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Geospatial Hydrological Analysis for Selecting Potential Water Reservoirs for Innovative Planning and Management for Resilient Agriculture and Food Security in Kogi State

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Abstract **Original Research Article**

Geospatial technology, with its most advanced and cutting-edge tools, has transformed watershed study by providing spatial data for characterizing and modeling watershed characteristics. This study used geospatial hydrological modeling to characterized geohydrological systems in order to better understand the hydrological dynamics and potential point locations for locating water reservoirs. The approaches used include statistical computation of land resources using Sentinel 2 in Google Earth Engine, as well as spatial analysis of hydrological systems utilizing digital elevation model data for stream network analysis. A multi-criteria decision analysis was used to identify and choose potential reservoir sites, taking into account topography, stream order, catchment area, and slope. These locations were chosen as strategic points for prospective water harvesting structures based on their hydrological characteristics and potential storage capacity. Watershed hydrological features are influenced by a variety of elements, including topography, land use, soil type, geology, and climate. This study clearly identified and delineated eighteen (18) prospective watersheds in the state, ranging in area from 204.77 to 4159.74 Km2 and covering a total of 20,592.31 Km2. More than half (50%) of these watersheds had circularity ratios between 0.4 and 0.5, indicating irregular shape, moderate run-off, and high permeability. The streams in the area feature a dendritic network that flows primarily NE-SW, in conformity with the Nigerian regional lineament, demonstrating structural control and acting as conduits for groundwater recharge. The tectonic pressures that formed the failed triple-arm rifting system, which resulted in the Niger and Benue river valleys and sedimentary basins, have had a significant structural influence in these places. The land resources in the area suggest that forests dominated the state, covering 15694.2366 km2. The prospective watersheds in the state have the ability to irrigate approximately 2,271.23km2 of agricultural land. The result also revealed that twelve (12) secondary watersheds were located at the confluence, with sizes ranging from 0.006 to 337.53 Km2 with the capacity to irrigate 718.51 km2 of agricultural land. These watersheds indicate an abundance of undiscovered water resources throughout the state and near the confluence, necessitating innovative management for enhanced food production. The absence of dams in the state demonstrates underutilization of the hydrological potentials inherent in both the state and the confluence. This study suggests effective collaboration with investors and to deploy cutting-edge watershed management technologies and irrigation infrastructure to support farming clusters in participating communities. As a result, Nigeria's food security position will be greatly improved for sustainability and aid in the attainment of SDGs 2 and 6.

Keyword: Hydrological, geospatial, watershed, agriculture, sustainability, management.

1.0 INTRODUCTION

A watershed is a natural geohydrological unit in which water flows downslope, exits through a network of streams, and is distributed to rivers and reservoirs. It consists of a natural water divider that separates drainage basins and acts as a natural barrier to the planning, management, and expansion of smart irrigation agriculture. Watersheds range in size, shape, and form from small local areas to massive river basins that span entire regions. Several variables influence the watershed's hydrological characteristics, including land use, soil type, geology, geography, and climate. Identifying appropriate watersheds is a prerequisite for implementing planning interventions for agricultural growth. Numerous prospective watersheds and dams in Nigeria are currently being underutilized (Shanono et al (2024). Therefore, innovative watershed planning and management is imperative to resolving watershed-related issues in a sustainable manner to increased food security. Watersheds are natural geohydrological units in which water flows downslope, exits through a network of streams, and is distributed to rivers and reservoirs. It consists of a natural water divider that separates drainage basins and acts as a natural barrier to the planning, management, and expansion of smart irrigation agriculture. Watersheds range in size, shape, and form from small local areas to massive river basins that span entire regions. Several variables influence the watershed's hydrological characteristics, including land use, soil type, geology, geography, and climate. Identifying appropriate watersheds is a prerequisite for implementing planning interventions for agricultural growth. Watersheds and dams also help to support ecosystems by providing reliable water management, boosting food security, and supporting sustainable irrigation agriculture. However, a dearth of data on watersheds and dams has far-reaching global ramifications for irrigation agriculture and food security, especially in developing countries. Climate-induced disruptions like as floods and droughts, combined with poorly managed watersheds and dams, have far-reaching implications and decimate crops, resulting in decreased yields and an increased risk of food shortages. These issues underscore the importance of long-term management and innovation in addressing the challenges that irrigation agriculture faces as a result of effective management. Furthermore, fundamental land and water resource management principles, such as watershed development, catchment and sub-catchment development, should be prioritized to ensure Nigeria's environmental and agricultural sustainability. Kogi State boasts one of Nigeria's most significant hydrological profiles, defined by the confluence of the Niger and Benue rivers at Lokoja, which earned the state the nickname "Confluence State." This river system forms a wide network of streams, floodplains, and wetlands that affect the state's ecosystem, communities, and economy. Aside from these major rivers. The state is richly endowed with geohydrological units suitable for irrigated agriculture. With numerous stream distributions across the state, it is evident that there are enormous water resource potentials that may be used to irrigate vast agricultural lands and ensure food security if properly harnessed. Identifying prospective watersheds is a prerequisite to operationalizing planning interventions for agricultural development for implementing geospatial-based planning interventions to improve and sustain irrigation agriculture in this region to facilitate the attainment of SDG 2 and 6.

2.0 STUDY AREA

Kogi State is situated in Nigeria's North Central geopolitical zone, precisely between latitudes 6°30'N and 8°50'N and longitudes 5°23'E and 7°48'E (Adeyemi, 2019). The state has a total land area of approximately 29,833 square kilometers, ranking as Nigeria's 13th largest state by land mass (National Bureau of Statistics [NBS], 2019). As shown in Figure 1, Kogi borders nine other states: Niger, Kwara, and the Federal Capital Territory to the north; Nasarawa and Benue to the east; Enugu and Anambra to the south; and Edo and Ondo to the west. Kogi State's center location makes it an important transit zone between Nigeria's northern and southern areas.

The state's most distinctive geographical feature is the confluence of the Niger and Benue rivers at Lokoja, the state capital. This confluence point creates a Y-shaped formation visible from several vantage points, including Mount Patti, which rises approximately 458 meters above sea level and offers panoramic views of the surrounding landscape (Audu et al., 2021).

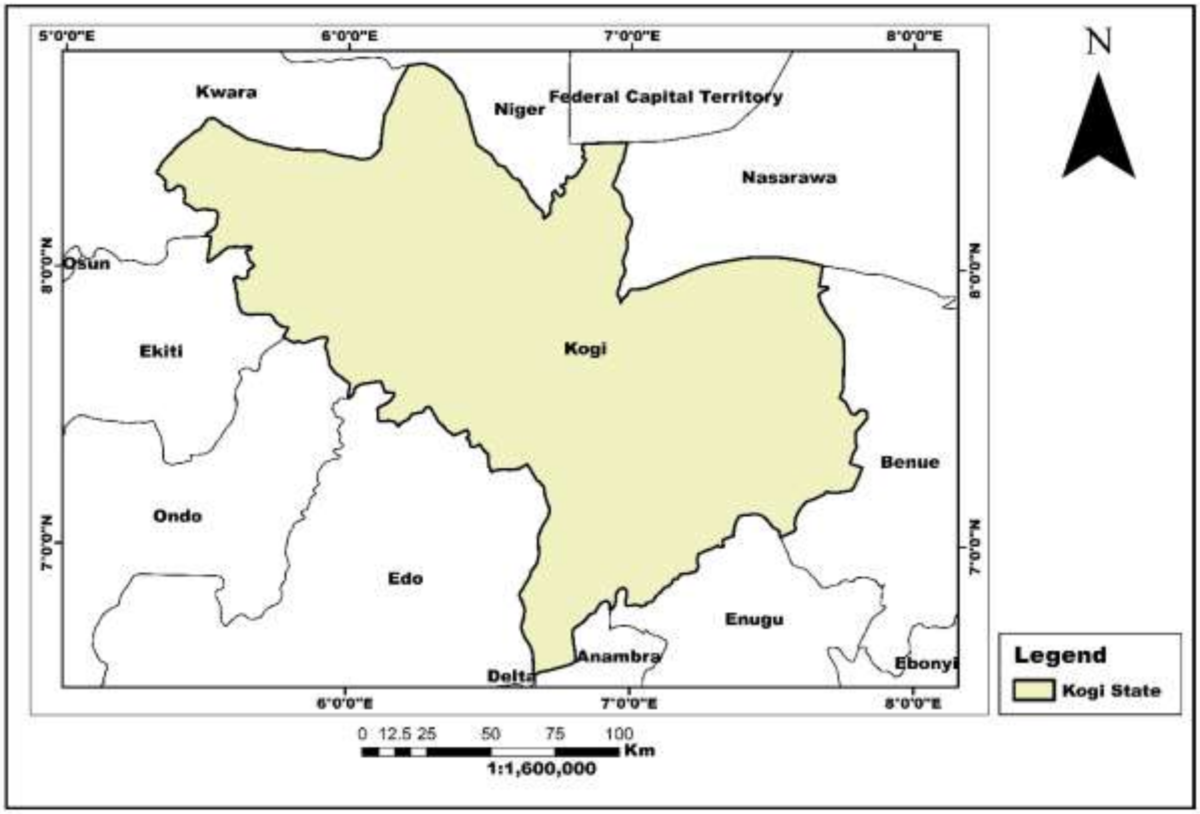

Figure 1: The Study Area (Kogi State).

