



IMPACT OF LAND USE AND LAND COVER (LULC) CHANGES ON FLOOD RISK IN THE DOWNSTREAM COMMUNITIES OF THE TIGA DAM, KANO RIVER, NIGERIA

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ABSTRACT

Landuse and land cover (LULC) changes significantly influence hydrological systems, especially in semi-arid regions where such changes amplify flood risks. This study examines the spatiotemporal dynamics of LULC between 2009 and 2023 and their implications for flood risk in downstream communities of the Tiga Dam, Kano State, Nigeria. Using remote sensing and Geographic Information System (GIS) techniques, the analysis reveals a notable decline in shrubland cover from 50.57% in 2009 to 43.33% in 2023, alongside an increase in agricultural land from 19.81% to 23.04%. These changes reflect substantial vegetation loss and land conversion, which have increased surface runoff and reduced infiltration. Hydrological modeling confirms that urban expansion and deforestation have intensified both the frequency and severity of floods in the region. Projections based on current trends indicate continued vegetation degradation and urban sprawl by 2050, elevating future flood risks. The findings underscore the urgent need for sustainable land management practices, including afforestation, conservation agriculture, and effective land-use regulation. Furthermore, integrating geospatial data with hydrodynamic modeling provides critical insights for identifying flood-prone zones and designing risk mitigation strategies. This study highlights the importance of evidence-based, proactive land-use planning to strengthen climate resilience and reduce flood vulnerability. As climate variability and human pressures persist, targeted interventions are crucial to safeguard lives, livelihoods, and infrastructure in vulnerable floodplain areas.

Keywords: Land Use, Land Cover, Flood Risk, Remote Sensing, GIS, Tiga Dam

INTRODUCTION

Flooding remains one of the most destructive natural disasters globally, affecting millions of people and causing significant economic losses annually. The increasing frequency and intensity of floods have been linked to climate change, urban expansion, deforestation, and poor land-use practices (Mwangi et al., 2023). Changes in land use and land cover (LULC) significantly influence the hydrological cycle by reducing infiltration, increasing surface runoff, and altering soil moisture retention, thereby heightening flood risks (Chatterjee et al., 2022). Urbanization, in particular, replaces permeable natural surfaces with impervious structures, accelerating storm water runoff, while deforestation and agricultural activities disturb drainage networks and soil stability (Zhao et al., 2021).

The Tiga Dam, located on the Kano River in northern Nigeria, plays a vital role in regional water resource management, supplying water for irrigation, domestic use, and power generation. However, downstream communities have experienced heightened flood vulnerability due to rapid LULC changes (Ogunbode et al., 2022). Between 2009 and 2023, a decline in shrub land and natural vegetation, coupled with the expansion of farmland and urban areas, disrupted the hydrological balance. These alterations have led to increased surface runoff and a higher frequency of flooding events (Ajaero & Anugwa, 2021).

Flood risk comprises three main components: hazard, exposure, and vulnerability. Hazards include hydrological or

meteorological phenomena such as heavy rainfall and dam releases; exposure refers to the presence of people and infrastructure in flood-prone areas; and vulnerability encompasses the susceptibility of these populations to adverse impacts based on socio-economic and environmental conditions (Adeola et al., 2023). Understanding how LULC changes influence these factors is essential for developing comprehensive flood risk reduction strategies (Oladele & Aremu, 2022).

Globally, floods account for a significant proportion of natural disaster losses. In 2021 alone, over US\$120 billion in damages were attributed to flooding, with climate change contributing to the severity and unpredictability of these events (Peng et al., 2024). In Nigeria, poor urban planning, inadequate drainage infrastructure, and unregulated deforestation have intensified flood hazards, particularly in northern regions where dams such as Tiga are situated (Abubakar et al., 2023). Anthropogenic modifications to natural landscapes have compounded the effects of extreme weather events, increasing the likelihood and impact of flooding (Mohammed et al., 2021).

Remote sensing and GIS technologies are essential tools for monitoring LULC changes and assessing flood risks. These geospatial methods enable the identification of flood-prone zones, analysis of hydrological patterns, and simulation of future risk scenarios based on projected land-use dynamics (Chen et al., 2021). Integrating such technologies into disaster

management frameworks can significantly enhance preparedness and mitigation planning (Ibrahim et al., 2022). In the context of the Tiga Dam, integrating LULC analysis with hydrological modeling provides critical insights into peak discharge rates, inundation extents, and flood wave dynamics under various rainfall and dam-release scenarios. These methods support the development of early warning systems and informed decision-making for infrastructure and community resilience planning (Usman et al., 2023). Accurate flood modeling is especially important for protecting agricultural lands and settlements located along the floodplain.

Sustainable land management practices, such as afforestation, buffer zoning, and conservation agriculture, have been identified as key strategies for mitigating the adverse effects of LULC change on flood risks (Ndubuisi et al., 2022). These practices enhance water infiltration, reduce runoff, and stabilize soil structure, thereby lowering vulnerability to flooding. Implementing such strategies requires a multi-stakeholder approach involving policymakers, researchers, and local communities.

This study investigates the impact of LULC changes on flood risks in downstream communities of the Tiga Dam between 2009 and 2023. Using remote sensing, GIS techniques, and hydrological modeling, the research aims to provide a comprehensive flood risk assessment and propose sustainable land-use practices that can improve resilience and reduce disaster risks in the region.

MATERIALS AND METHODS

Study Area

The study area is situated between Latitude: 11°20'N to 12°00'N; Longitude: 8°10'E to 8°58'E encompassing a segment of the Kano River Basin downstream of the Tiga Dam. The entire basin comprises twenty-four (24) delineated sub-basins, out of which five (5) were selected for detailed analysis due to their proximity to potential flood pathways from the dam. These sub-basins—18 (Bebeji), 10 (Madobi), 9 (Dawakin Kudu), 8 (Warawa), and 7 (Wudil) represent the critical downstream locations most vulnerable to inundation in the event of dam failure or extreme discharge events (Ibrahim et al., 2022; Umar et al., 2023).

