

Stream Dynamics in Semi-Arid Regions: An Assessment of Sokoto-Rima River, Nigeria, 1965 – 2005

A. Soneye*

*Department of Geography, University of Lagos,
Akoka-Yaba, Lagos, Nigeria*

Abstract

The surface water of Nigeria is argued to be under threat in most parts of the country, especially in the rural environment where it is a main life support system. The level of surface water recession within Sokoto-Rima River Basin in the northwest Sudano-Sahellian environment of Nigeria is assessed in the study. Interactive remote sensing and Geographic Information System (GIS) techniques are used to map and analyze the hydrology of the basin over a 40-year period (1965 to 2005). The results show alarming reductions in the floodplain area, as well as the lengths, orders and densities of the river segments and tributaries. The floodplain reduced by about 40% in areal extent and the length of stream channels by 90%. More recessions are identified around stream headways. The implication for water security and sustainability in the close settled and desert encroached rural areas are reviewed in the conclusion.

Keywords: Stream, Dynamics, Semi-Arid, Regions, Assessment, River

Résumé

Les eaux de surface du Nigeria sont sous des menaces dans la plupart des parties du pays, particulièrement dans le milieu rural où c'est un système majeur de support vital. Le niveau de récession d'eau de surface dans le Bassin Fluvial Sokoto-Rima dans le nord-ouest de la zone Soudano-Sahélienne du Nigeria est évalué dans cette étude. Les techniques interactives de télédétection et de Système d'information Géographique (GIS) sont utilisées pour cartographier et analyser l'hydrologie du bassin au cours d'une période de 40 ans (1965 à 2005). Les résultats ont montré des réductions alarmantes dans les zones

de plaine inondable, de même que les longueurs, les ordres et les densités des segments fluviaux et des tributaires. La plaine inondable a été réduite de près de 40 % dans sa superficie et la longueur des canaux d'eau de 90 %. D'importantes récessions sont identifiées aussi autour des ruisseaux. L'implication pour la sécurité en matière d'eau et la durabilité dans les agglomérations proches et menacées de l'avancée de la désertification, sont exposées dans la conclusion.

Mots clés: ruisseau : Dynamiques, Semi-arides, Régions, Evaluation, Cours d'eau

Introduction

Water is an essential of life and an abode for numerous living organisms. This accounts for why people are attracted to settle close to waterbodies. About 54% of the surface freshwater resource of Nigeria is used for agriculture, 31% for domestic purposes and 15% for industrial (FAO, 2007). Naturally, the main sources are surface-based ponds, rivers and streams. A meager proportion is from rain harvesting during wet seasons.

Apprehensions are being generated over reducing access to water in a greater part of the country currently. The semi-arid environment is more affected due to rapidly increasing population size, pressure and associated anthropogenic (landuse) activities, evapotranspiration and menace of desert encroachment which are pronounced all the year round (Oyebande & Balogun, 1991). Harvests from rainwater are also reducing as a result of changing rainfall regimes.

A particular interest is the construction of large scale dams and reservoirs upstream of major rivers (Soneye, 2004). Many of the projects are abandoned shortly after the dams are built and started trapping headwaters. Some are not only moribund already but of safety concern along respective floodplains downstream. Access to decision support data is a main challenge to surface water planning and development in developing countries.

The earliest interest at monitoring surface water in Nigeria commenced with the installation of a water level gauge station on River Niger at Jebba in 1908 (NEDECO, 1959). Seven other stations were created in 1914 for a denser network. Data from the stations served as useful input into the water resources planning and management of the country for a long time (Nwa & Martins, 1998). Earliest attempts within the Nigeria semi-arid region commenced with a water impoundment on Sokoto-Rima River system and a canalization of Sheila Stream tributary

in 1900 (Asaju, 1998; Oyebande, 2001). A regulatory Sokoto-Rima River Basin Authority (SRBDA) was established in 1976.

