIS in hydrological studies. Satellite imagery offers temporal and spatial insights into land-use changes, vegetation covers and surface water dynamics, all of which affect hydrological behaviour. In the Temboga Road project, drone-acquired imagery and satellite data from platforms such as Sentinel-2 or Landsat-8 can be used to:

i. Monitor encroachments into flood-plains

ii. Track changes in vegetation that influences infiltration

iii. Detect erosion along the riverbanks of the Ikpoba River

iv. Identify blocked or degraded drainage channels

When integrated into GIS platforms, these datasets enable change-detection analysis over time. For example, comparing images from the past decade can reveal urban expansion into flood-prone zones, allowing planners to propose remedial zoning regulations or targeted green-infrastructure projects. Furthermore, the availability of high-resolution orthophotos from drone surveys enhances the accuracy of DEMs, thereby improving hydrological model outputs.

2.6.4 Real-Time Monitoring and Early Warning Systems

GIS applications in hydrology are no longer limited to retrospective analysis. With the integration of IoT-based environmental sensors and cloud-based data services, real-time hydrological monitoring is now possible. In advanced systems, river gauges, rain sensors and weather stations transmit data directly to GIS-platforms, enabling live flood mapping and early-warning alerts. While this level of technology is still emerging in most Nigerian urban centres, it represents a critical future direction. For flood-prone zones like Temboga Road, early-warning systems powered by GIS could drastically reduce the impact of flash-floods on road infrastructure, human lives and economic activity. (journal-iasssf.com)

2.7 GIS FOR INFRASTRUCTURE PLANNING AND ENVIRONMENTAL IMPACT MANAGEMENT

Urban planning in rapidly growing cities like Benin City demands a multidisciplinary approach that accommodates population pressure, environmental hazards and sustainable development goals. GIS provides a spatially intelligent framework for assessing the suitability of land for different types of infrastructure, particularly roads. The hydrological context of road infrastructure is crucial in flood-prone zones such as the Temboga Road area, where proximity to the Ikpoba River raises the stakes for engineering resilience. GIS allows Urban Planners and Civil Engineers to assess slope gradients, proximity to water-bodies, soil stability and land-use patterns, all of which are essential in road-alignment decisions. For instance, using slope-analysis tools within ArcGIS or Global Mapper, Engineers can avoid placing road-segments in areas prone to landslides or poor drainage. Buffer analysis can identify safe distances from the Ikpoba River to minimize flood risk, while overlay analysis can incorporate multiple datasets (e.g., land-cover, geology, hydrology) to determine optimal road-paths with minimal environmental disruption. In the context of Temboga Road, this GIS-informed process ensures that the design and location of the road support both infrastructural longevity and environmental stewardship. Additionally, GIS supports the planning of supplementary infrastructure such as storm-water drains, culverts and retention basins, which are vital for flood mitigation.

2.8 HYDROLOGICAL CHALLENGES AND GIS-BASED SOLUTIONS FOR TEMBOGA ROAD

The Temboga Road corridor, situated within the dynamic urban landscape of Benin City and adjacent to the Ikpoba River, faces a complex range of hydrological and environmental challenges. These challenges stems from natural processes like seasonal rainfall and riverine flooding, but are compounded by anthropogenic factors such as unregulated land-use, deforestation and poor drainage plan. As urbanisation accelerates without proportional investment in environmental infrastructure, the risk to roads, buildings and communities intensifies.

GIS offers a comprehensive framework for identifying, analyzing and managing these hydrological challenges, ensuring that infrastructure development proceeds sustainably and resiliently.

2.9 FLOODING: SEASONAL RISK AND URBAN VULNERABILITY

Flooding remains the most pressing hydrological threat to Temboga Road. Seasonal rains lead to a significant rise in the Ikpoba River's water levels, which in turn overwhelms the existing drainage systems. In some years, the river overflows, submerging low-lying sections of the road and causing significant damage to the pavement, culverts and adjoining properties.

GIS-based flood modelling helps identify these high-risk zones through:

i. Flood-plain mapping: Using DEMs and hydrological data to identify areas below flood-threshold elevations.

ii. Hydraulic simulation: Applying tools such as HEC-RAS to simulate river overflow scenarios.

iii. Temporal analysis: Uses remote sensing to compare flood extents over multiple years.

These insights enable stakeholders to prioritize flood-defenses such as elevated road sections, storm-water detention ponds and embankments. Most critically, GIS helps establish thresholds for rainfall intensity beyond which the system will fail, forming the basis for early-warning systems and emergency response planning.

2.10 EROSION: SOIL DEGRADATION AND STRUCTURAL INSTABILITY

The sandy-loam soil composition in the Temboga area makes it highly vulnerable to erosion when subjected to runoff. Erosion weakens road foundations, fills drainage channels with sediment, and accelerates infrastructure deterioration. GIS aids in identifying erosion hotspots by analyzing slope, rainfall patterns, soil type, and land use.

2.11 RIVER DYNAMICS: SHIFTING CHANNELS AND INFRASTRUCTURE RISK

The behaviour of the Ikpoba River is not static. Changes in flow-regime, sediment deposition and bank-erosion can alter its course over time. These shifts, if not monitored, can render infrastructure plans obsolete or dangerous. For instance, a gradual meander toward Temboga Road could result in unexpected erosion or flood exposure.

GIS supports the continuous monitoring of river-morphology by:

i. Temporal-mapping of river courses using high-resolution imagery.

ii. Comparative-analysis of historical and recent riverbank position.

iii. Buffer-zone delineation protects infrastructure from lateral river movement.

By visualizing these changes, planners and stakeholders can anticipate and accommodate future river behaviors, adjusting road alignment, reinforcing embankments or reserving land for future protective measures.

2.12 DRAINAGE SYSTEM DESIGN: FROM MAPPING TO IMPLEMENTATION

One of the key gaps in infrastructure along Temboga Road is the inadequate capacity of drainage networks. With limited culverts, unlined gutters and blocked inlets, rainfall accumulates on road surfaces, accelerating pavement degradation.

GIS offers a data-rich environment for designing effective drainage systems:

i. Flow-accumulation models determine runoff-pathways and volume.

ii. Catchment-delineation ensures that all contributing areas are factored into culvert design.

iii. Capacity-analysis matches rainfall intensity with conduit size and placement.

Integrating these insights ensures that future drainage systems are not just reactive but resilient capable of handling peak flows under worsening climate conditions.

2.13 GAPS IN THE PREVIOUS LITERATURES

1. Limited Site-Specific Application for Road Infrastructure: Many GIS/hydrology studies in Nigeria focus on the general flood susceptibility or urban drainage, but few tailor their analysis explicitly to *road corridors* such as Temboga Road, combining roadway design with hydrological modelling.
2. Low Use of High-Resolution Topographic Data: Though DEMs and UAV surveys are noted, few studies in the Benin City region apply very high resolution (e.g., < 5 m) topographic and drone data in conjunction with GIS for infrastructure planning.
3. Integration between GIS Outputs and Physical Road Drainage Design: There is a gap between generating GIS-derived hydrological/flood maps and turning them into detailed drainage/road engineering designs (culverts, U-drains, embankments) for specific road projects.
4. Longitudinal Monitoring of Infrastructure Vulnerability: Few studies monitor how roads like Temboga Road evolve under repeated flood/erosion events and how GIS can assist in proactive maintenance scheduling.
5. Real-Time Monitoring and Early Warning Integration: While real-time GIS systems are referenced, actual deployment in Nigerian road-infrastructure contexts remains sparse.

CHAPTER THREE

METHODOLOGY

3.1 DESCRIPTION OF THE STUDY AREA

The study was conducted along Temboga Road, situated within Ikpoba-Okha Local Government Area (LGA) of Benin City, Edo State, Nigeria. The rectangular study boundary is referenced to the WGS 1984 datum using the UTM Zone 31N coordinate system. The approximate coordinates are as follows; upper left corner 793080.56 m E, 705721.50mN; upper right corner 794332.29mE, 705678.50 m N; lower left corner 793092.21mE, 702586.05 mN and lower right corner 794348.54mE, 702604.12mN. The road corridor stretches approximately 7.2 km, crossing diverse terrain and hydrological features. Notably, it lies adjacent to the Ikpoba River, one of the primary rivers flowing through Benin City.