2.1 Rainfall Distribution and Pattern

The rainfall pattern in Kogi State, depicted in figure 2, shows a range of 26.4 cm to 41.0 cm across different regions. The southwestern and southeastern corners receive the highest precipitation (35-41 cm), while the northern portions, particularly the northeast, experience significantly lower rainfall amounts (26-28 cm). This precipitation gradient aligns with Nigeria's broader north-south rainfall pattern, where southern regions typically receive more rainfall than northern areas. The state's rainfall regime is characterized by a bimodal distribution with peaks in July and September, separated by a brief dry spell known locally as the "August break" (Ifatimehin & Ufuah, 2020). Recent climate change impacts have led to increasing unpredictability in rainfall onset, duration, and intensity, affecting agricultural planning and water resource management. Historical precipitation data from 1990-2020 indicates a slight but significant decrease in total annual rainfall coupled with increased variability and more intense rainfall events (Adewuyi & Olofin, 2023). The confluence area, despite its proximity to major water bodies, does not show exceptionally high rainfall, suggesting that orographic and other meteorological factors play more significant roles in determining precipitation patterns than mere proximity to rivers.

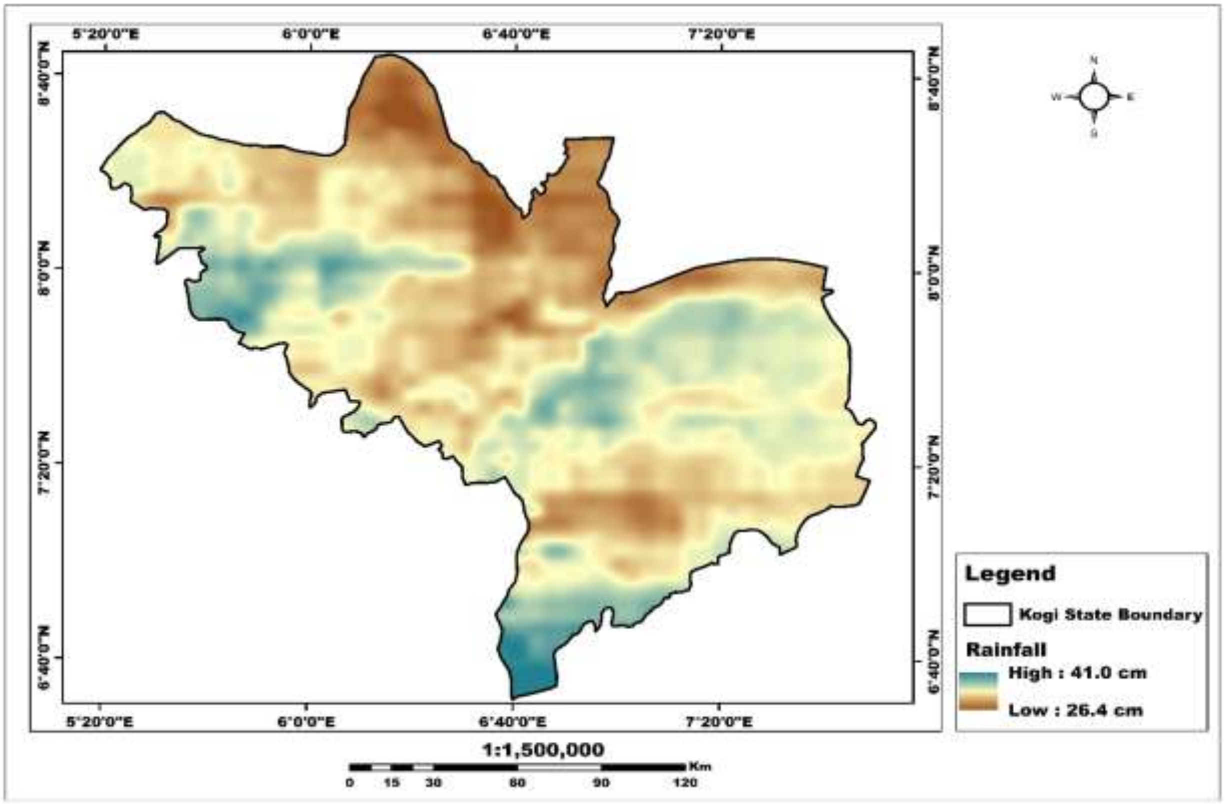

Figure 2: Annual rainfall Distribution in Kogi State

2.3 Temperature Variation

Figure 3 reveals the spatial distribution of temperature across Kogi State, with values ranging from 25.9°C to 35.8°C. The northwestern region and portions of the north-central area experience the highest temperatures (30-35.8°C), while the eastern half of the state enjoys relatively cooler conditions (25.9-29°C). This temperature gradient creates distinct agricultural zones, with heat-tolerant crops dominating the northwestern regions. The state's temperature regime is influenced by several factors, including elevation, vegetation cover, and prevailing winds. The eastern regions' lower temperatures correlate with higher elevation and denser vegetation cover, which moderate the local climate through evapotranspiration and surface albedo effects (Mohammed et al., 2021). Seasonal temperature variations are substantial, with the hottest period occurring between February and April (pre-monsoon) when temperatures frequently exceed 35°C in the northwestern zones. The harmattan period (December-January) brings cooler nighttime temperatures of 20-25°C, with significant diurnal temperature ranges that can exceed 15°C (Ifatimehin & Ufuah, 2020). Long-term temperature trends indicate a warming pattern consistent with global climate change, with mean annual temperatures increasing by approximately 0.8°C since 1970 (Adewuyi & Olofin, 2023).

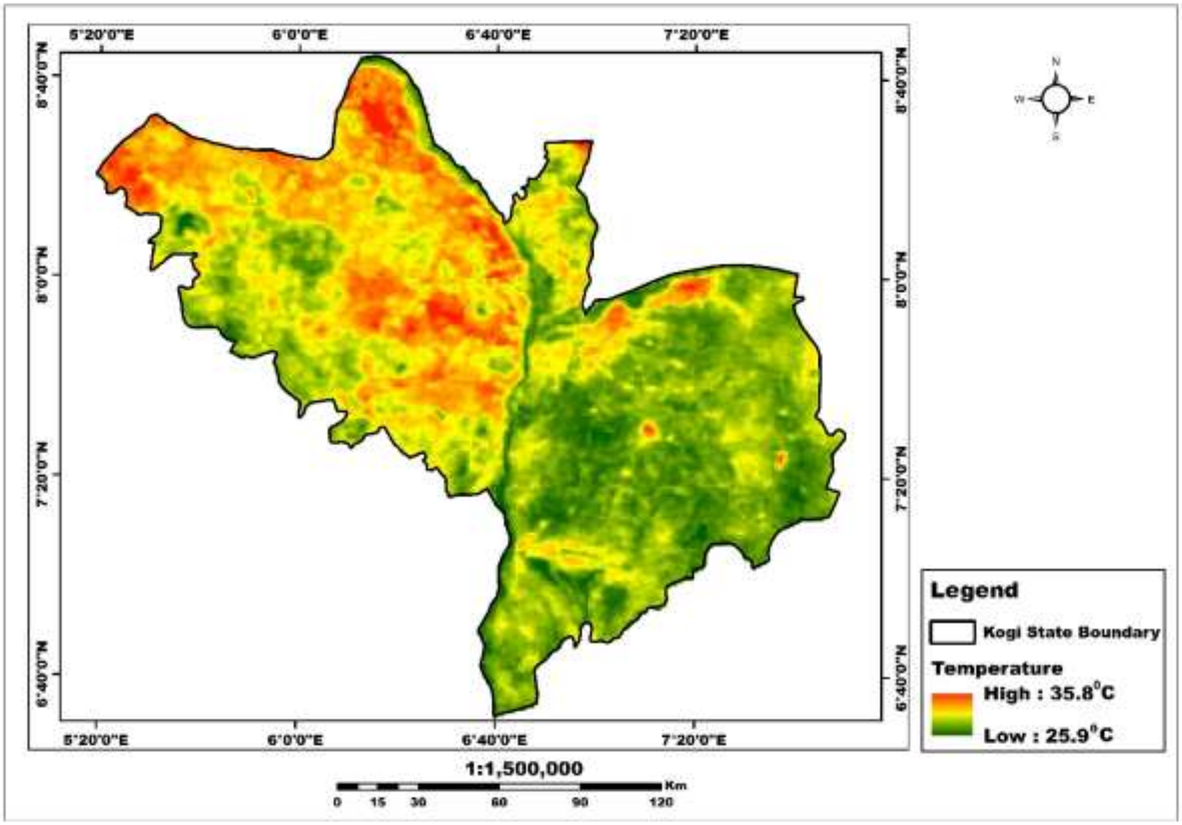

Figure 3: Annual temperature distribution in Kogi State.