Dismay performance of resource development projects in developing countries are traced to gross inadequacy of the volume and quality of decision-making data that exist at both local, national, regional and trans-boundary levels. The need for improvement on hydrological and water supply data has always been canvassed (Davis, 1987; Oyebande, 2001). Stakeholders have always lamented large scale dysfunctional tools, neglect of support infrastructures and obsolete methods of collection. These require more concerted interests in improved tools, higher density gauge stations and analytical processes of spatial and temporal integrity (Adeniyi, 1979; Adeniyi & Omojola, 1999; Olorunfemi, 1984).

A watershed is the most fundamental unit upon which hydrology of drainage networks are based. It provides an integrated understanding of stream networks, pathways and characteristic regimes of runoffs and abstraction for respective uses (Arnold *et al.*, 1990; Ogodo, 2010). The usual government efforts at mitigating retreating waters in the arid and semi-arid environments are through continuous construction of new dams nonetheless. Some 45 of the 1,269 dams in Africa are concentrated in the semi-arid region of Nigeria (FAO, 2007). Yet, it is estimated that an average of about 20,000 people are displaced by each dam project at inception alone (Davis, 1987).

Increasing number of spatial-based elements for watershed understanding and management justifies the need for advancement in methodological approaches beyond the current conventional methods of mere gauging streams as is common in developing nations. Geographical Information System (GIS) is an analytical tool for mapping and creating databases on geo-resources (Jeffery & Estes, 1990). It is useful for analyzing geomorphic characteristics of hydrographic basins, their sub-units and space-based hydrologic parameters. It is ideal for hydrologic simulations and modeling that take relevant geographical factors into consideration especially if combined with remotely sensed data.

Interactive GIS and Remote Sensing (RS) tools are ideal for the '4Ms' of resource analysis including Measure, Map, Monitor and Model (Arnold *et al.*, 1990). They are valuable for routine complex spatial data collection, manipulation, revision and modeling on resources, their characteristic constituents and impacts on the environment.

Stakeholders have shown substantial interest on the application of geospatial tools locally and internationally. The wealth of satellite RS data about Africa by European and Canadian Space Agencies are well acknowledged by Ogodo (2010). The contributions by the Nigeria Academia to GIS and RS researches are reviewed by Soneye (1999).

Some specific examples of these studies include Adeniyi, *et al* (1992), Fasona *et al* (2011), Ikuosemoran (2011), Omojola *et al* (2011), Rilwani & Ikhuoria (2011). Despite all these, the tools are hardly utilized in the Nigeria environment due to low level of awareness, characteristic methodological approaches and access to basic systems components.

Networking drainage is considered an organized system of channels transferring water (and sediments) in incremental amounts into sequences of tributaries via defined sequences in the same basin. The measurable properties established in the literature are summarized in Table 1, with emphasis on a series of studies by Chorley, 1969; Horton, 1945; Strahler, 1952 & 1964; Schumm, 1956; Hammond and McCullagh, 1977; Linsley *et al.*, 1982; Faniran, 1969 and Tarboton *et al.*, 1991).

The indices defined in Table 1 are pointers to the principal hydrological and catchment evolution basins. If considered over space and time, they provide insight into the development stages and behavioural patterns of the streams in a watershed. In particular, they are vital sources of essential environmental baseline data for natural resources development projects, especially in areas with insufficient data access.

The paper is focused on the network analysis of the semi-arid Sokoto-Rima River watershed, Nigeria. It adopts the analytical tool of GIS to assess the hydrology of surface water resources and the network properties over a 40-year period.

Area of Study

The area of study is in the northwestern geo-political zone of Nigeria. It spans through latitude $13^{\circ}00'N$ to $13^{\circ}15'N$ and $5^{\circ}15'E$ to $5^{\circ}30'E$ (Figure 1). It spans over about 749 km^2 covering Kware, Wurno, Rabah, Sokoto, Dange/Shuni and Wamako Local Government Areas of Sokoto State in parts. The settlers are Hausa/Fulani. Rain falls in the region only in the months of June through September only. They are usually torrential and sometimes with storms. The total amount is about 600 mm annually. Average daily temperature ranges between about $26^{\circ}C$ to $33^{\circ}C$. The Topographical Map shows that the highest altitude in the region is about 335.3m above sea level and the elevation of the basin area ranges from 240m to 258m.