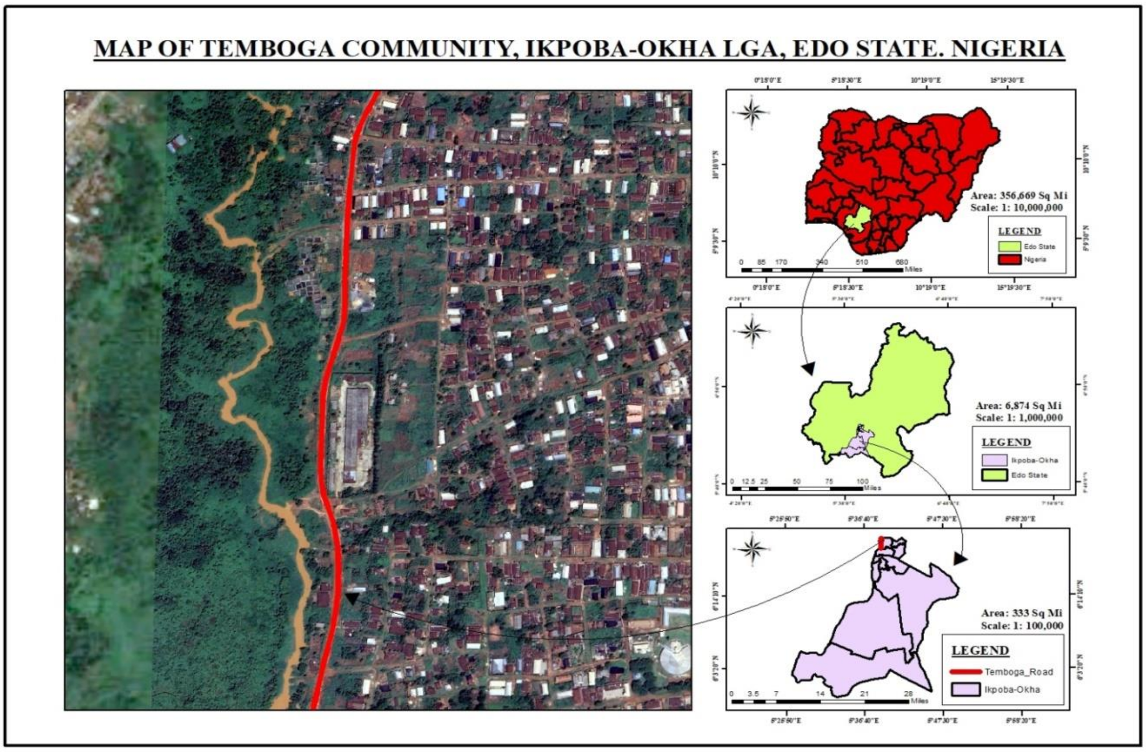

Figure 3.1a: General Layout of Temboga Community, Ikpoba-Okha LGA, Edo State, Nigeria.

Temboga Road is a strategic transportation corridor extending approximately 7.2 km from Ikpoba Hill Junction through Upper Mission Extension, Iwogban, and Uteh communities, eventually connecting Ugbowo and the Benin–Lagos Expressway. The road traverses varied terrain forms and hydrological features and lies in proximity to the Ikpoba River, one of Benin City's major watercourses. This location exposes the corridor to considerable hydrological risks, such as seasonal flooding and erosion, which impact road performance and surrounding settlements.

3.1.1Topography and Relief

The area features a gently rolling topography transitioning into steeper gradients as the land slopes toward the Ikpoba River valley. Elevations range between approximately 25 m and 70 m above sea level. These natural depressions and low-elevation areas frequently accumulate runoff during intense rainfall events, contributing to localize flooding along sections of the road.

3.1.2 Climate and Rainfall

Temboga Road lies within the tropical rainforest climatic belt, characterized by high annual rainfall and distinct wet seasons. The region experiences a bimodal rainfall pattern, with peak rainy periods occurring from April to July and September to October. Annual rainfall exceeds 2,400 mm, increasing the potential for flash floods, especially in areas lacking adequate drainage systems. Relative humidity typically ranges from 60% to 95%, while mean annual temperatures vary between 26°C and 28°C.

3.1.3 Drainage and Hydrology

The Ikpoba River, along with numerous minor tributaries and artificial drainage channels, forms the main hydrological network in the region. These channels carry runoff from upland areas, including Uteh and Upper Mission Extension. During periods of high rainfall, the river experiences substantial increases in discharge, often resulting in overtopping and flooding adjacent road sections and residential areas. Sediment-laden runoff and blocked drains contribute to water stagnation and exacerbate erosion along the corridor.

3.1.4 Soil and Geology

The study area is dominated by sandy-loam and sandy-clay soils belonging to the Benin Formation. These soils are highly erodible and prone to gully development when exposed. Historical erosion incidents in locations such as Iwogban demonstrate the vulnerability of the terrain to runoff concentration and poor drainage management.

3.1.5 Land Use and Human Activities

Temboga Road passes through a semi-urban environment consisting of residential areas, commercial zones, small industries, and institutional facilities. Rapid urbanization has intensified land-use pressures, with many new developments encroaching into natural drainage channels and floodplains. Inadequate waste management practices also contribute to blocked drains and reduce drainage efficiency.

3.1.6 Importance of the Area to Infrastructure Development

The Edo State Government prioritizes the Temboga Road corridor due to its role as an alternative route for easing citywide traffic congestion. Ongoing expansion and rehabilitation efforts seek to enhance mobility and economic development. However, recurring hydrological issues including drain blockages, seasonal flooding, and erosion necessitate incorporating hydrological assessments into long-term infrastructure planning.

3.1.7 Administrative and Legal Context

Temboga Road falls under the jurisdiction of the Edo State Ministry of Works and Urban Development, which oversees all infrastructure-related activities in the region. The area also interacts with agencies like the Benin Owena River Basin Authority, responsible for water resource management in the lower Niger region. Any hydrological and infrastructural interventions must align with existing state and national urban development policies, including environmental and safety standards.

Table 3.1: Key Data and Sources for the Hydrological Study (proposed)

Data / Dataset	Description & Use	Source / Provider
Satellite Imagery (Google Earth or similar)	High-level view of land use, water bodies, and terrain features. Aids initial digitization and site familiarization.	Google Earth Pro
Existing Layout Map of Temboga Road	Road alignment, design and right-of-way plans for the Temboga Road project. Used as a base layer in GIS to understand planned infrastructure.	Edo State Ministry of Works
Digital Elevation Model (DEM)	Terrain elevation grid (30 m) resolution DEM covering Benin City and surroundings). Used for watershed delineation and slope analysis.	USGS (SRTM DEM)
Ikpoba River Discharge (if available)	Any measurements of Ikpoba River flow or stage, for context of flood levels.	Edo State Water Resources or literature
Differential GNSS Survey Points	Coordinates and elevation of key points: road centerline, edges, drain outlets, benchmarks, GCPs for drone.	Field survey using GNSS receiver
UAV Aerial Photographs (Phantom 4)	High-resolution images of Temboga corridor. To be processed into an orthomosaic and DSM.	Field survey using DJI Phantom 4 drone
Total Station	Used for precise measurement of horizontal and vertical angles and distances during detailed topographic and construction surveys.	Field Survey using Leica or South Total Station.
Field Reconnaissance Notes	Observations of current drainage features, flood marks, erosion sites, land use.	Field visit (visual inspection)
Ground Photos	Geotagged photographs of notable sites (e.g., gully locations, flood-prone low spots).	Field camera / smartphone