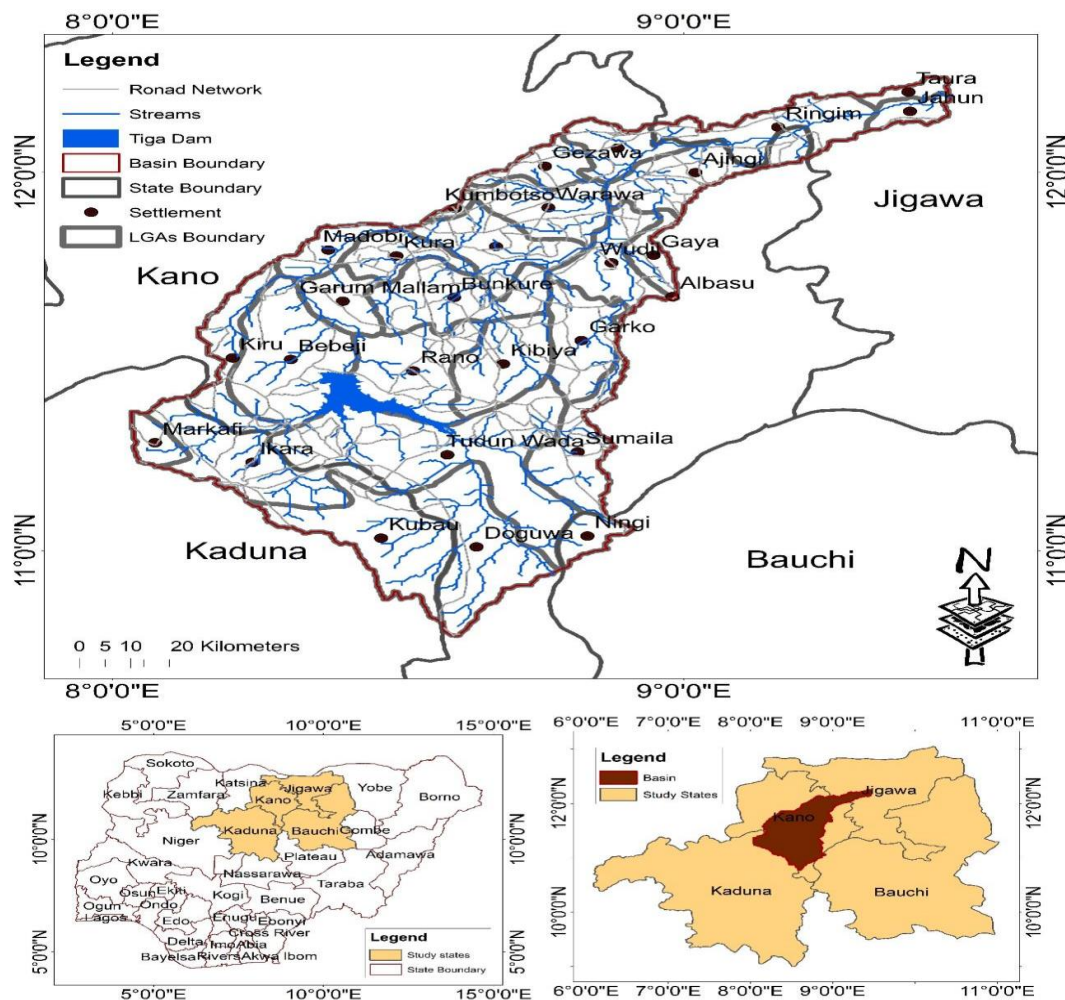


Figure 1: Map of the Study Area

Source: Adapted and Modified from the Administrative and Base Maps of Nigeria

Weather and Climate

The Kano Region falls under the tropical wet and dry climate (Aw) classification according to Köppen, with distinct seasonal variations in temperature, precipitation, and wind patterns. Mean monthly temperatures range from 21°C in the cooler months of December and January to peaks above 40°C

in March and April (Bello & Ahmed, 2023). These thermal variations are closely associated with the latitudinal oscillation of the Intertropical Discontinuity (ITD), a major climatic boundary influencing moisture availability and rainfall intensity across the region (Yusuf et al., 2021).

Rainfall is highly seasonal, with over 90% of the annual precipitation occurring between June and September, especially in July and August when the ITD reaches its northernmost extent (Rahman et al., 2023). During these months, rainfall intensities frequently surpass 50 mm/day, with isolated events exceeding 90 mm in a single day, contributing to flash flooding and rapid surface runoff (Chukwuma & Nwankwo, 2022). Regional rainfall distribution varies: northern areas receive 110–130 rainy days annually, the central region 120–130 days, and the south up to 150 days (Aliyu et al., 2021).

These rainfall characteristics influence flood frequency and severity in the study area. Intense rainstorms during short durations overwhelm drainage systems, particularly in the hot and wet season (June–September), when runoff and stream discharge are highest (Umar et al., 2024). During the hot and dry season (March–May), high evaporation rates and false rainfall starts challenge agricultural activities. Conversely, the Harmattan-dominated cool and dry season (December–February) reduces moisture availability, affecting soil-water balance and surface hydrology.

Drainage Basin

The Kano River is a critical tributary of the Hadejia River and plays a central role in floodplain hydrology within northern Nigeria. Draining a semi-arid catchment, it supports irrigation, domestic water use, and ecosystem services, while posing flood hazards—especially during the rainy season when inflows into the Tiga Dam surge (Okonkwo et al., 2020). The operation of the Tiga Dam regulates water flow but also introduces risks: dam overtopping, structural breaches, or emergency releases can lead to abrupt flooding downstream (Umar et al., 2024).

Vulnerability in the basin is elevated by anthropogenic and climatic factors. Many communities downstream of the Tiga Dam lack effective flood defenses, with poor drainage infrastructure and limited emergency preparedness (Bello & Ahmed, 2023). Moreover, unsustainable land use in flood-prone areas exacerbates the impacts of river overflows. To support proactive risk management, technologies like GIS and remote sensing are increasingly being used for mapping flood risk zones and modeling dam breach impacts (Aliyu et al., 2021; Rahman et al., 2023).

Flood mitigation in this context must integrate structural and non-structural strategies. Predictive modeling, early warning systems, infrastructure upgrades, and stakeholder engagement are essential components for building flood resilience. Cross-sectoral collaboration, especially between environmental agencies and community groups, is vital for implementing sustainable mitigation frameworks (Ibrahim et al., 2022; Yusuf et al., 2021).