River Rima and River Sokoto control the hydrology of the area. The rivers are the major tributaries of the main River Niger before the confluence with River Benue (the second largest river in the country). The natural vegetation is that of Guinea and Sudan Savanna fringes. It is

dominated by grassland mixed with shrubs. Geologically, the region is of Pre-Cambrian Complex. It is mixed with lateritic sandy, clay and loam soils. They are of low permeability. Head-ward erosion by tributary streams produces badland topography over the area. Some large quantities of sediment are deposited at confluences of tributaries due to sudden reduction in velocity, loss of energy and occasional floods of slow-moving shallow sheets of water.

Table 1: Measurable Hydrological Indices for the Catchment Area of a Drainage Basin

S/N	Indices	Operational Definition	Usefulness
1	Drainage Patterns	The shape or pattern developed by the network in a catchment. Examples are dendritic, rectangular and radial.	To determine the coarseness of the basin in response to local topography, subsurface geology, resistance to percolation, etc.
2	Magnitude: Length (L) & Area (A)	The length is the "longness" of individual streams in a basin. Area is the coverage of each river, lake, reservoir, etc. as could be determined cartographically	To determine the magnitude of the waterbodies; and for estimating other parameters e.g. water volume in a basin
3	Stream Order (O)	The nature of channel branches relative to their hierarchical status.	For establishing the hierarchical status of channels and those that 'rapture' into others in a watershed
4	Bifurcation Ratio (B_r)	The ratio of the number of streams of an order to that of the next lower order. $B_r = S_n / S_{n+1} \dots \dots \dots$ <i>.. (i)</i> <i>where S_n = number of streams of a given order n</i> <i>S_{n+1} = number of streams of the next higher order to n.</i>	To establish the ratio of the number and density of lower-order streams that are likely to increase (or decrease) as connectivity improves or otherwise.
5	Drainage Density (D_d)	The total length of streams draining a unit area of a basin. $D_d = L/A_d \dots \dots \dots$ <i>. (ii)</i> <i>where L is the total channel length in a drainage basin, and A_d is the area of the drainage basin.</i>	For understanding the magnitude of the streams in the network per unit area of the basin. These are needed for establishing rainfall regimes and intensity as well as other basin hydrological responses

Sources: Extracts from Chorley (1969); Faniran (1969); Horton (1952); Strahler (1952, 1964); Schumm (1956); Hammond and McCullagh (1977); Linsley et al., (1982); & Tarboton et al. (1991).

The Township of Sokoto is located at their confluence. Total population over the areal extent is about 190 people per sq. km (ppsk). Sokoto LGA is highest with 3,230 ppsk, followed by Wamako (210 ppsk). Rabah is the lowest with 45 ppsk. The means of livelihood revolve around extensive subsistence agriculture by the dominant Hausas almost all year round in the floodplain and during the short rainy season in the upland area. The main cultivations are millet, sorghum (i.e. guinea corn), groundnut, beans, rice, onions, sugarcane, and cassava, tobacco and a number of citrus. The Fulanis are into transhumance animal husbandry and rearing of goats, cattle, donkeys and camels mostly.