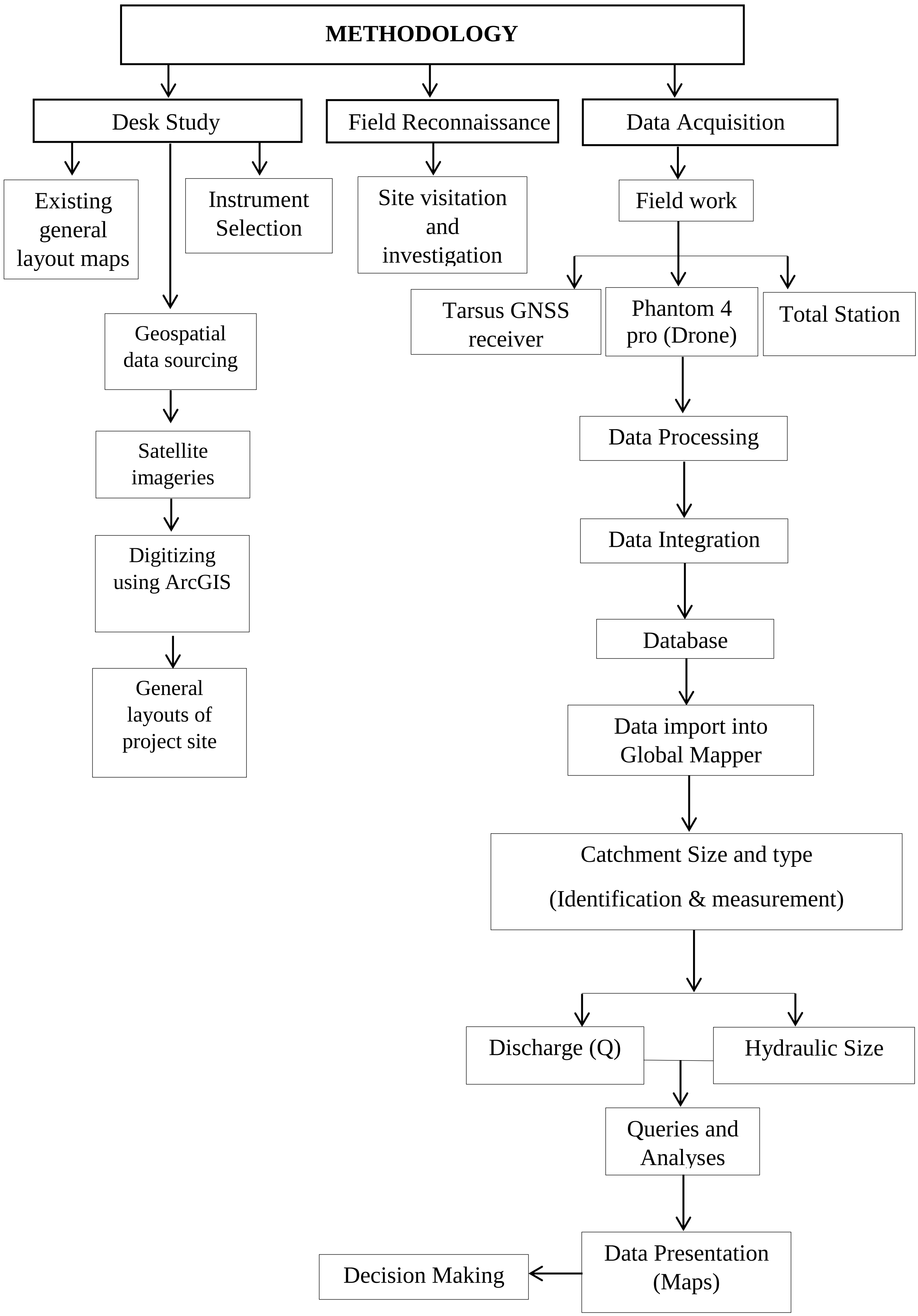

Figure 3.1b: Flow Chart for the study

3.2 DESK STUDY AND PRELIMINARY DATA COLLECTION

The study commenced with an extensive desk study, which involved gathering and reviewing existing information about the project area. First, a general layout map of Temboga Road was obtained from the Edo State Ministry of Works. This showed the planned route alignment, design features (such as where bridges or culverts are to be placed), and surveyed benchmarks. The layout map provided the foundational context on which new data was superimposed.

Relevant topographic and environmental datasets were collected. The USGS SRTM DEM (30 m resolution) for the region was downloaded via Earth Explorer. This DEM was clipped to the study extent that included the Ikpoba River catchment influencing Temboga Road. GIS software was used (ArcGIS Pro and Global Mapper), the DEM allowed delineation of the watershed and identification of flow directions (via tools like "Flow Direction" and "Flow Accumulation").

High-resolution satellite imagery (such as recent Google Earth images) was used to digitize current features; the course of Ikpoba River, existing structures along the road, vegetative cover, etc. This was part of creating the base map in the GIS. The desk study digitized layers like rivers, roads, and buildings from imagery prior to field verification, similar to the approach by Oyetunji et al. (2019) in their Ikpoba flood vulnerability mapping. Doing this early allowed identification of specific locations that needed field checking (for example, a map showed a drainage channel crossing the road; we marked it and later confirmed on site if it exists and its condition).

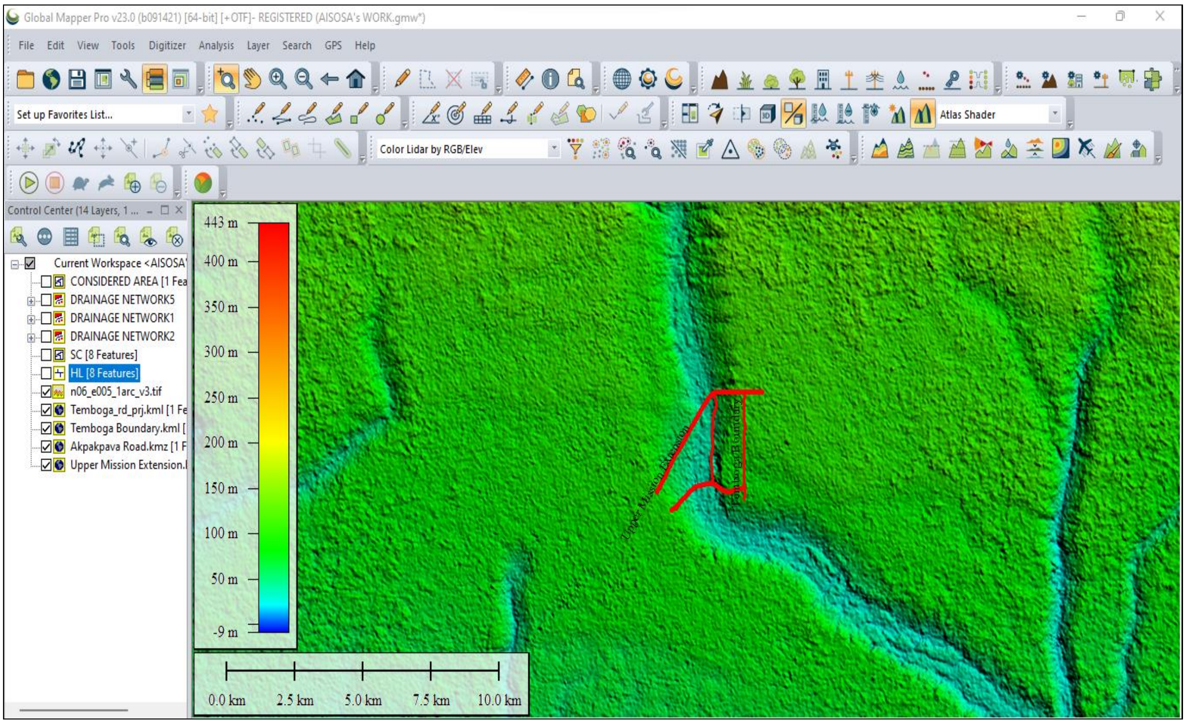

Fig 3.2a: DEM data clipped to the study area (Source:Global Mapper)

Figure 3.2b: Google earth imagery of study area (Source: Google Earth Pro)

3.3 FIELD RECONNAISSANCE (SITE VISIT)

A field reconnaissance visit was carried out along Temboga Road and its environs. The purpose of this reconnaissance was to ground-truth the information gathered in the desk study in which the practical insight was gained into local conditions that was not evident from the maps and satellite images. This visit involved a physical walk/drive through the entire stretch of the road (approx. 7 km), including the river crossing at Ikpoba.

During reconnaissance, the team (including the GIS analyst and civil engineers) noted the following:

Drainage Features: Locations of existing drains, culverts, and ditches were recorded. For example, the Ministry’s layout map indicated a culvert at a certain chainage, we verified its presence and noted its size and state (cleared).

Signs of Flooding: Indicators such as water marks on bridge abutments, flood debris caught in vegetation, and stagnant water bodies were documented. Local residents were informally interviewed for anecdotal evidence of flood history (e.g., “the water reached this point on the road last rainy season”). Such qualitative data was very useful to validate our flood hazard mapping.

Erosion Sites: The reconnaissance paid special attention to the gully formation and severe erosion near the road. In the Iwogban/Upper Temboga area, there was an accessible view of the reclaimed gully, observations were made on how water was being managed (e.g., presence of concrete chutes or retaining walls).

Topography and Land Use: Walking the site gave a sense of the topographic undulations that a DEM might smooth over. We identified sharp breaks in slope, high points, or depressions along the road. Land use (e.g. built-up vs. vegetated) influences runoff, so noting areas of recent deforestation or construction was useful. Temboga Road passes through semi-urban areas; changes like new buildings or cleared land (not captured in slightly older satellite imagery) were noted.

Field reconnaissance was essentially the qualitative validation step. It ensured our subsequent analytical models in GIS were based on reality. For example, during the visit we discovered that a supposed “drainage channel” on the map was actually choked with sediment and non-functional, we treated that area as more flood-prone in our analysis.

3.4 INSTRUMENTATION AND EQUIPMENT SELECTION

Following reconnaissance, the next step was to conduct precise surveys using selected instruments. Two primary instruments were deployed; a high-precision GNSS receiver and a DJI Phantom 4 drone. The rationale for each and the procedure are explained below.

1. **GNSS Receiver (Trimble R8):** Specifically, the Trimble R8 was used for precise coordination of data acquisition. The Trimble R8 is a high precision surveying instrument capable of receiving signals from multiple satellite constellations such as GPS, GLONASS, Galileo and BeiDou. It provides centimeter-level accuracy in real-time using **Real-Time Kinematic (RTK)** positioning or differential correction. In this study, it was employed to obtain accurate georeferenced control points and coordinate data for mapping, georeferencing of imagery, and validating positional accuracy. Its internal antenna, advanced satellite tracking capability, and long-lasting battery made it suitable for field operations in varying terrain conditions such as the Temboga Road corridor.

1. **DJI Phantom 4Pro UAV:** The DJI Phantom 4Pro UAV was used to acquire high-resolution aerial photograph (orthophotos) of the study area. The phantom 4 pro is equipped with a 20-megapixel camera mounted on a 3-axis gimbal, ensuring image stability and clarity. It has a flight time of approximately 30 minutes and can fly autonomously along pre-programmed flight paths for systematics data capture. The UAV was flown at a controlled altitude of 30m to ensure adequate image overlap (typically 70-80%) for accurate photogrammetric processing. The captured images were later processed using Photogrammetry software (Agisoft Pro) to generate orthomosaic images, Digital Elevation Models (DEM).