2.4 Relative Humidity

As revealed in figure 4, relative humidity across Kogi State exhibits considerable spatial variation, ranging from 41.5% to 79.85%. The humidity distribution follows a distinctive pattern, with a prominent high-humidity corridor running north-south through the central portion of the state. This corridor closely corresponds to the major river systems, particularly the Niger River, highlighting the significant impact of surface water bodies on atmospheric moisture content. The western and eastern regions display moderate to low humidity levels, with the northeastern section showing the most pronounced aridity. These humidity patterns directly influence agricultural practices, biodiversity distribution, and human comfort across different parts of the state (Adewuyi et al., 2022). Seasonal fluctuations in humidity are pronounced, with peak levels occurring during July-September when monsoonal winds bring moisture-laden air from the Atlantic Ocean (NIMET, 2021).

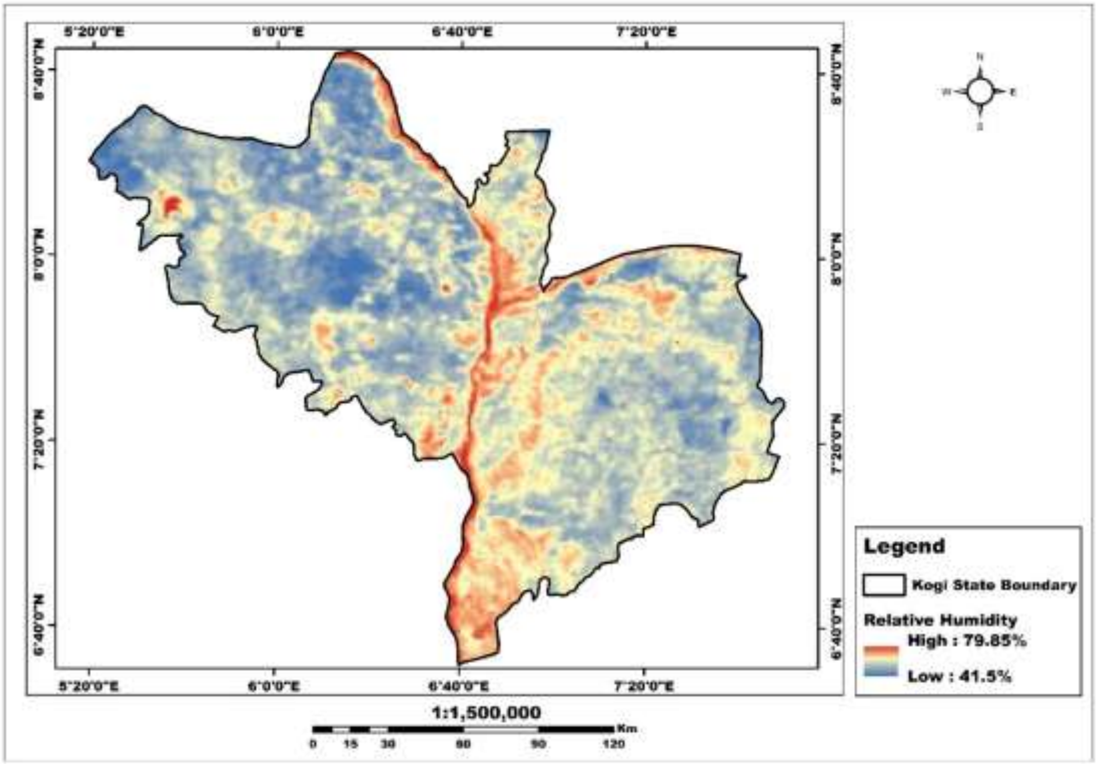

Figure 4: Relative humidity of Kogi State.

2.5 Geological Setting

Geologically, Kogi State is characterized by diverse formations that reflect its position within the broader Nigerian geological context. The state predominantly sits on the Basement Complex of central Nigeria, with some sedimentary formations in areas closer to the Niger-Benue confluence (Obaje et al., 2020). The Basement Complex consists primarily of metamorphic and igneous rocks, including gneisses, migmatites, granites, and schists, which date back to the Precambrian era. The sedimentary formations, particularly in the southern parts of the state, belong to the Anambra Basin and contain significant deposits of coal, limestone, and ironstone. These deposits have contributed to the state's mineral resource potential, with limestone mining being particularly significant in the Obajana area, home to one of Africa's largest cement factories (Obaje et al., 2020). The state's terrain varies from lowland floodplains along the Niger and Benue rivers to undulating plains and scattered hills and inselbergs in the interior. Notable highland areas include the Okene-Kabba plateau and the Bassa Hills, which rise to elevations of 300-600 meters above sea level (Audu et al 2021). These varied topographical features influence local climate patterns, drainage systems, and agricultural activities across different parts of the state.

2.6 Topography

Kogi State presents a captivating topographical landscape defined by its strategic position at the confluence of Nigeria's two greatest rivers, the Niger and Benue (Figure 5). This dramatic meeting point creates a Y-shaped lowland basin with elevations as low as 1 meter, effectively dividing the state into three distinct elevated regions. The western portion rises into undulating hills and isolated inselbergs, culminating in dramatic highlands that reach elevations of up to 674 meters, displayed in vibrant red and orange hues on elevation maps. This varied relief not only shapes the state's climate patterns but also historically influenced settlement distribution, with communities clustering along the fertile riverbanks and in protected valleys between highlands, as well as affecting agricultural practices and transportation corridors throughout the region.

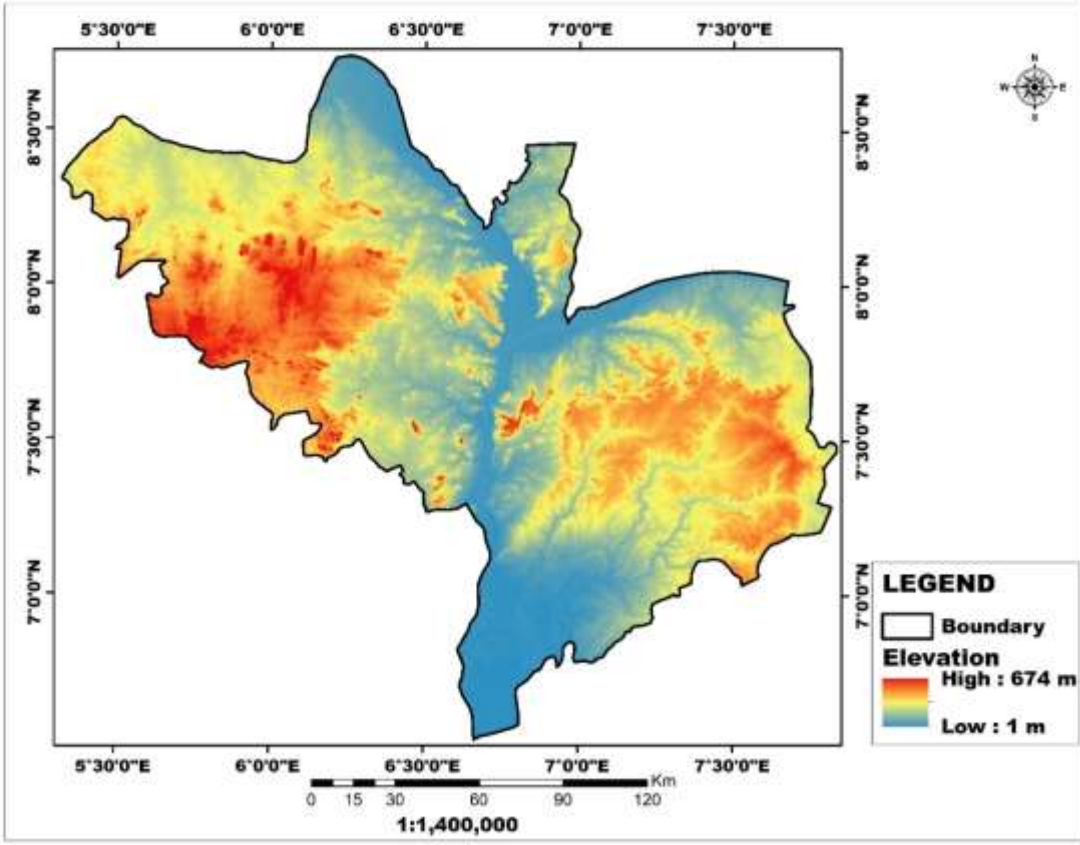

Figure 5: Elevation of Kogi State

2.7 Hydrological Characteristics

Kogi State possesses one of Nigeria's most significant hydrological profiles, dominated by the confluence of the Niger and Benue rivers at Lokoja, a feature that gives the state its nickname as the "Confluence State." This river system creates an extensive network of waterways, floodplains, and wetlands that influence the state's ecology, settlements, and economic activities. Beyond these major rivers, Kogi's hydrological landscape includes numerous tributaries such as the Mimi, Okura, and Ofu rivers, alongside seasonal streams that flow more vigorously during the wet season (April-October) and diminish considerably during the dry months (November-March). The state's groundwater resources vary geologically, with the Basement Complex areas having limited groundwater potential restricted to weathered zones and fracture systems, while the sedimentary areas, particularly in the southern parts, contain more productive aquifers (Amadi et al., 2022). Seasonal flooding, particularly at the confluence zone, represents both an ecological process that rejuvenates floodplain soils and a recurring hazard for riverine communities, with major flood events in 2012 and 2022 having caused substantial displacement and economic losses. Anthropogenic factors including deforestation in watershed areas, sand mining from riverbeds, and increasing urbanization have altered natural drainage patterns and contributed to problems like erosion, sedimentation, and localized flooding in urban centers such as Lokoja and Idah (Olatunde & Mohammed, 2021).