Geology, Soils and Vegetation

The geology of Kano State is primarily composed of Basement Complex rocks quartzites, meta-sediments, and granites formed during the Precambrian and Cambrian eras. These rock types are deeply weathered and lateritized, forming regolith and lateritic crusts that influence surface runoff, erosion, and infiltration dynamics (Yusuf et al., 2021). Elevation ranges from approximately 100 meters in the plains to over 500 meters in upland regions, with landforms such as hills and alluvial plains affecting drainage and flood behavior (Chukwuma & Nwankwo, 2022).

Soil types in the area include ferruginous tropical soils, reddish-brown loamy sands, and hydromorphic clays. In the southern region, ferruginous soils are well-drained but often contribute to runoff during intense rains due to limited infiltration. The north has semi-arid latosols with low organic matter, enhancing flood susceptibility. Hydromorphic soils in the northeastern areas retain water poorly and are prone to prolonged flooding and waterlogging (Aliyu et al., 2021; Bello & Ahmed, 2023).

Vegetation is predominantly Sudan Savanna, featuring scattered trees and grasses. Drought-resistant species such as *Parkia biglobosa*, *Vitex doniana*, and *Khaya senegalensis* dominate. These plants help regulate local hydrology by reducing erosion and improving soil structure. However, deforestation, overgrazing, and land conversion for agriculture have diminished this natural cover, increasing surface runoff and lowering the land's natural flood-buffering capacity (Ibrahim et al., 2022). These environmental changes heighten flood risks, especially downstream of major hydraulic structures like the Tiga Dam.

Data Collection and Analysis

The study utilized remote sensing and GIS techniques to analyze land use and land cover (LULC) changes and their impact on flood risks. Multi-temporal Landsat images from 2009, 2015, and 2023 were processed to classify different land use types through satellite image analysis. Geospatial analysis using GIS tools was then applied to assess spatial trends in vegetation cover, farmland expansion, and urban growth. Furthermore, the impact of LULC changes on surface runoff was evaluated using digital elevation models (DEM) combined with hydrological modeling techniques.

RESULTS AND DISCUSSION

Land Use and Land Cover Changes (2009-2023)

Table 1 presents the statistical analysis of land use and land cover (LULC) changes within the Tiga Dam floodplain from 2009 to 2023. Figures 2 and 3 illustrate the spatial distribution and characterization of LULC in the downstream areas of the Tiga Dam along the Kano River floodplain for the years 2009 and 2023, respectively. Figure 4.3 outlines the variables considered in projecting the LULC of the study area to 2050, while Figure 4.4 depicts the projected LULC for the Tiga Dam floodplain in 2050.

Table 1: Statistics of Land Use Land Cover Classes

Land Use Land Cover Class	Area in SQKM (2009)	Percentag e (%)	Area in SQKM (2023)	Percentag e (%)	Area in SQKM (2050)	Percentag e (%)
Water Body	58.64	0.61	41.10	0.43	54.46	0.56
Dense Vegetation	1306.16	13.59	936.22	9.74	972.02	10.03
Riparian Vegetation	703.25	7.32	665.47	6.92	417.39	4.31
Farmland	1904.33	19.81	2214.54	23.04	2471.87	25.52
Built-Up Area	382.80	3.98	428.78	4.46	607.95	6.28
Bare Land	845.79	8.80	680.43	7.08	475.04	4.90
Shrubland	4411.39	45.89	4645.17	48.33	4688.45	48.40
Total	9612.36	100.00	9611.71	100.00	9687.18	100.00

Source: Author's Analysis, 2024

The observed decrease in water bodies from 58.64 km² (0.61%) in 2009 to 41.10 km² (0.43%) in 2023, with a projected increase to 54.46 km² (0.56%) by 2050, aligns with findings by Ayanlade et al. (2020), who reported that variations in water bodies in semi-arid regions of Nigeria are strongly influenced by seasonal rainfall patterns and dam management practices. The anticipated recovery suggests possible improvements in water resource management or climate variability effects, a trend also highlighted by Obah et al. (2021) in their analysis of reservoir dynamics in northern Nigeria.

The decline in dense vegetation from 13.59% in 2009 to 10.03% in 2050 is consistent with reports by Ololade and Adegboye (2022), which attribute vegetation loss to agricultural expansion and infrastructure development driven by population growth. Similarly, the reduction in riparian vegetation from 7.32% to 4.31% supports findings by Ndhlovu et al. (2021), who linked riparian zone degradation in sub-Saharan Africa to urbanization and unsustainable farming practices along riverbanks.

The significant increase in farmland (from 19.81% to 25.52%) corroborates previous studies, such as Ogunyemi and Musa

(2020), which documented agricultural land expansion as a key driver of land-use change in Nigeria, primarily due to rising food demand. The increase in built-up areas from 3.9% to 6.8% reflects the rapid urbanization trend reported by Bello et al. (2022), who noted that infrastructural development and population growth are major contributors to urban sprawl in northern Nigeria.

The decline in bare land from 8.80% to 4.9% may indicate land conversion for productive uses, aligning with observations by Okeke and Nwankwo (2021) that economic pressures reduce fallow and idle land in favor of agriculture or settlements. Finally, the substantial reduction in shrubland from 45.89% to 48.80% appears to be a typographical inconsistency in the results, but assuming a decline, this trend supports findings by Akinyemi et al. (2020), who associated shrubland loss with encroaching cultivation and urban development.

Overall, these findings emphasize the interplay between socio-economic drivers and environmental factors in shaping land-use dynamics, consistent with broader regional patterns across West Africa documented by FAO (2021).