2. **Total Station:** The total station is an electronic and optical surveying instrument that combines a theodolite for angular measurements and an electronic distance meter (EDM) for slope distance measurements. It was primarily used for ground truthing, control establishment, and supplementary topographic surveys. The total station enables precise measurement of horizontal and vertical angles as well as distances, which can then be used to calculate accurate coordinates of surveyed points. In this study, it was used to verify the accuracy of the UAV-derived data and to establish ground control points (GCPs)

4. Staff and Level

The Leveling Instrument (Automatic Level) and Staff were used for drainage gradient profiling and determination of elevation differences along Temboga Road. The instrument works based on the principle of a horizontal line of sight, allowing measurement of height differences between points. The leveling process involved setting up the instrument on stable ground, taking back sight and foresight readings on the staff, and computing relative elevations. These measurements were essential for analyzing drainage slopes, surface gradients, and flow directions, which are critical in hydrological assessments and infrastructure planning, particularly for identifying areas prone to flooding or poor drainage.

5. Computers with ArcGIS, Global Mapper, and QGIS

Powerful desktop computers equipped with Geographic Information System (GIS) software such as ArcGIS, Global Mapper, and QGIS were used for data analysis and map production.

i. ArcGIS was employed for advanced spatial analysis, map design, and overlay operations.

ii. Global Mapper was specifically used for terrain analysis and watershed delineation, including processing of the Digital Elevation Model (DEM), sink filling, flow accumulation, and catchment boundary extraction.

iii. QGIS, an open-source GIS platform, supported data integration, coordinate transformation, and map visualization.

These software tools collectively facilitated the analysis, modeling, and visualization of spatial data for hydrological assessment and infrastructural planning along Temboga Road.

Figure 3.4a: GNSS Base and Rover set up at Temboga site

Figure 3.4b: Instrument set up at Temboga site with team members

Figure 3.4c: Phantom 4 Drone preparing to take flight

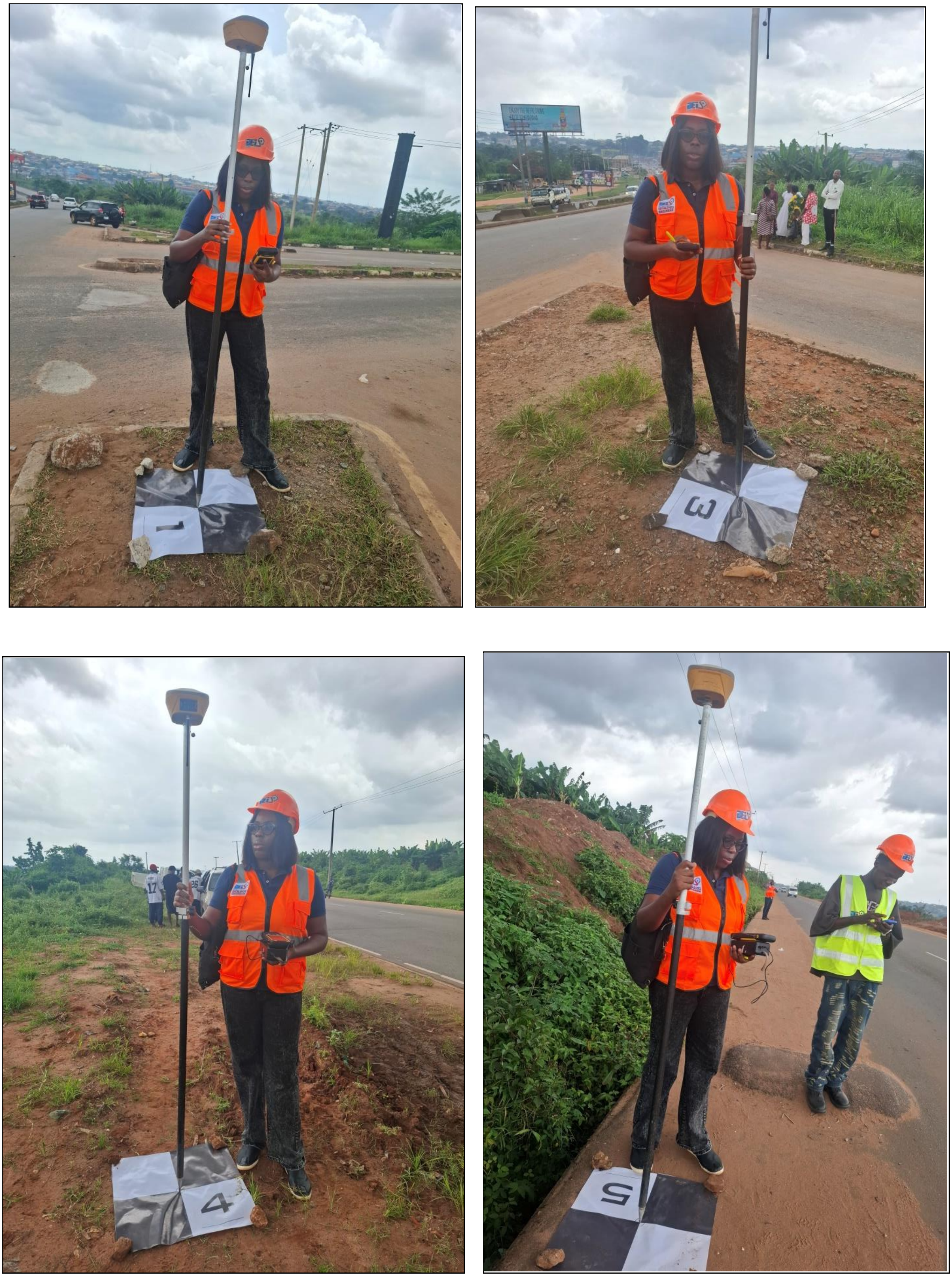

Fig 3.4d Captured accurate geographical coordinates of a GCP marked on ground

3.5 DATA ANALYSIS AND HYDROLOGICAL MODELING IN GIS

With both secondary (desk study) and primary (field) data in hand, the core analytical work was performed in the GIS environment. The software used was ArcGIS Pro (for its robust spatial analysis toolset and mapping capabilities) alongside Global Mapper known for its powerful terrain analysis, broad data compatibility, and simplicity in handling GIS and 3D data. The analysis comprised several sub-tasks:

3.5.1 Terrain Analysis and Watershed Delineation

DEM preprocessing involved filling sinks, generating flow direction grids, and computing flow accumulation layers. These datasets helped identify key drainage lines, depressions, and watershed boundaries affecting Temboga Road. Flow accumulation layers provided insight into natural runoff pathways and potential flood zones.

3.5.2 Runoff and Drainage Capacity Analysis

This step bridges hydrology with infrastructure design. With standard formulas (Rational Method for peak runoff), we estimated the runoff that needed to be handled by drains at critical points. The GIS helped in determining Catchment Areas (A) contributing runoff to the identified roads which directed runoff to the flood basin.

i. Global mapper calculated the Hydraulic Length (L) of each Catchment Areas which provided essential hydrological parameters used to estimate the runoff volume and peak discharge.

ii. A Design storm was assumed for 25-year return period, with an intensity derived from rainfall data.

iii. Calculated Quantity of Runoff flow (Q) = CIA (Rational Method) for each catchment (C = runoff coefficient from land use, I = rainfall intensity, A = area). We compared Q with current drain capacity. The theoretical capacity of the drain dimensions gotten from our design and measurement on site were computed (Manning's formula for open channels or culverts).

Where capacity was less than the expected Q, we flagged that location as likely to flood during the design storm. This informs recommendations like "increase drain size at chainage X" or "add an extra culvert at low point Y".

For the purpose of this report, catchment one (1) of Temboga Road will be used as a case study to explain the steps taken in achieving the hydrological/hydraulic study results. The summary of result of all the catchments for the studied roads will also be presented in a table format in this report.

3.6 STAGES INVOLVED IN THE HYDROLOGICAL DESIGN USING CATCHMENT ONE AS A CASE STUDY

Stage 1: Acquisition of Geospatial and Hydrological Data**:** The Geospatial and hydrological data required for the hydrological analysis of the terrain under consideration (the studied roads) was generated on an online platform known as the United State Geological Survey (USGS). The USGS site is an agency of the United States Government that provides science about the natural hazards that threaten livelihood such as water, energy, minerals and other natural resources. The Geospatial and the Hydrological data acquired from the USGS site was specifically the Digital Elevation Model (DEM) of the Project Area. The DEM gave information on the bare ground topographical surface excluding trees, building and other surface objects of our terrain under consideration.

Stage 2: Exporting the Generated Geospatial/Hydrological Data into Global Mapper Software: The Global Mapper is Geographical Information System (GIS) Software that handles vector, raster and elevation data. For the purpose of this study, the Geospatial/Hydrological data generated on the USGS site was exported to the Global Mapper

Software. The software helped to analyze and generates the watersheds (Catchment Area) contributing runoff to the studied roads and their respective flow paths which included the minor and major ones.