3.0 METHODOLOGY

3.1 Data Acquisition

This research commenced with comprehensive data acquisition for Kogi State of Nigeria. High-resolution satellite imagery, digital elevation models, and existing geospatial datasets such as annual temperature, rainfall and humidity data were collected from multiple sources, mainly USGS Earth Explorer, Copernicus and Google Earth Engine. These datasets were subsequently processed using the ArcGIS 10.8 software. Different scenes of the satellite imagery were mosaicked into one composite to extract the whole extent of the area of interest (Kogi State). After that, band combination was carried out to achieve the “false color composite” with which to carry out the classification task. All spatial data were standardized to UTM projection (Zone 32N) and resampled to a uniform 30-meter resolution to facilitate seamless integration. A structured geodatabase was established to maintain data integrity throughout the analytical process, with appropriate metadata documentation for each layer. This initial preparation stage was crucial for ensuring spatial and temporal consistency across the diverse datasets, particularly when dealing with information from varied sources and collection periods.

3.2 Climatic Data Analysis

The climate variable mapping phase focused on visualizing three critical parameters: relative humidity, rainfall distribution, and temperature patterns. For the relative humidity analysis, satellite-derived atmospheric moisture data was processed and interpolated using Inverse Distance Weight (IDW) method to generate a continuous surface across the study area. The resulting map revealed significant spatial variation, with humidity values ranging from 37.0% in the central regions to 94.7% along specific western boundaries and waterways. These findings highlighted the considerable microclimatic variations, influenced by topography, vegetation cover, and proximity to water bodies. The rainfall distribution map was created by processing precipitation data from multiple meteorological stations on Google Earth Engine, which was then interpolated and validated against historical records. This analysis exposed notable precipitation gradients across the states, with distinct wet and dry zones that corresponded to topographic features and regional climatic patterns. Temperature variation across Kogi State was mapped using thermal infrared bands from satellite imagery, revealing thermal hotspots and cooler zones that correlated with both natural features and anthropogenic influences.

3.3 Land use Land Cover Analysis

Land cover classification was performed using supervised maximum likelihood classification technique on multi-spectral satellite imagery. Training samples were carefully selected for each land cover category based on field data and high-resolution reference imagery. The classification process involved meticulous digitization of representative samples for each land cover type, followed by spectral signature analysis to ensure separability between classes. The classification process identified eight distinct land use/land cover (LULC) classes: forest, shrubland, grassland, agricultural land, built-up areas, water bodies, wetlands, and rock outcrops. This detailed categorization allowed for comprehensive landscape characterization essential for understanding hydrological processes and watershed dynamics. Post-classification refinement included majority filtering and contextual correction to reduce salt-and-pepper effects. Accuracy assessment was conducted using a confusion matrix against independent validation points, achieving an overall accuracy of 87% with Kappa coefficient of 0.83

3.4 Hydrological Analysis

The watershed delineation methodology employed a systematic approach based on hydrological modeling principles. First, a hierologically corrected digital elevation model was prepared by filling sinks and removing imperfections. This process was computationally intensive but essential for creating a continuous flow surface that accurately represented the terrain. Flow direction and flow accumulation analyses were subsequently performed to identify natural drainage patterns and stream networks. The watershed characteristics analysis examined the relationship between drainage patterns and potential water resource management opportunities. Drainage density calculations revealed areas of high surface runoff potential, visualized through a multi-tiered intensity classification. These calculations considered the total stream length per unit area within each sub-watershed, providing quantitative metrics for comparative analysis. Watersheds were classified based on multiple criteria including slope, soil permeability, and stream density, with darker red areas indicating higher flood risk or erosion potential. Potential reservoir sites were identified through a multi-criteria decision analysis that considered topographic suitability, stream order, catchment area, and proximity to settlements. Each site was evaluated using a weighted scoring system that prioritized locations with optimal combinations of these factors. These locations represented strategic points for potential water harvesting structures based on their hydrological characteristics and estimated storage capacity. The hydrological analyses were carried out as presented in Figure 6;

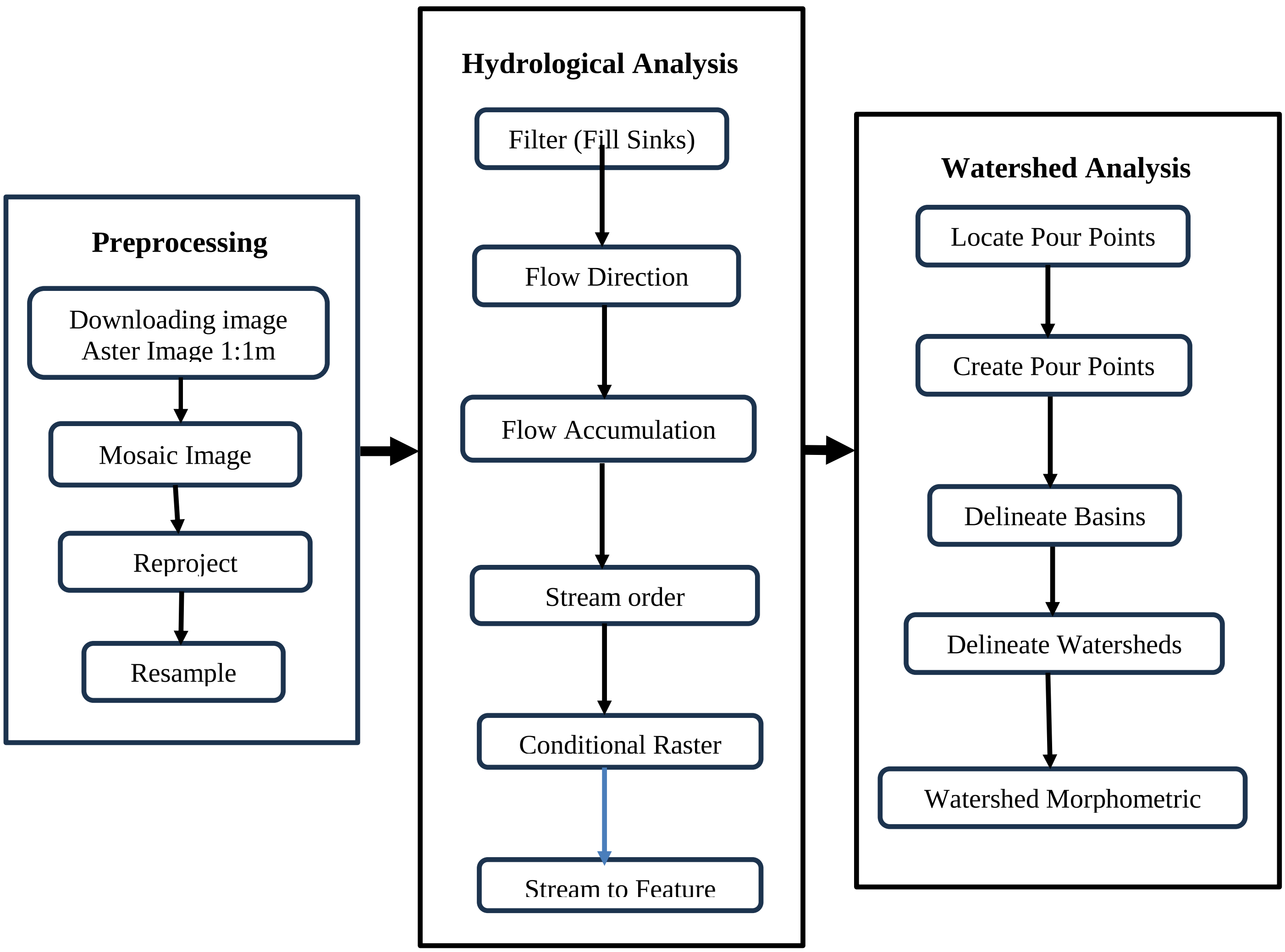

Figure 6: Flow Chart of Methodology

4.0 RESULTS AND DISCUSSION

4.1 Watersheds and Potential Water Reservoirs in Kogi State

Figures 7 and 8 depict the state's watersheds and prospective water reservoirs, while Table 1 indicates the spatial distribution of these resources. Approximately 18 possible water reservoirs were identified and delineated. The particular situation of Kogi state is aptly captured in the states nickname; 'Confluence State'. Its location astride the confluence of two of west Africa's major regional water bodies, in the form of the rivers Niger and Benue, means that the state is, effectively, a part of a regional watershed that extends from the heights of Futa Jallon in the west to the highlands of Northern Cameroon to the east. At the nexus of these two regional waters, huge quantities of water pass through each day on the way to the Atlantic Ocean, providing immense hydrological potential and opportunity for interventions and management. While the regional watershed and basin extends far beyond the boundaries of the state, local basins can be delineated within the area covered by the state.