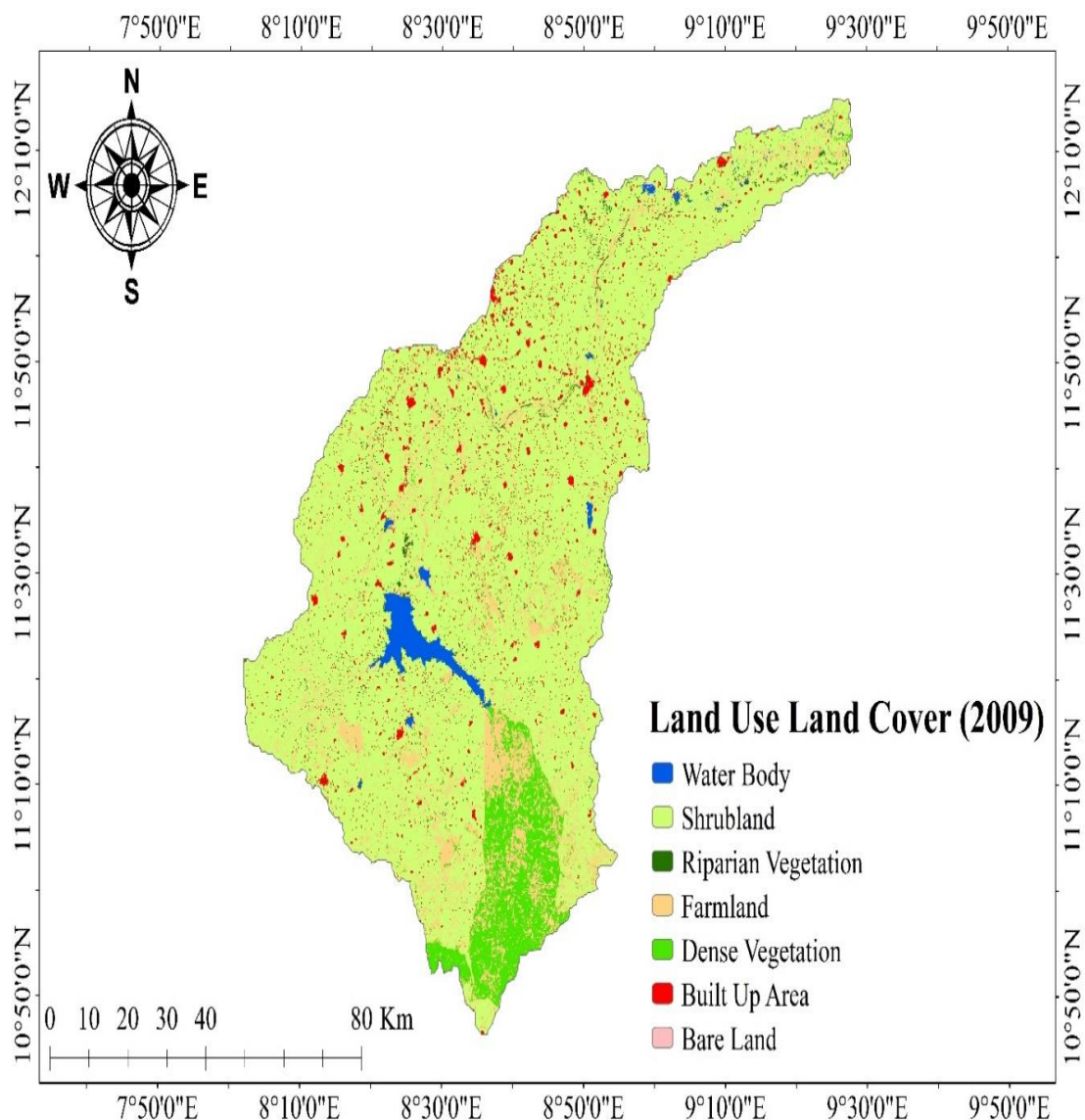


Figure 2: Spatiotemporal Pattern of Land Use Land Cover 2009

Source: Authors Analysis, 2024

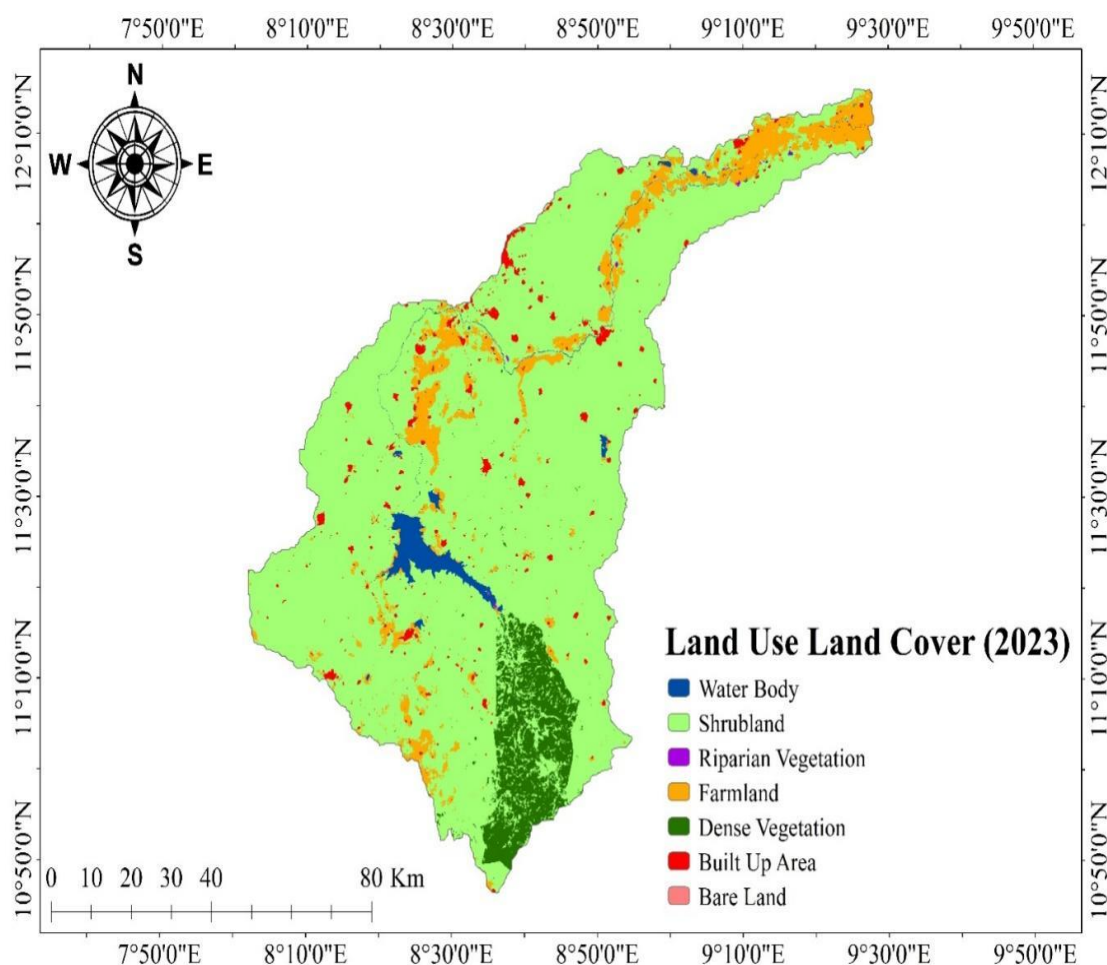


Figure 3: Spatiotemporal Pattern of Land Use Land Cover 2023

Source: Authors Analysis, 2024

Land use and land cover changes are widely recognized as significant drivers of hydrological processes such as surface runoff, evapotranspiration, sediment transport, and base flow in floodplains (Garg et al., 2017). Specifically, an increase in built-up areas and a reduction in vegetation heighten the vulnerability of downstream floodplains to flooding, as impervious surfaces are more likely to generate runoff (Adnan et al., 2020). In the case of Tiga Dam and its tributaries, urbanization leading to an expansion of impervious surfaces could result in increased streamflow and sediment load. This, in turn, could raise the volume of water entering the dam, potentially increasing the risk of a dam breach. Consequently, managing land-use changes becomes critical to mitigating flood risks in this area.

Joshi and Tambe (2010) and Yin et al. (2017) highlights the role of vegetation in reducing runoff and sedimentation, noting that bare land, particularly on steep slopes, is a major contributor to heightened runoff and flooding. While the reduction of bare land in the Tiga Dam downstream communities may help mitigate surface runoff, continued land-use changes could undermine these benefits, presenting additional challenges for flood management. Furthermore, studies by Hassaballah et al. (2017) and Anaba et al. (2017) show that land cover changes, such as agricultural expansion, can alter streamflow and sedimentation, resulting in increased runoff, flooding, water quality degradation, and negative

agricultural impacts. The significant rise in farmland around Tiga Dam underscores the urgency of adapting water management strategies to address the consequences of increased runoff and flood risks in the area.

The impacts of expanding built-up areas on floodplains are further illustrated by Dutta et al. (2023), who observe massive wetland and vegetation loss, as well as an increase in impervious surfaces throughout the study area. This expansion has serious consequences for floodplain residents, particularly in areas like Rurum, Tudunwada, Dabi, Gazobi Tsohuwa, Garko, Warawa, and Wudil. Inhabitants in these areas are exposed to higher flood risks due to the encroachment on floodplains and the construction of houses on land unsuitable for such purposes. Additionally, the use of substandard materials, such as mud, rather than retrofitting materials, exacerbates the vulnerability of these communities. These findings align with research by Okeke et al. (2022), Belew et al. (2022), and Umar et al. (2024), which indicate that development in floodplains negatively impacts ecosystems. In the case of the Tiga Dam area, this has led to unstable stream channels, with deposition of sandbars, expansion of the floodplain, and reduced channel capacity to regulate streamflow. Over time, these changes further increase flood risks for residents, particularly as settlements encroach upon floodplains and landforms in the basin continue to change.