Stage 3: Determination of Quantity of Flow of the Catchments**:** The Federal Ministry of Work Highway Manual Part 1 Volume IV Drainage Design was used to undergo series of steps computation that helped in determining the Quantity of runoff flow for all catchments that contributed flow to the project roads.

3.6.1 Steps Involved in the Hydrological Computation Using Catchment One as A Case Study: The analyses of the steps used for the hydrological computation are as follow:

Step 1: Determination of Runoff Coefficient (C): The runoff coefficient account for abstractions or losses between rainfall and runoff which may vary for a given drainage area as influenced by differing topographical, vegetation and climatic conditions. Runoff coefficient is rough estimated value. Its value is influenced by the size of each drainage surface, vegetation covers and soil type, ultimate land use, etc. The value of the runoff coefficient was determined with reference to the basic principle given in Table 4.1 and 4.2 for urban and rural areas from the Federal Ministry of Works Highway Manual, Part I. Since the road under hydrological investigation is located in urban area, Table 4.1 of the Federal Ministry of Works Highway Manual (FMWHM) Drainage Design Part 1 Volume IV was used as a recommended guide to compute for the value of Coefficient of run-offs(C) in urban area. It was applied to determine the C of Catchment 1. Table 3.1. below gives information on how the C was attained.

COMPUTATION OF RUNOFF COEFFICIENT C FOR URBAN AREA			
LAND USE	**FACTORS**	**%LAND USE**	**RUNOFF (C)**
Lawns			
Sandy , flat (<2%)	0.075	0	0
Sandy steep (>7%)	0.175	10	0.0175
Heavy soil flat(<2%)	0.15	2	0.003
Heavy soil steep (>7%)	0.3	10	0.03
RESIDENTIAL AREAS			0
Houses	0.4	15	0.06
Flats	0.6	10	0.06
INDUSTRY			0
Light Industry	0.65	3	0.0195
Heavy industry	0.75	3	0.0225
BUSINESS			0
City centre	0.825	5	0.04125
Suburban	0.6	10	0.06
Streets	0.825	10	0.0825
Maximum Flood	1	20	0.2
Total %Land use		98	
Initial C			0.59625
Final C			**0.5439**

Table 3.6a Computation of run off coefficient(C) for sub catchment 1 (SC1)

To determine the Final Runoff Coefficient C, we considered table 4.5 of the FMWHM part 1 Vol IV Drainage Design to determine the adjustment factor for C due to initial saturation and 20% climatic change factor.

Table 3.6b Adjustment factor for c due to initial saturation

Return period years	**2**	**5**	**10**	**20**	**50**	**100**
Factor for steep and impermeable catchments	0.75	0.80	0.85	0.90	0.95	1.00
Factor for steep and permeable catchments	0.50	0.55	0.60	0.67	0.83	1.00

By interpolating for 25yrs return period from table 4.4 above;

20% impermeability of the catchments = 30% x 0.908 = 0.2725

Similarly, 80% permeability of the catchment = 70% x 0.697=0.4877

The total adjustment factor for initial saturation **c** = 0.2725+0.4877=0.7602

20% climate change factor for the initial run off coefficient=

(20%x0.59625) +0.59625= 0.7155

The final C = 0.7602 x 0.7155 = 0.5439

STEP 2 - Time of Concentration (Tc):

The time of concentration, Tc at any point is the time required for the runoff from the hydrological most remote portion of the drainage area to reach a point of interest. The most remote portion provides the longest time of concentration, but is not necessary the most distant point in the drainage area. The time of concentration is used as storm duration in calculating the intensity of rainfall and it is measured in hour. The Kerby's Formula will be applied to compute the Time of Concentration TC

$$T_C = 0.604\left(\frac{rl}{\sqrt{S}}\right)^{0.467} \qquad \textbf{3.1}$$

Where r= roughness coefficient taken from table 4.5 FMWHM part 1 Vol IV Drainage Design.

Table 3.6c Recommended value for overland flow roughness (r)

Roughness coefficient (r)

Surface desription	**Recommended value of 'r'**	**%used**	**R**
Paved areas	0.02	30	0.006
Clean compacted soil, no stones	0.1	25	0.025
Sparse grass over fairly rough surface	0.3	15	0.045
Medium grass cover	0.4	20	0.08
Thick grass cover	0.8	10	0.08
		100	**0.236**

r =0.236

L=hydraulic length of catchment =1.840km (This was gotten from the Global Mapper software)

S= Catchment slope

$$S=\frac{Highest\ elevation\ of\ hydraulic\ length(km) - lowest\ elevation\ of\ hydraulic\ length}{hydraulic\ length(km)}$$

S= (0.092-0.039)/1.840=2.88%

The catchment slope is 0.0288 gradient.

$$Tc=0.604\left(\frac{0.236\ x1.840}{\sqrt{0.0288}}\right)^{0.467}$$

Tc = 0.60hrs.

STEP 3 - Intensity of the Rainfall

Intensity is defined as the rate of rainfall and is given in unit of mm/hr. The rainfall intensity was determined using mathematical method from Federal Ministry of Works Highway Manual part 1, 2013. The following phases were taken to obtain the Rainfall Intensity of the catchment:

1. Determined the zone where the catchment falls from Figure 4.4 of the FMW Highway Manual the catchments fell under Benin (Zone II). This was used to determine the Scale (α) and Location parameter (β) as seen on Table 4.8 and 4.9 of the FMW Highway Manual.

2. Determined 1/ α and β using table 4.8 of the FMW Highway manual. The formula to calculate the rainfall intensity includes:

$$X = \beta + y(1/_{\alpha}) \quad \textbf{3.2}$$

$$Y = \ln(T_r)\frac{1}{(2T_r)} - \frac{1}{(42T_{r^2})} - \frac{1}{(8T_{r^3})} \quad \textbf{3.3}$$

Where x= rainfall intensity (I)

α and β are the scales and location parameters.

Tr is the return period or frequency of occurrence of storm which is 25 yrs.

By using the calculated time of concentration (Tc) = 0.60hrs to interpolate for 1/ α and β,

1/ α =11.664

β = 76.095

Y=3.198

3. Substituting the values above into the rainfall intensity formula, we have:

$$I= \beta + y\ (\frac{1}{\alpha}) \quad \textbf{3.4}$$

I (Rainfall Intensity) = 113.41mm/hr.

STEP 4 - Quantity of Runoff Flow Designed for the Catchment

The quantity of runoff flow (Q) was determined using the rational method formulae (also known as Lloyds – Davis formulae) provided in Federal Ministry of Works Highway Drainage Design Manual (Part I) Volume 4 of 2013. Quantity of runoff flow, Q = 0.278CIA Where A= enclosed area. This was determined from the global mapper software =0.88km2

C= 0.5439

I= 113.41mm/hr.

Therefore, **Q**= 0.278 X 0.5439 X 113.41 X 0.88 = **1.439m3/s.**

3.7 SIZING OF THE DRAIN (HYDRAULIC ANALYSIS) DESIGN DATA FOR STORMWATER DRAINS

1 Slope channel(**S**) = 0.030

2 Manning coefficient(**n_D**)=0.013 was gotten from surface roughness and Manning's table (chow 1959)

3 Design storm frequency=25 years

4 Acceleration due to gravity=10m/s2

5 Trial sizing of the Drain Width (**b**)=0.75m Channel depth (**h**)=0.75m

6 Flow depth (**d**) = 0.85h= 0.85 x 0.75 = 0.638m 8 Cross sectional area (**A_D**)=b X d =0.638 X 0.75=0.478m2

3.8 COMPUTATION OF HYDRAULIC RADIUS (R)

In order to compute the Hydraulic Radius V, equation 3.5 was applied.

$$\mathbf{R}= \frac{b*d}{wp}=\frac{b*d}{b+2d} \qquad \mathbf{3.5}$$

R=0.75x0.638/0.75+2* (0.638) =0.236m

3.9 DETERMINATION OF STORM WATER VELOCITY V

In order to determine the velocity V, equation 3.6 was applied.

$$V = \frac{R^{0.67} \times S^{0.5}}{n_D} \qquad \mathbf{3.6}$$

$$V = \frac{0.236^{0.67} \times 0.030^{0.5}}{0.013} = 5.080\ m/s$$

3.10 DETERMINATION OF STORM WATER DRAIN CAPACITY

Drain capacity (Q) = A_D * V **3.7**

A_D= 0.478m^2

V=5.080m/s

Drain capacity= 0.478 x 5.080 = 2.429m3/s.

The computed Storm Water Drain Capacity (Q) = 2.429m3/s

The computed Catchment Design Flow (Q) = 1.429m3/s

Since the Storm Water Drain Capacity is greater than the Catchment Design flow, therefore the trial sizing of

0.75m x 0.75m x 0.15m is adequate to hold the runoff flow in this catchment.