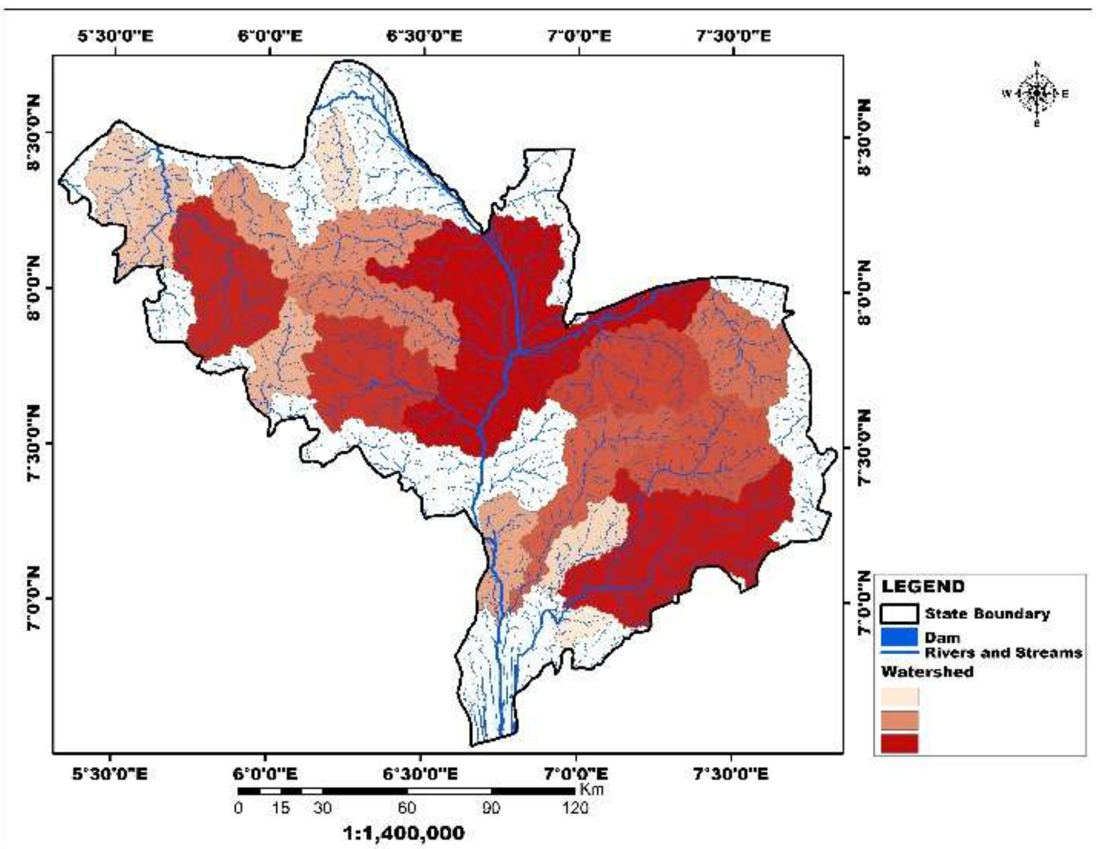

Figure 7: Watershed Boundaries in Kogi State.

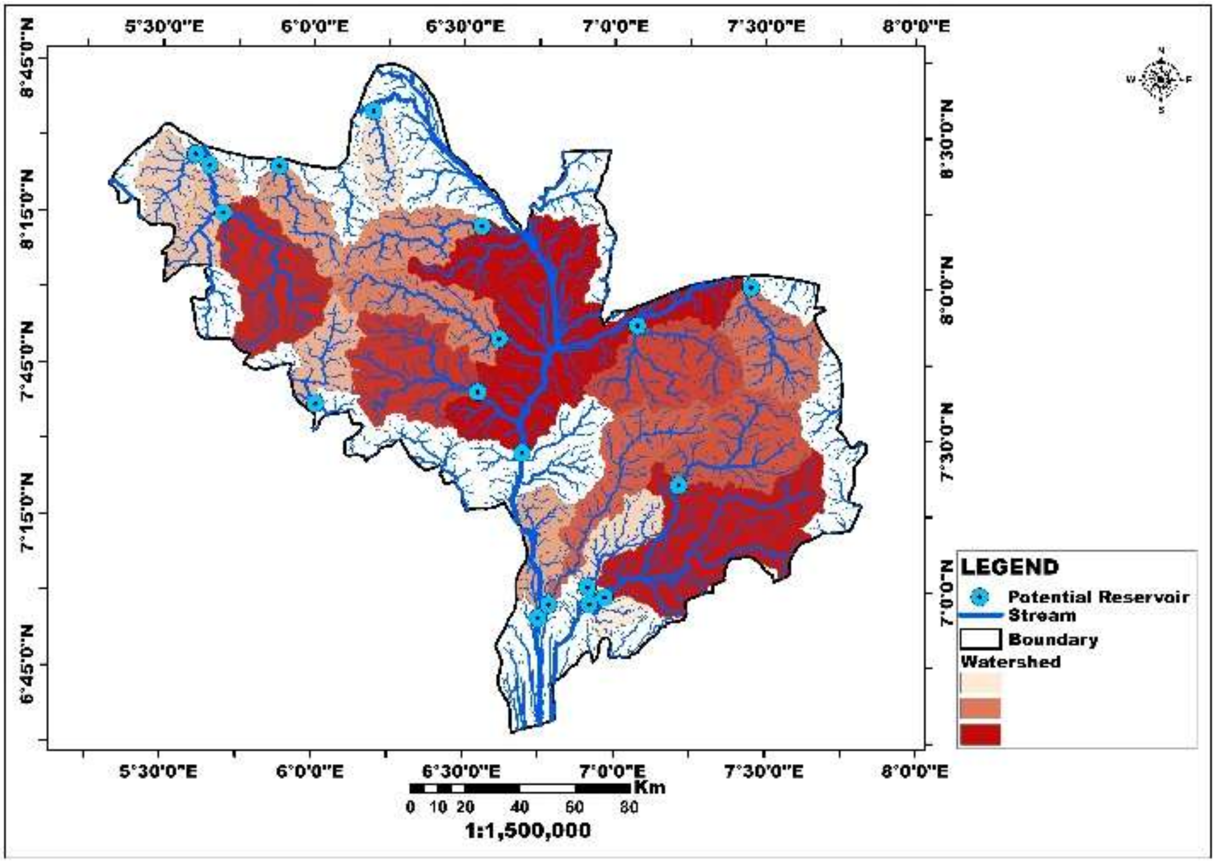

Figure 8: Potential Reservoirs and Watershed boundaries in Kogi State.

Table 1: Statistics of the Watersheds

S/N	Geohydrological Unit	Perimeter	Area (Km2)	Circularity Ratio
1	Watershed 1	114515.16	391.47	0.3751
2	Watershed 2	124841.44	565.22	0.4557
3	Watershed 3	146622.26	650.25	0.3801
4	Watershed 4	159466.02	587.75	0.2905
5	Watershed 5	187579.06	842.02	0.3007
6	Watershed 6	216270.00	1512.20	0,4065
7	Watershed 7	223651.13	1013.02	0.2545
8	Watershed 8	171076.76	1037.05	0,4433
9	Watershed 9	156608.55	624.78	0.3201
10	Watershed 10	208707.46	1386.75	0.4
11	Watershed 11	228321.29	1451.92	0.35
12	Watershed 12	547269.22	4159.74	0.1745
13	Watershed 13	211194.64	1328.40	0.3743
14	Watershed 14	152375.37	515.21	0.6536
15	Watershed 15	320875.84	1207.70	0.1474

16	Watershed 16	152052.29	628.17	0.3414
17	Watershed 17	362212.25	2485.88	0.281
18	Watershed 18	82509.99	204.77	0.378

4.2 Spatial Distribution of Natural Resources in Kogi State

Figure 9 shows that forests dominate land use in Kogi state, covering 15694.2366 Km^2. This is followed by shrubland, which covers 6684.3392 km2. The bare surface has the least coverage, at 43.9117 Km^2. Wetland, built-up, and waterbodies cover somewhat greater area, accounting for 66.7817, 320.6775, and 361.4763 Km^2, respectively (Figure 9 and Table 2). Although rock outcrops are not depicted here, they play a significant role in the evolution of numerous hydrological variables in the study area. This is not unique to Kogi state, but is common throughout Nigeria's north central area, where the quantity of crystalline basement rock outcrops and their underlying structural features have always played an important role in the formation of hydrological systems. The considerable amount of forests in the state can be attributed to the ample water supply enjoyed year-round within the zone due to the proximity of the confluence and its two major rivers. This constant influx also makes the state a high risk region with respect to flooding which has become a perennial threat to lives and property in the area. This is most notable in Lokoja, which is situated at the confluence and, being the state capital and administrative center, is the largest city in the state and also in several areas downstream, extending towards and beyond Idah.