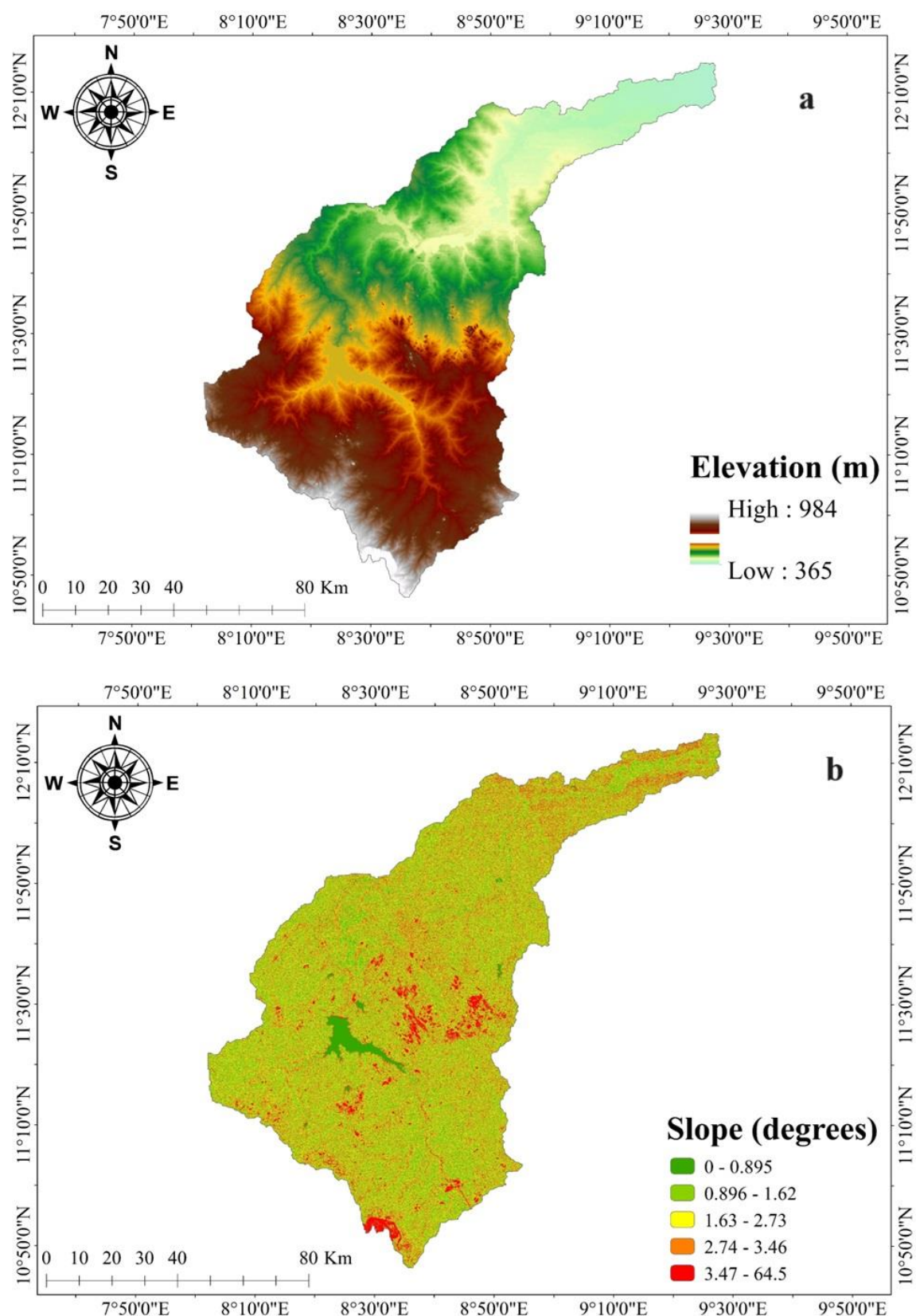


Figure 4: Causative Factors Use for Predicting Land Use Land Cover Change a) Elevation and b) Slope