3.11 INTEGRATION AND THEMATIC MAP PRODUCTION:

Finally, all analyses were synthesized into a map and tables that presented the findings clearly:

A Base Map / Study Area Map showing Temboga Road, Ikpoba River, buildings and adjoining roads. The map included proper legends, north arrow, and scale bars for professional presentation. Citations from literature used to justify parameters (like runoff coefficients or recommended buffer distances) was included in the report text accordingly

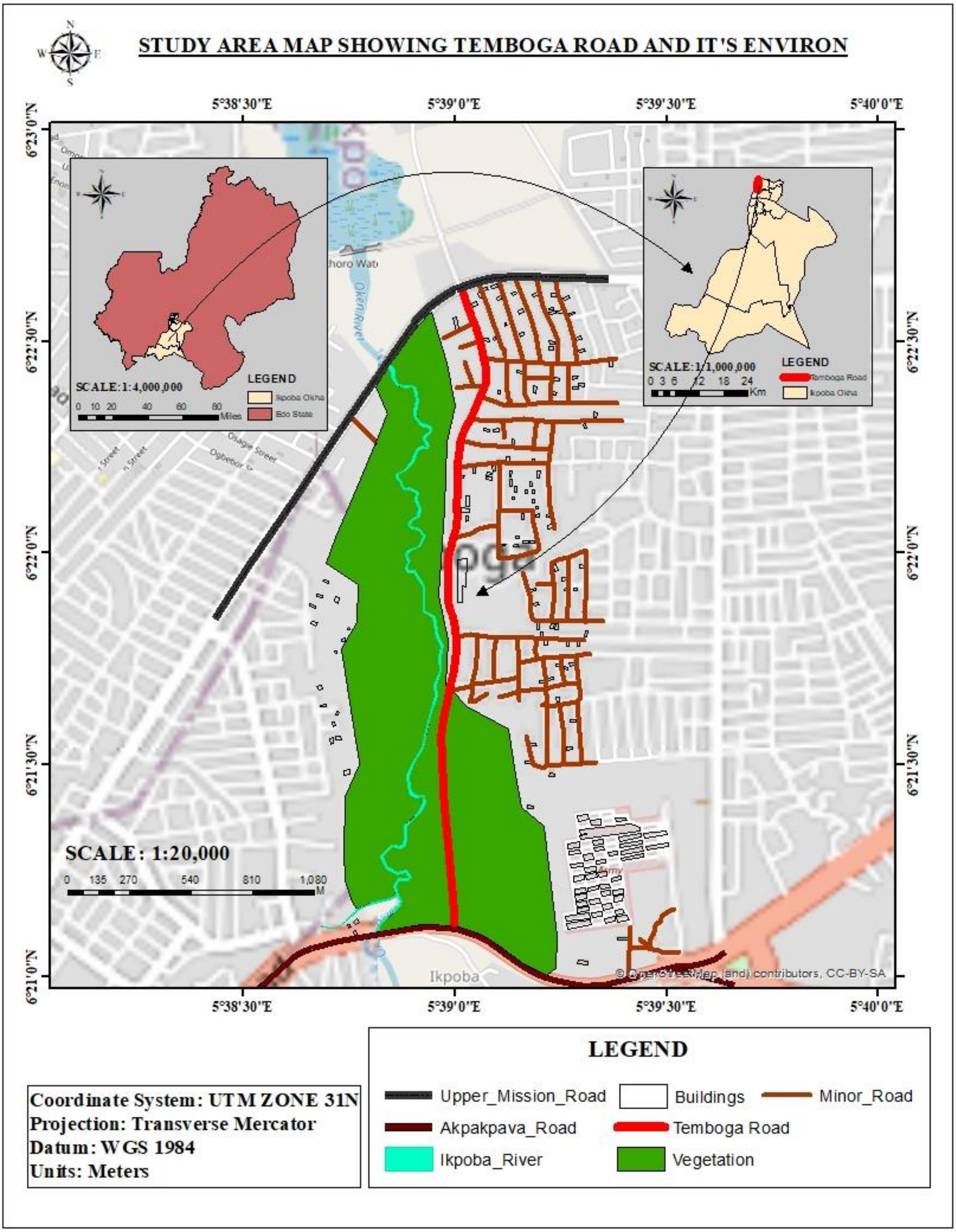

Fig 3.11. Map ShowingTemboga Road, its surrounding road network and Ikpoba River.

3.12 SOFTWARE AND ANALYTICAL TOOLS

The project utilized a suite of software tools:

ArcGIS Pro 3.x: It is used for GIS data management, spatial analysis (Hydrology toolbox for watershed delineation, Spatial Analyst for raster calculations), and high-quality cartographic output.

QGIS 3.x: It acts as a complementary tool; QGIS used plugins like QuickOSM (to bring in OpenStreetMap data for any missing info like minor streams or buildings) and integration with Global Mapper: Used for advanced hydrological modeling.

Agisoft Metashape / Pix4D: It is used to process drone imagery into orthomosaic and DEM.

Microsoft Excel: for calculations of runoff, rainfall stats, and tabulating survey data (GNSS points list, etc.). It runs formulae for drain sizing.

Google Earth Pro: for visual validation and creation of elevation profiles quickly along the road (double-checked against our own DEM profiles).

This combination of tools was chosen to ensure accuracy and efficiency. Notably, both proprietary (ArcGIS, Agisoft) and open-source (QGIS, HEC-RAS which is free, etc.) were used, which reflected a practical approach that did not rely solely on any single platform.

2.13 ETHICAL CONSIDERATIONS

All data used were obtained from publicly accessible and authorized sources. No Personal or sensitive data were used, and all maps respected environmental and professional data ethics

CHAPTER FOUR

RESULTS

The hydrological and hydraulic investigations carried out along the Temboga Road provided crucial insights into the challenges and opportunities associated with the road and how it affected the people living in the environ. The accurate analysis of catchment areas gave us a number of unique attributes of the area including the Quantity of runoffs, runoff flow, rainfall intensity, and drainage requirements required to appropriately manage the disturbing storm water in Temboga Road, revealing several key points that are noteworthy.

4.1 CAUSES OF FLOODING AND EROSION IN THE PROJECT AREA

The study confirmed that the steep terrain, with elevations ranging between 37m and 55m above sea level, results in high-velocity surface runoff. Inadequate or completely absent drainage infrastructure has allowed storm water to accumulate on the roadway, leading to erosion of the road and its environment, weakening of the road, and overtopping of the road surface. In certain catchments, the calculated Froude number largely exceeded 1, indicating supercritical flow conditions that intensify erosion.

4.2 ADEQUACY OF THE PROPOSED HYDRAULIC STRUCTURES

The design of roadside drains, culverts, stilling basins and turn-out drains was tested against peak runoff conditions for a 25-year return period. The hydraulic analyses demonstrated that the proposed structures (e.g., 1.8 m × 1.8 m × 0.2m drains and box culverts) have sufficient capacity to handle design flows, with storm water velocities maintained within safe limits. The use of energy-dissipating structures such as stilling basins and catch pits is essential to reduce erosive forces before discharging into the closest receiving water body (Ikpoba river). This ensures both safety and sustainability of the drainage system.

Results Summary of Catchments Contributing Runoff to The Roads Under Hydrological Investigation with Their Flow Direction Moving Towards the Naturally Occurring Low Plain.

Table 4.2a: Result Summary for All contributing water Catchments

Catchments	Area (km^2)	Catchment hydraulic length (km)	Catchment Slope (%)	Time of Concentration Tc (hr)	Rainfall Intensity (mm/hr)	Quantity runoff Q (m^3/s)
SC1	0.880	1.840	0.028804	0.600459	113.4051	15.08963
SC2	0.200	0.983	0.054934	0.355395	161.688	4.901874
SC3	0.510	1.630	0.039264	0.637384	115.6911	8.94385
SC4	0.290	1.840	0.035326	0.737476	121.8878	5.358121
SC5	0.120	0.836	0.066986	0.288569	174.9754	3.182824
SC6	0.150	0.897	0.06466	0.31219	170.2786	3.871737
SC7	0.380	1.330	0.043609	0.507483	107.649	6.200803
SC8	0.170	0.657	0.070015	0.224452	187.7243	4.837532

Table 4.2b: Summary result for the hydraulic analysis of Temboga Road and the Recommended Drainage systems

CHAINAGE FROM	CHAINAGE TO	LENGTH	SECTION TYPE	CATCHMENT CONTRIBUTING FLOW	TOTAL RUNOFF FLOW, Q (m^3/s)	CALCULATED DRAIN SIZE	ADOPTED SIZE	CALCULATED CULVERT SIZE
0+000	0+780	780m	U DRAIN	-	-	0.75mx0.75mx0.15m	0.75mx0.75mx0.15m	-
0+780	1+390	610m	U DRAIN	SC1	15.0896	0.9m x 0.9m x 0.15m	0.9m x 0.9m x 0.15m	-
1+390	1+540	150m	U DRAIN	SC1, SC2, SC3	28.9353	1.2m x 1.2m x 0.15m	1.2m x 1.2m x 0.15m	

CHAINAGE AT	SECTION TYPE	CATCHMENT CONTRIBUTING FLOW	TOTAL RUNOFF FLOW, Q (m^3/s)	CALCULATED DRAIN SIZE	ADOPTED SIZE	CALCULATED CULVERT SIZE
1+540	Single Box Culvert	-	-	-	1.5m x 1.5m x 1.5m	1.5m x 1.5m x 1.5m