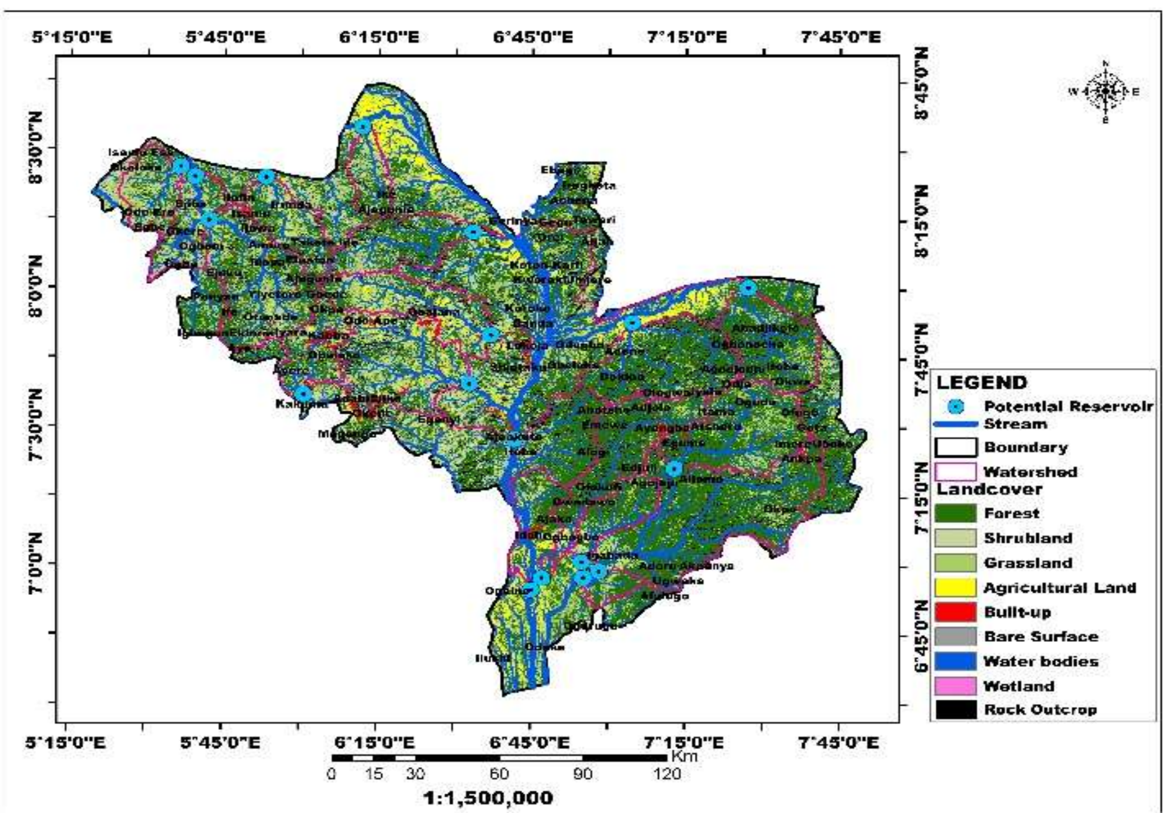

Figure 9: Distribution of Natural Resources

Table 2: Distribution of Natural Resources (SqKm)

S/N	LANDCOVER	AREA (Km^2)
1	Agricultural Land	2271.23
2	Bare Surface	43.91
3	Built-up	320.68
4	Forest	15694.24
5	Grassland	3253.03
6	Shrubland	5584.34
7	Waterbodies	361.48
8	Wetland	66.78

4.3 Spatial Distribution of Natural Resources in the Confluence Watershed

Figure 10 displays the distribution of natural resources within the confluence watershed, which is comparable to the numbers reported throughout the state. Forests cover the most area with 3291.1805 Km^2, followed by shrubland with 1106.6219 Km^2 and agricultural land with 718.5064 Km^2. Grassland, Water bodies, Built-up, and Wetland encompass 710.3074, 177.831, 85.5662, and 28.8865 Km^2 correspondingly, with a bare surface of 7.2761 Km^2 (Table 3).

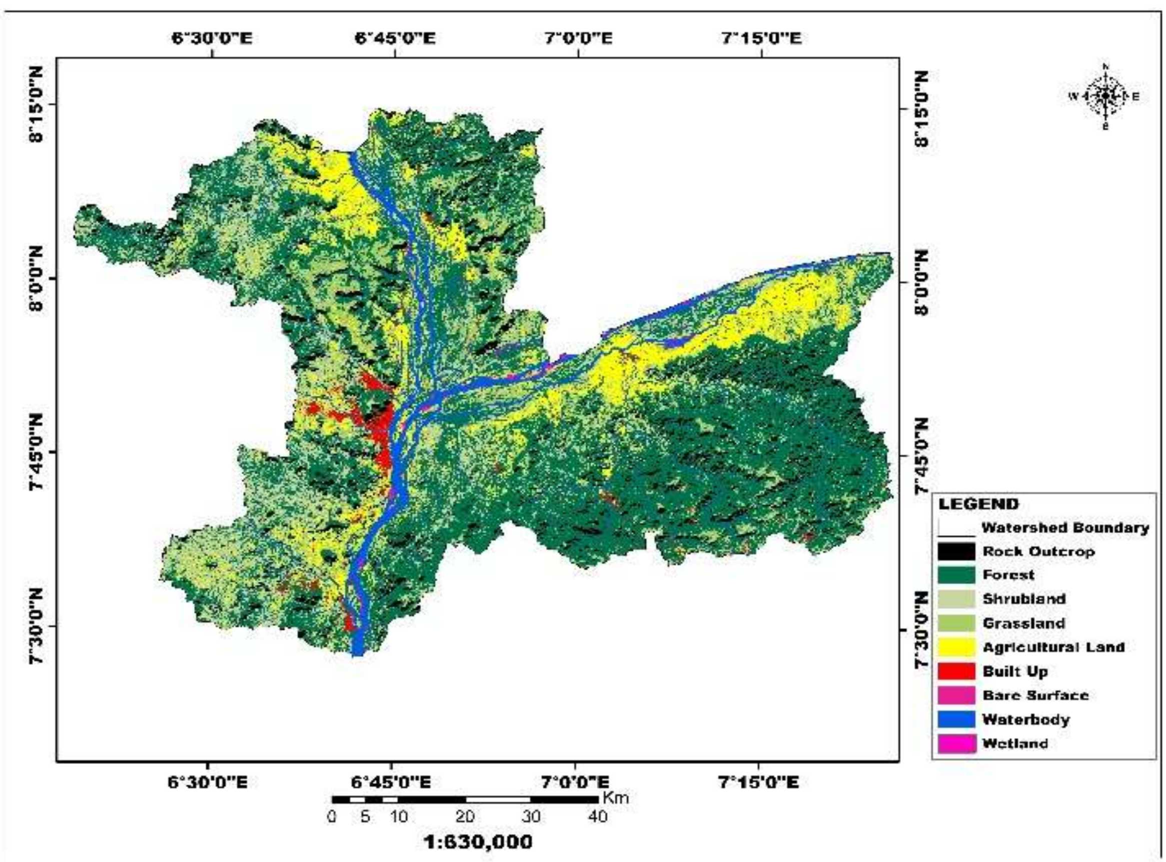

Figure 10: Distribution of Natural Resources

Table 3: Statistics of the Natural Resources

LANDCOVER	AREA (Km^2)
Agricultural Land	718.5064
Bare Surface	7.2761
Built-up	85.5662
Forest	3291.1805
Grassland	710.3074
Shrubland	1106.6219
Waterbodies	177.831
Wetland	28.8865

4.4 Potential Reservoirs within the Confluence Watershed

Figures 11 and 12 show twelve watersheds defined from the enormous watershed containing the confluence of the rivers Niger and Benue. These were labeled watersheds A through L. They range in size from the little watershed H (0.0056 km^2) to the massive watershed G (337.5256 km2). J, K, L, and D encompass more than 200 Km2 each, with 272.0405, 222.1424, 244.0178, and 223.2771 Km2, respectively. Watersheds I, B, and C each cover more than 100 km2 (155.5906, 129.2632, and 115.4572 km2, respectively). The remaining three watersheds, E (94.3761 km2), A (79.7637 km^2), and F (67.7667 km^2), each have an area of less than 100 km2. The perimeters range from 339.5615 m to 96161.2945 m (Table 4). In terms of circularity, seven of the watersheds lie within the structurally indicative 0.4 and 0.5 threshold (I; 0.4074, C; 0.4096, F; 0.4487, J; 0.4621, B; 0.4656, D; 0.489 and G; 0.4965. While two watersheds lie below this threshold (L; 0.3316 and E; 0.3936), three are recorded above that narrow window (K; 0.5202, A; 05955 and H; 0.6103).