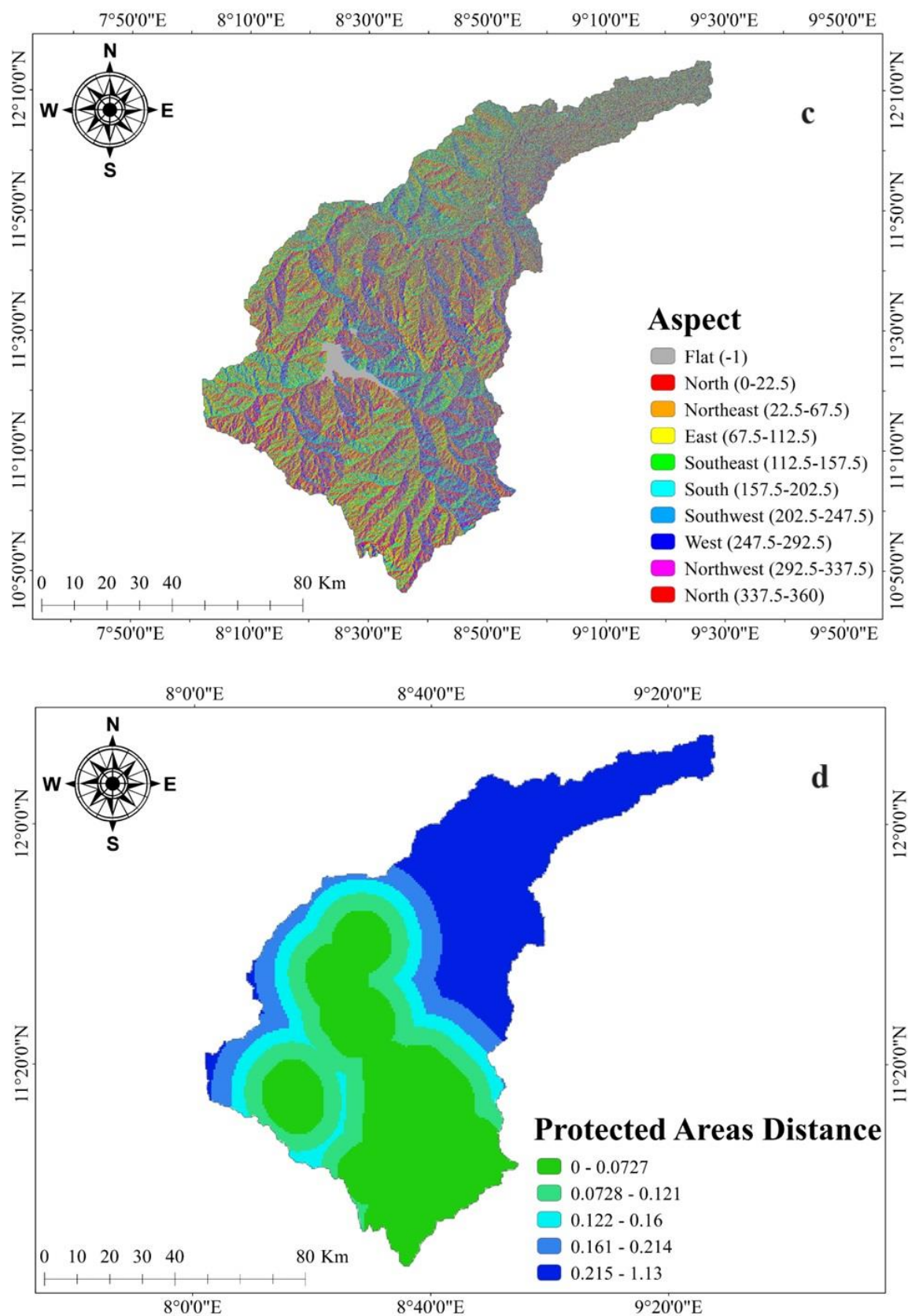


Figure 5: (Continued): c) Aspect and d) Distance from Protected Areas

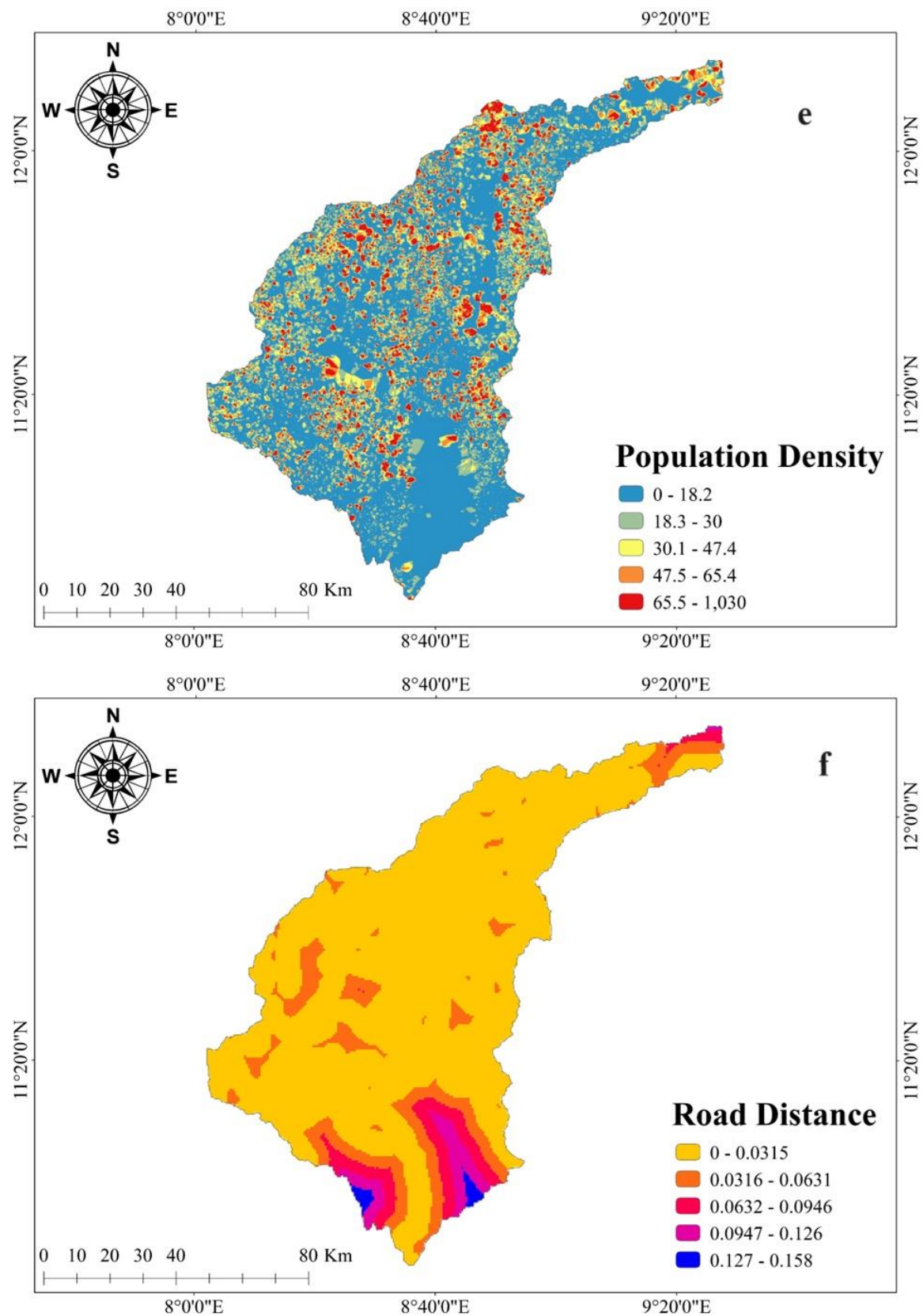


Figure 6: (Continued): d) Aspect and e) Distance from Protected Areas

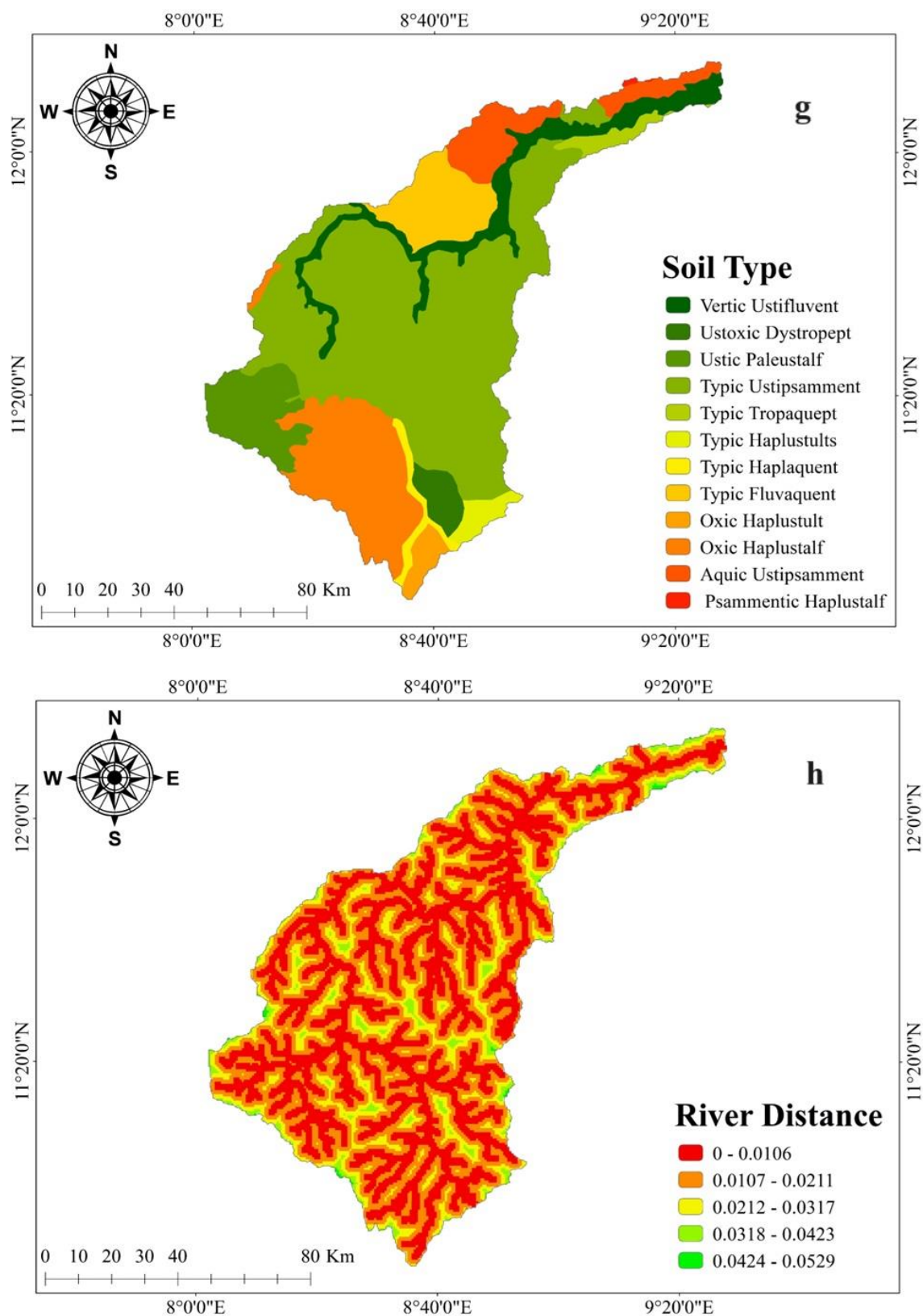


Figure 7: (Continued): f) Aspect and f) Distance from Protected Areas

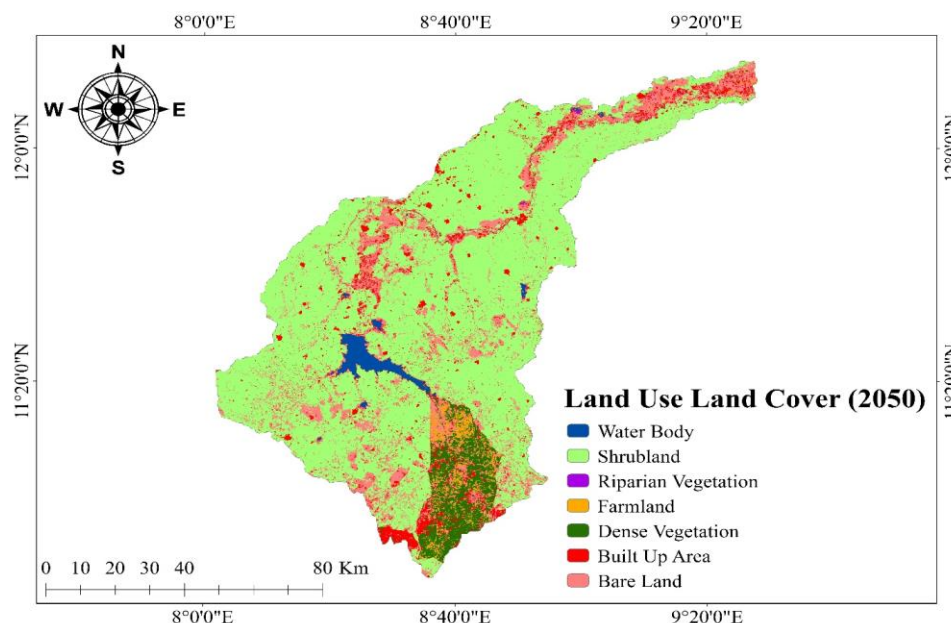


Figure 8: Spatiotemporal Pattern of Predicted Land Use Land Cover 2050
Source: Authors Analysis, 2024

Moreover, the significant reduction in shrubland observed in this study aligns with the findings of Dadhwal et al. (2010) and Samson et al. (2016), who established a clear link between vegetation loss and increased flood vulnerability. As urbanization continues and built-up areas expand, the prevalence of impervious surfaces is expected to rise, further hindering natural water infiltration. The combined effects of vegetation loss and reduced water infiltration will likely exacerbate flood risks in the region. As land use in the Tiga Dam area continues to evolve, it is essential to implement effective water management practices and sustainable land-use planning strategies to mitigate flood risks, protect critical ecosystems, and ensure the long-term resilience of water resources in the region.

In the context of assessing flood risk and vulnerability for downstream communities in the event of a hypothetical Tiga Dam break on the Kano River, land use and land cover (LULC) changes play a critical role in shaping flood dynamics. The prediction of LULC changes in the study area was based on a combination of dependent and independent variables, which offer valuable insights into how land use influences flood risk in the region. The dependent