CHAINAGE FROM	CHAINAGE TO	LENGTH	SECTION TYPE	CATCHMENT CONTRIBUTING FLOW	TOTAL RUNOFF FLOW, Q (m^3/s)	CALCULATED DRAIN SIZE	ADOPTED SIZE	CALCULATED CULVERT SIZE
1+540	1+733	193m	U DRAIN	SC8,SC7, SC6, SC5,SC4	23.4510	1.2m x 1.2m x 0.15m	1.2m x 1.2m x 0.15m	-
1+733	1+940	207m	U DRAIN	SC8,SC7, SC6, SC5	18.0929	1.2m x 1.2m x 0.15m	1.2m x 1.2m x 0.15m	-
1+940	2+080	140m	U DRAIN	SC8,SC7, SC6	14.9101	1.2m x 1.2m x 0.15m	1.2m x 1.2m x 0.15m	-
2+080	2+343	263m	U DRAIN	SC8,SC7	11.0383	1.0m x 1.0m x 0.15m	1.0m x 1.0m x 0.15m	-
2+343	2+592	249m	U DRAIN	SC8	4.8375	0.9m x 0.9m x 0.15m	0.9m x 0.9m x 0.15m	-
2+592	2+833	241m	U DRAIN	-	-	0.75m x 0.75m x 0.15m	0.75m x 0.75m x 0.15m	-

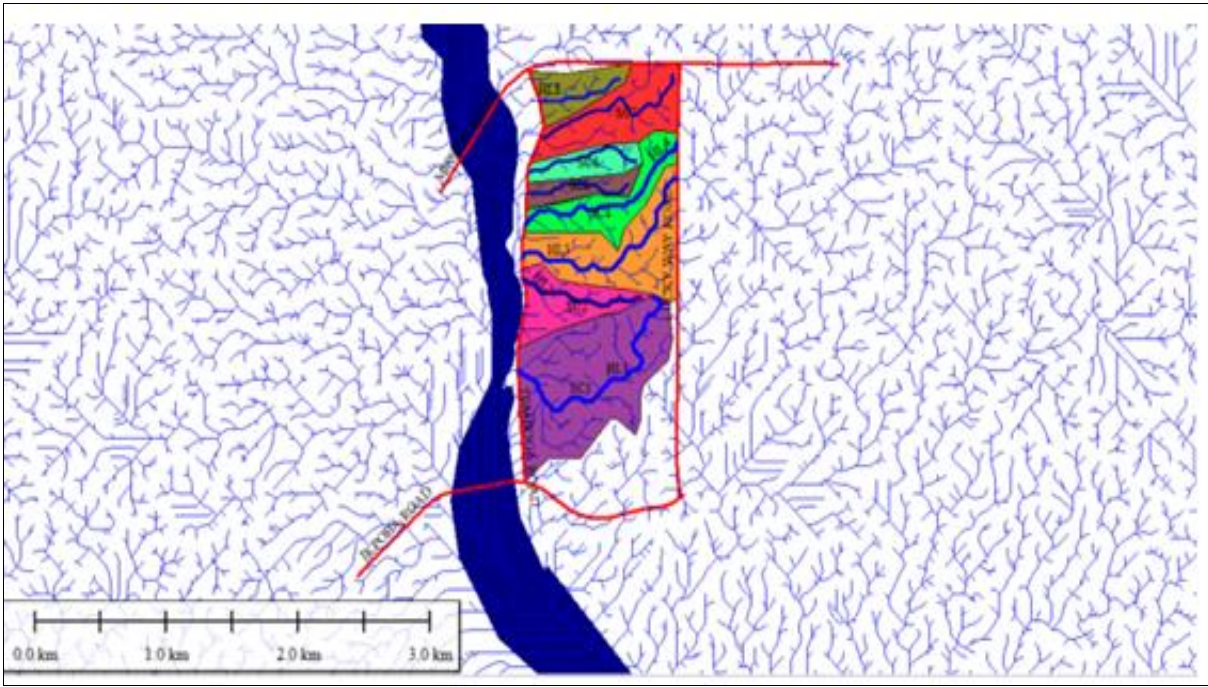

Figure 4.2a: General Plan Layout of Catchments Contributing Flow to Temboga Road

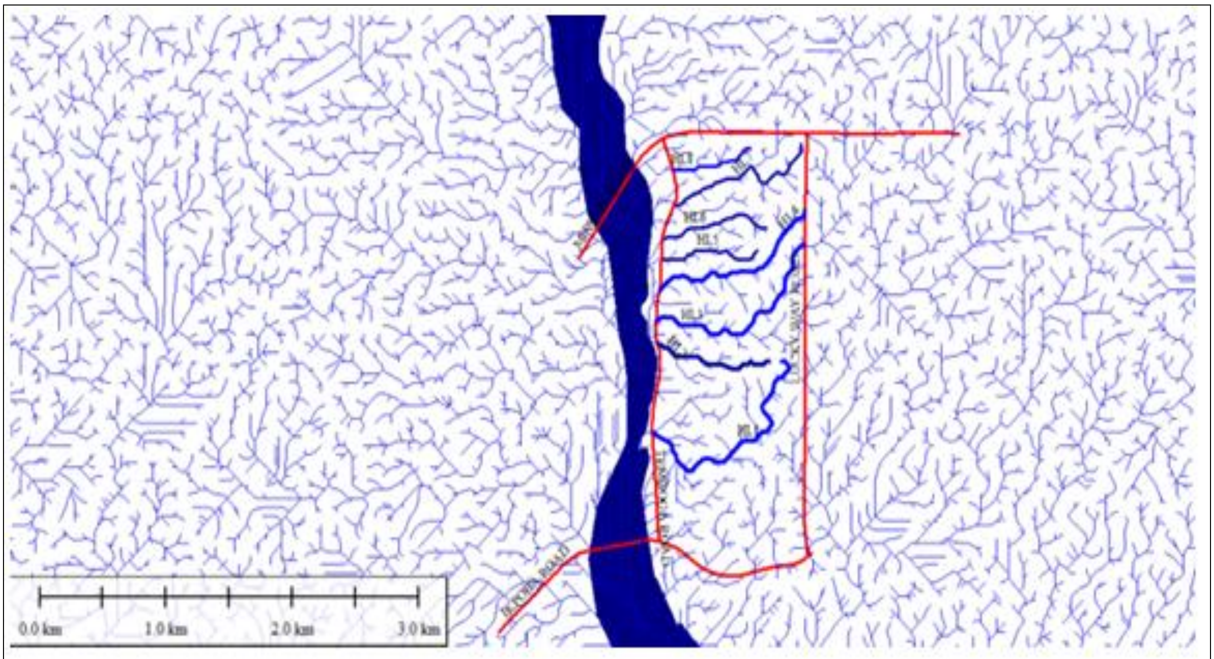

Figure 4.2b: General Plan Layout of Drainage Networks of Catchments contributing runoff to Temboga Road.

Fig 4.2c: Hydrological analyzed Temboga catchments visualized on Google Earth Pro

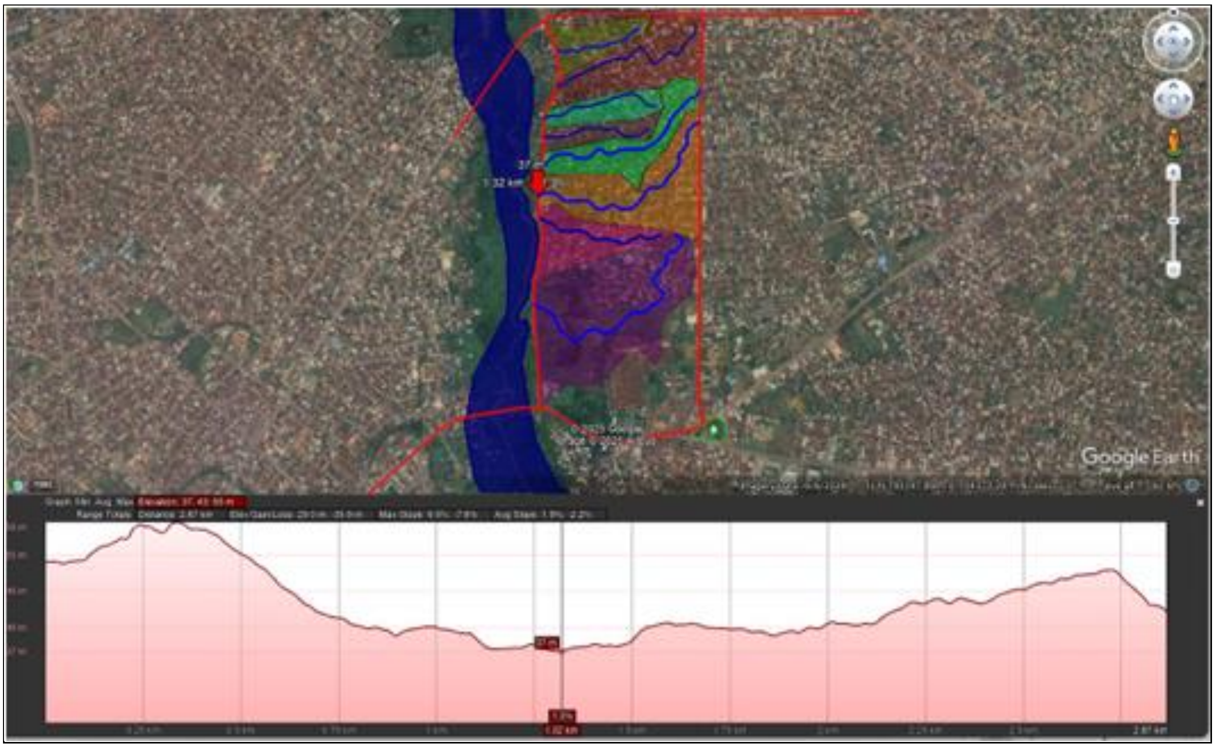

Figure 4.2d: Satellite imagery showing elevation profile of Temboga Road (Steep Terrain).