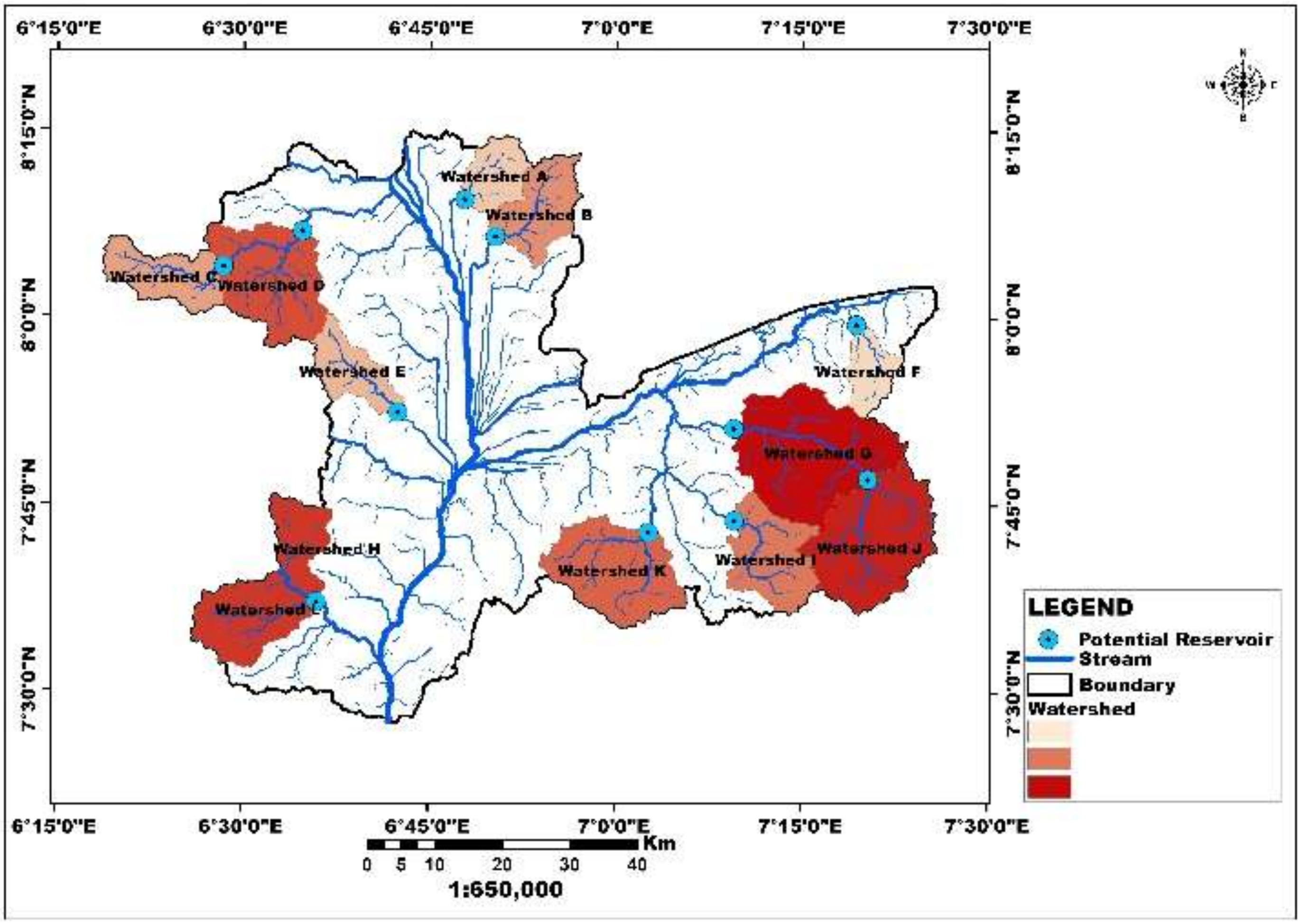

Figure 11: Potential Reservoirs within the Confluence Watershed.

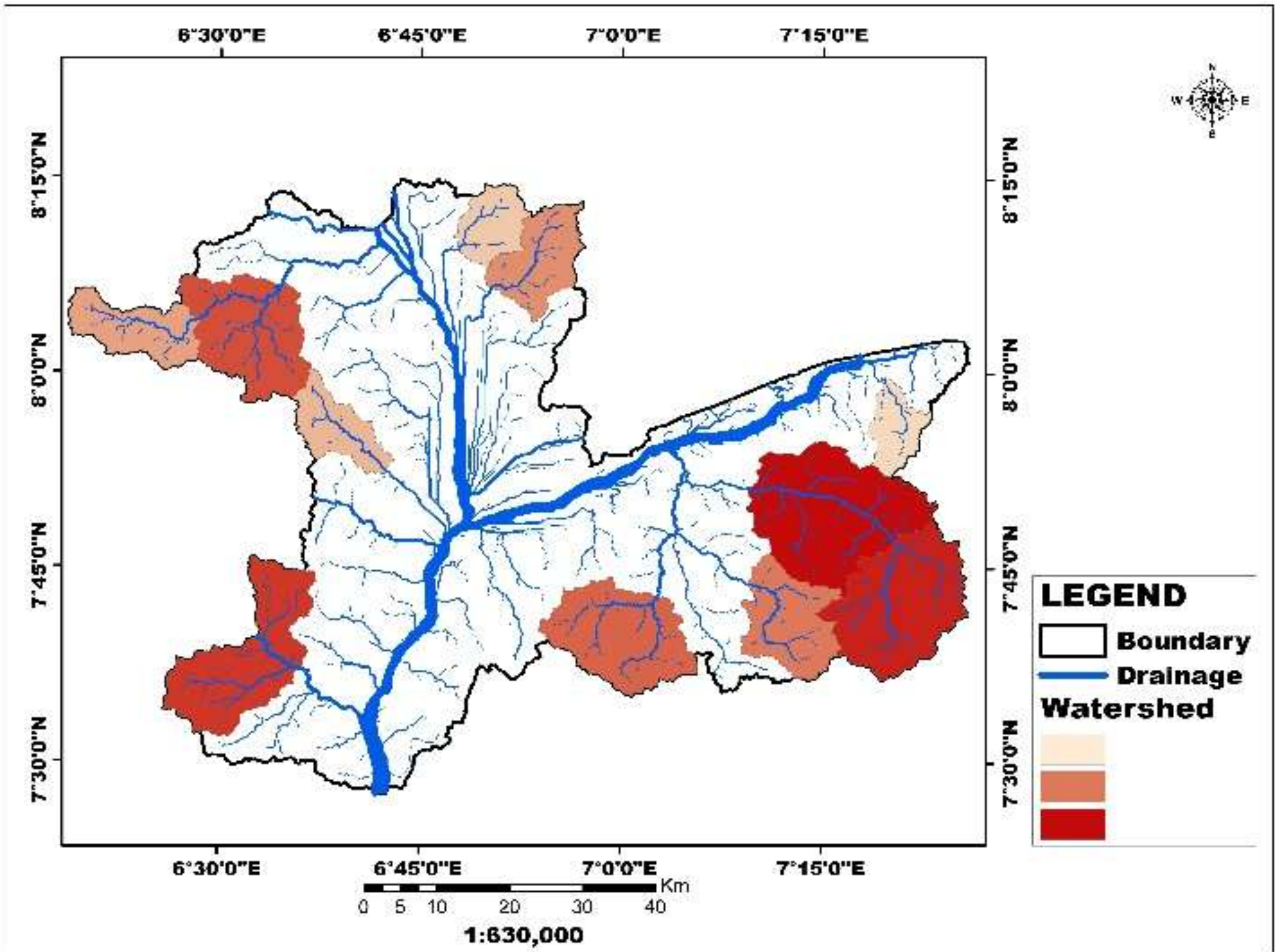

Figure 12: Map of Watersheds Generated in the Vicinity of the Confluence.

Table 4: Statistics of the Watersheds

S/N	Geohydrological Unit	Perimeter	Area (Km^2)	Circularity Ratio
1	Watershed A	41028.41	79.76365	0.5955
2	Watershed B	59066.01	126.2632	0.4656
3	Watershed C	59515.09	115.4572	0.4096
4	Watershed D	75750.35	223.2771	0.489
5	Watershed E	54890.17	94.37607	0.3936
6	Watershed F	43545.05	67.70672	0.4487
7	Watershed G	92424.93	337.5265	0.4965
8	Watershed H	339.5615	0.005546	0.6103
9	Watershed I	69927.52	155.5906	0.4074
10	Watershed J	86009.07	272.0405	0.4821
11	Watershed K	73256.95	222.1424	0.5202
12	Watershed L	96161.29	244.0178	0.3316

Generally, the study yielded eighteen (18) prospective reservoirs across Kogi State. The watersheds that service these potential reservoirs range in size from 204.77 to 1512.2 km^2, with an average area of 1144.017 km^2 (Figures 7 and 8). These massive areas indicate enormous potential for new reservoirs in the state, which might be used for irrigation, water supply, and a variety of other purposes. The circularity ratios of the watersheds show that the majority of them are very elongated (Table 1 and 4). This influences flow rates, sediment transport potential, water travel time, and flooding duration within certain watersheds. Such elements govern the rate at which water collects within the reservoirs, the rate of sedimentation in such reservoirs and the potential of reservoirs to be employed as a medium for flood control. It is particularly noticeable that more than half of the watersheds within the state fall within 0.4 to 0.5 circularity (Table 3 and 4). This is an indicative of structural controls, either from relic tectonic structures in the underlying crystalline rocks, or from newer sedimentary structural elements of overlying sedimentary strata of sections of the Benue basin. The predominant structural effect inside this area can be traced to the tectonic pressures that caused the failed triple-arm rifting system of which the Niger and Benue river valleys and sedimentary basins are outcomes.