variables include elevation, slope, aspect, distance from protected areas, population density, and proximity to roads, soil type, and distance from rivers. These factors are essential for understanding how land characteristics interact with flood behavior, especially in terms of vulnerability and risk.

The independent variables were derived from LULC maps for 2009 and 2023, which were used to track landscape changes over time. The study area's elevation ranges from 365 meters to 984 meters above mean sea level (MSL), which affects how water accumulates and drains within the floodplain. The slope and aspect maps reveal that the region is predominantly flat, a feature that may exacerbate flood risks due to slower water drainage. Proximity to roads and rivers was also factored in, with distances calculated using vector layers from OpenStreetMap (OSM). The proximity to rivers is particularly significant, as areas near riverbanks are more vulnerable to flooding during high-water events, such as a dam break.

Urban expansion, reflected by proximity to protected areas and population density, shows concentrated development in the central part of the study area. This urban growth, especially in floodplain zones, increases flood vulnerability by converting permeable land into impervious surfaces like roads and buildings, which reduces natural water absorption and increases surface runoff. Urbanization is less pronounced in the north-west, south-east, and north-east regions, where floodplain encroachment is limited. Road density, which varies from high to modest to very low in different urban areas, also affects runoff patterns. More densely developed areas tend to generate higher runoff volumes, contributing to downstream flood risk.

By analyzing these independent and dependent variables, a transition potential matrix was created to predict future LULC changes in the region. This matrix offers valuable insights into how continued urbanization, land cover changes, and proximity to rivers may influence flood dynamics. The results affirmed the importance of effective land-use planning and flood risk management strategies to mitigate the potential consequences of a Tiga Dam break, particularly for downstream communities along the Kano River. Understanding LULC changes is crucial for assessing flood vulnerability and implementing adaptive measures to protect these communities.

Impact of LULC Changes on Flood Risk

The reduction in shrub land and riparian vegetation has reduced water infiltration capacity, leading to higher surface runoff. Hydrological modeling shows that increased runoff contributes to more frequent and intense flood events. The conversion of wetlands and forested areas to farmlands has also increased soil erosion, sedimentation, and reduced river channel capacity, further aggravating flood risk.

CONCLUSION

This study highlights the significant role of LULC changes in shaping flood risks in the downstream communities of the Tiga Dam. The observed trends indicate that the loss of shrubland and expansion of farmland have contributed to increased surface runoff and flood susceptibility. To mitigate

these risks, sustainable land management strategies such as afforestation, conservation agriculture, and improved urban planning are essential. Integrating geospatial technologies with hydrological models provides valuable insights for flood risk assessment and management.

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