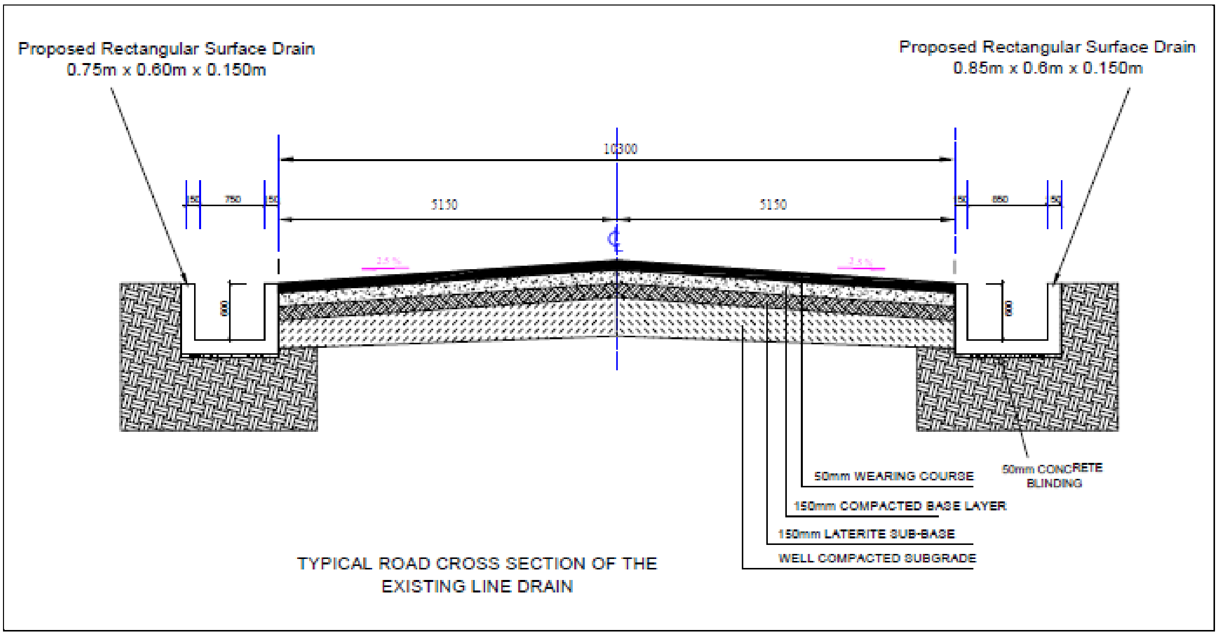

Figure 4.2e: Typical Road Cross Section of the Existing Line Drain.

The cross section above illustrates the existing road profile with proposed rectangular surface drains on both sides to improve runoff management. The road consists of a 50mm wearing course, 150mm compacted base layer, and 150mm lateritic sub-base resting on a well-compacted subgrade. The surface drains (0.75m *0.60m*0.15m and 0.85m*0.60*0.15m) are provided to channel stormwater effectively, ensuring pavement durability and minimizing erosion along Temboga Road.

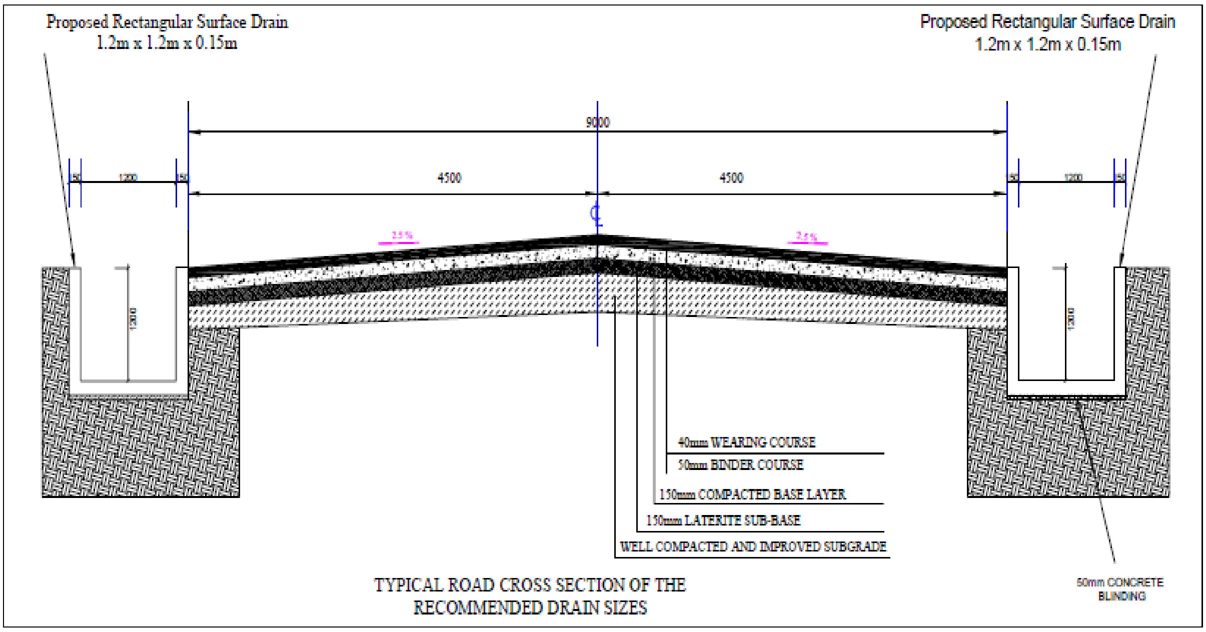

Figure 4.2f: Typical Road Cross Section of the Recommended Drain Size

The section above represents the improved road design with optimized road drainage dimensions to enhance surface runoff control. The pavement comprises a 40mm wearing course, 90mm binder course, 150mm compacted base layer, and 150mm lateritic sub-base on a well-compacted and improved subgrade. The proposed rectangular surface drains (1.2m*1.2m*0.15m) on both side ensures efficient stormwater discharge, promoting pavement longevity and minimizing flooding along Temboga Road

Figure 4.2g: Aerial view showing beginning of Temboga road captured using Phantom 4 Pro

Figure 4.2h: Aerial view showing a section of Temboga road captured using Phantom 4 Pro

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

This study has demonstrated that GIS is a powerful, cost-effective, and integrative tool for hydrological investigation and infrastructural planning. By applying GIS-based watershed and drainage modeling along Temboga Road, it was possible to quantify runoff, delineate catchments, and evaluate drainage adequacy, thereby providing spatial intelligence for engineering design. The findings affirm that sustainable infrastructure in flood-prone environments like Benin City must be grounded in geospatial hydrological analysis to ensure durability, safety, and environmental compatibility.

From the analysis and field observations carried out during the course of this study, it was discovered that the design dimensions obtained from the GIS-based hydrological analysis were larger than the actual measurements observed on ground. This variation can be attributed to several factors encountered during both data acquisition and processing stages.

One major factor responsible for this discrepancy is the accuracy of the Digital Elevation Model (DEM) used in generating the hydrological parameters. Although DEM data provides an effective representation of terrain morphology, its vertical and horizontal resolution can influence the precision of derived features such as slopes, contours, and drainage boundaries. Minor interpolation errors or inconsistencies in elevation values may lead to exaggerated design dimensions when compared with real-world measurements.

The flight altitude limitation of 30 meters imposed by the no-fly zone regulation reduced the spatial extent and precision of aerial mapping. Temperature-induced drone instability and limited ground control points also contributed to minor discrepancies between the digital model and on-ground data. Despite these variations, the GIS-based analysis effectively delineated drainage patterns and provided useful information for hydrological and infrastructural assessment along Temboga Road, Benin City.

5.2 RECOMMENDATIONS

In designing hydraulic structures, the required discharge capacity of every drainage system including channels and culverts of the calculated dimensions will be determined from Intensity-Duration-Frequency analysis and catchments characteristics of the drainage area. Design runoff return period of 25-years will be adopted at this final state for this design. The sections of all hydraulic structures will be appropriately sized for their respective flows, and finally designed for structural stability. A total number of drains and culverts with catch pits will be installed to eradicate the flooding issues in the area computed in our study are required to convey runoff to a stilling basin to dissipate energy flow of water runoffs.

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