For a clearer view of the dynamics within the hydrological systems in this area, a more detailed investigation was carried out into one of the larger basins in the state. Potential reservoirs were located within this basin and their watersheds analyzed. Twelve (12) watersheds were identified and named Watersheds A to L (Figures 11 and 12, Table 4). Within this smaller area, the link between the watershed characteristics and the structures of the underlying rock formations are even more obvious. Seven (7) of the twelve (12) watershed had circularity ratios lying between 0.4 and 0.5 (Table 4). This is as expected because the larger watershed from which these smaller ones were delineated encloses the Niger-Benue confluence, which is the epicenter of the tectonic activities that lend the structural character to much of the terrain through which these hydrological systems operate. Much of the watersheds in this region are also elongated to sub-oval, having a desirable balance between the hydrological qualities of round/oval (0.9 - 1.0 and 0.8 - 0.9 circularity ratio) and more elongated watershed shapes. This contributes to making this region (immediately around the confluence) a viable option for reservoir sites and other water harvesting processes. In particular, hydrological interventions on the eastern portion of this watershed may contribute, in no small way, to managing the perennial flooding on the Benue river due to discharge from the Lagdo dam which is situated further upstream in northern Cameroun and excessive rainfall as a product of climate change.

The presence of sedimentary formations of the middle and lower Benue trough as well as parts of the Anambra basin (further downstream, towards the Niger delta) present some concerns about locating a reservoir within this area. The capacity of these formations to host aboveground reservoirs may be compromised (in certain areas) either due to structural or compositional characteristics that may keep the watershed from retaining water at an optimal level. These could include faults and fractures which may present means for stored water to drain away into adjacent rock crevasses or into loosely aggregated sedimentary beds. Landuse within Kogi state is dominated by forests which covers 15694.2366 Km^2 of the land mass (Figure 7). This is followed by shrubland covering 6684.3392 Km^2. The least coverage is bare surface with 43.9117 Km^2. Covering slightly more area, wetland, built-up and water bodies account for 66.7817, 320.6775 and 361.4763 Km^2 (Table 1) respectively. Though rock outcrops are not captured here, they are very important in the evolution of various hydrological variables within the study area. This is not peculiar to only Kogi state but is prevalent throughout the North central region of Nigeria where the abundance of crystalline basement rock outcrops and their underlying structural traits have always played a huge part in the emergence of hydrological systems. The considerable amount of forests in the state can be attributed to the ample water supply enjoyed year-round within the zone due to the proximity of the confluence and its two major rivers. This constant influx also makes the state a high risk region with respect to flooding which has become a perennial threat to lives and property in the area. This is most notable in Lokoja, which is situated at the confluence and, being the state capital and administrative center, is the largest city in the state and in several areas downstream, extending towards and beyond Idah.

5.1 Watersheds Management Plan for Sustainable Irrigation Agriculture

Watershed management is a comprehensive approach to managing land and water resources in a specific geographic area within a watershed (geo-hydrological unit). On the other hand, it can be described as the adoption of best practices targeted at sustaining land and water resources, with the overarching goal of increasing the quality of these resources and other attributable resources in a reasonable and comprehensive manner. This sustainable use and protection of natural resources within a watershed, aiming to balance ecological, economic, and social needs through land and water resource management. It includes the entire management of all aspects of the watershed, including land, water, vegetation, and socioeconomic variables. The goal is to promote the preservation, rehabilitation, and appropriate utilization of natural resources while also meeting the needs and ambitions of local communities. With eighteen (18) watersheds identified, watershed management in this context takes a holistic approach that includes soil and water conservation, plantation, agronomical practices, livestock management, renewable energy, and institutional development to achieve long-term and environmentally friendly outcomes. The management in the area will adhere to certain ideas for efficient and long-term impact, such as participatory approaches, integrated planning, watershed management as a geo-hydrological unit, adaptive management, and sustainable resource use. As a result, because the area is majorly macro-watersheds, management requires making strategic use of land and water resources to increase output while minimizing environmental and human damage. The identification and potential use of these watersheds has far-reaching consequences in all of these regions. Those that drain directly into the Benue River, in particular, can assist to alleviate or reduce the perennial flooding that occurs along its banks and expands westward to the confluence and southward to the delta. Damming these tributaries allows for more control over the volume of flow in the Benue and Niger States, providing some relief, especially when water from the Lagdo dam is discharged. According to (NEWMAP), there is a need for improved water resources management to address water scarcity challenges for irrigation agriculture and domestic purposes in the State. Land degradation, compounded by the effects of climate change (increase in temperature and decrease in rainfall intensity), reduces the water holding capacity of watersheds, increasing the impact of droughts and floods. Watershed management interventions and climate adaptation measures to better control erosion and sedimentation into existing dams include construction and rehabilitation of small storage reservoirs and rainwater harvesting structures to support communities, introduction of micro-irrigation, harnessing flood waters for productive uses, and identification of recharge areas to protect groundwater resources.

Best practice integrated watershed management usually includes a participatory planning approach at both landscape and micro scales, with management plans utilizing high quality scientific data from both field and geospatial sources. There is also the need for sustainable landscape management practices in targeted watersheds in northern Nigeria and strengthen Niger’s long-term enabling environment for integrated climate-resilient landscape management.

The watershed planning in the area should be carried out using analytical approaches and through development of a modern knowledge base (including collation of existing data from in situ and earth observation and biophysical surveys). Because of the hydrological characteristics of the watersheds in the area, it will require extensive multisectoral approach. Similarly, Ana et al. (2024) underline the importance of environmental awareness and legislative support in encouraging the use of green technologies, which can result in more efficient resource for sustainable water management in irrigation. Further, Youdeowei et al (2019), asserted that watershed management requires a careful balance between economic and environmental goals, as well as a thorough analysis of all biophysical interactions within the watershed system.

5.2 Comparative Analysis of This Study with similar Studies

A comparison of a comparable study conducted by Hyungjin Shin et al. (2024) on hydrological analysis of agricultural reservoir basins based on the water consumption system, utilizing the Catchment Hydrological Analysis Tool Model. The results were investigated by simulating three scenarios: treating the entire watershed as a single unit, dividing it into five sub-watersheds using traditional watershed criteria, and finally subdividing it into 27 watersheds while accounting for the presence of agricultural reservoirs. Similarly, Balasubramani (2024) assessed watershed resources for sustainable agricultural development, employing geospatial technology to establish an operational technique under Indian conditions. The study used well renowned empirical and quantitative methods to define the watershed and determine the geographical pattern of prospective watershed resource usage in agriculture. Ebenezer et al. (2024) revealed significant differences in travel distances to water sources, highlighting the necessity of improved water infrastructure such as dams, watersheds, and river access sites. Furthermore, Jankaro et al. (2023) conducted a similar study using GIS-based irrigation suitability evaluation of the Lapai-Agaie Irrigation Scheme in Niger State, and discovered that 59.0% of the area is extremely suitable for irrigation, 32.0% is moderately acceptable for surface irrigation, and 9.0% is marginally appropriate.

SUMMARY OF FINDINGS

1. The study identified Twenty (20) in Kogi State ranging, in area from 204.77 to 4159.74 Km^2 and covering a total of 20592.31 Km^2.
2. Of the twenty (20) watersheds in Kogi State, the one containing the confluence of the Niger and its tributary, the Benue, was chosen for further examination.
3. Twelve (12) minor watersheds were discovered at the junction, covering sizes ranging from 0.006 to 337.53 Km^2 and totaling 1938.17 Km^2.
4. These watersheds imply an abundance of undiscovered water resources throughout Kogi State and around the confluence.
5. Finding also revealed that a combination of factors such as, topography, land use, soil type, geology and climate influences the hydrological characteristics of watersheds in both States.
6. Geohydrological units with a circularity ratio greater than 0.5 indicate irregular shape, strong run-off, and moderate permeability.
7. Over 50% of watersheds have circularity of between 0.4 to 0.5 indicative of irregular shape, moderate run-off and high permeability.
8. The streams in the area have a dendritic network that flows predominantly NE-SW, which corresponds to the Nigerian regional lineament, indicating structural control and serving as conduits for recharging groundwater.
9. The major structural influence within these areas can be attributed to the tectonic tensions that created the failed triple-arm rifting system of which the Niger and Benue river valleys and sedimentary basins are results.
10. The lack of dams in Kogi State reveals underutilization of the hydrological potentials inherent within both the state and around the confluence.

Conclusion

The introduction of space-based technology, with its most advanced and novel advances, has transformed watershed analysis by giving spatial data to characterize and simulate watershed characteristics. As a result of this research, it is possible to infer that the right and sustainable use of these watersheds will assist to revitalize agricultural activity, boost the State's output of agro-allied goods, grow agri-businesses, and, eventually, improve food security.

There are also prospects for harnessing in the production of electrical power. Hydroelectric power producing plants can be integrated into many dams, increasing power availability either locally or nationally. Several other advantages can be drawn from the hydrological potential available in the study region; however, caution is advised to safeguard the ecological and environmental balance so that the least possible adverse or negative consequences are documented.

Recommendation

This study suggests strong collaboration with investors to implement innovative watershed management technologies and irrigation infrastructure to support farming clusters in participating communities. As a result, Nigeria's food security situation would improve dramatically, and the period of reliance on imported staple foods will begin to disappear. This can also help to prevent rural-urban migration by creating economic opportunities in local communities. It will help alleviate farmer-herder tensions by reducing strain on grazing grounds and fostering structured land use planning.

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