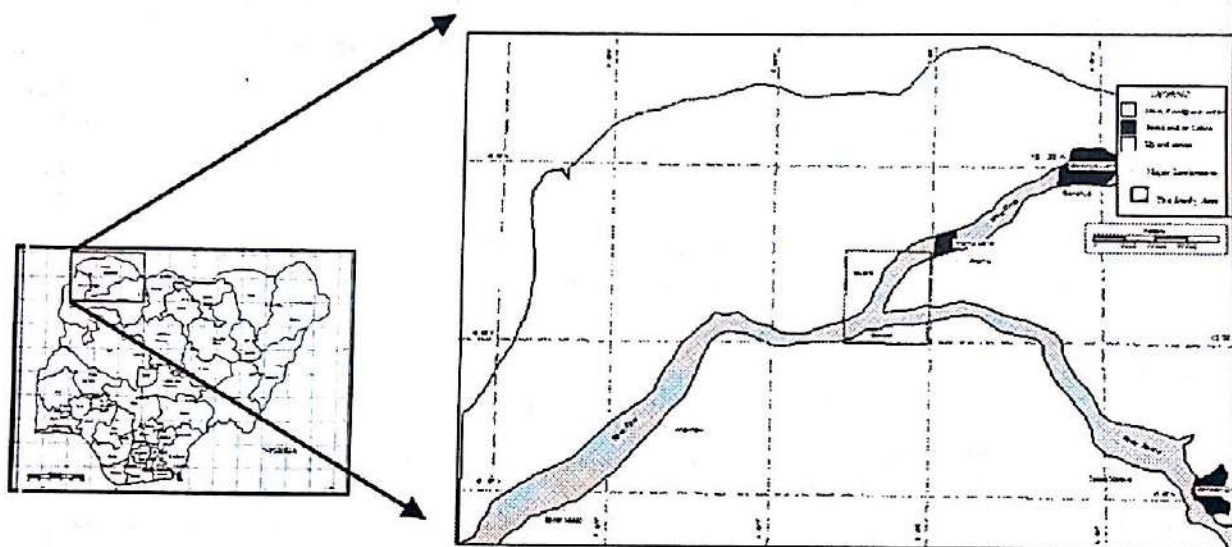


Fig. 1: The Study Area in North West Nigeria

The settlements in the area increased between 1965 and 1995 by about 4% in number and 10% by areal extent. About 83% of the increments are around floodplains. An average of 1% of the drier upland settlements in the area relocate to the floodplain yearly (Soneye, 2004). The natural ecology is giving way to scrubs and bare surfaces due to intensive farming, transhumance, fuelwood consumption and encroachment by Sahara desert.

Increasingly, high temperature and reducing rainfall over the years account for high evapo-transpiration. The construction of dams at Goronyo and Wurno on River Rima and Bakolori Dam on River Sokoto as well as the methods of agricultural practices, population pressure and surface water abrasion exert artificial controls on the surface water substantially.

Methodology

The basic hydrological indices of the basin area were evaluated spatio-temporally between 1965 and 2005 in an ArcView GIS environment.

The drainage network for the base year was extracted from 1965 Nigeria Topographical Map (Sokoto Sheet 10NE), produced by the Office of the Surveyor-General of the Federation (formerly Federal Surveys Department), Nigeria and accessible in hardcopy colour print. The 2005 data were from SPOT (P and XS) satellite remote sensing images of the area. The map was scanned, geo-referenced to geographical coordinate system and digitized with special emphasis on extracts of the networks of rivers and tributary channels depicted. A total of 16 Ground Control Points (GCPs) were selected for geo-referencing.

Base features for registration included roads, settlements, escarpments and drainage channels within each instantaneous field of view (IFOV). The satellite images were corrected and enhanced digitally before being interpreted using the 1965 map as base. Specific elements for the image interpretation exercise included feature pattern, shape, tone, association and site. The GCPs are established using a Garmin GPSMap 76CXS Global Positioning System (GPS) for respective field activities which were accomplished in October 2008. Supporting auxiliary records were harnessed from SRBDA while on the field. Generated GIS coverages for the 2 periods are projected to the same Universal Traverse Mercator (UTM), Zone 31 for topological building, statistics generation and analysis of the parameters for the defined hydrological indices.

Results and Discussion

The geographical spread of the basin and its networks are presented in Figure 2 on LGA basis and the statistics generated in Table 2.

Table 2: Magnitudes of Channel Segments and Land cover resources and their Changes within the Catchment over the 40-year period

Feature (and unit of measurements)	1965* (A)	2005** (B)	Change ('65 to '05)		Average Annual Change	
			Size (C = B - A)	%age (D = C/B%)	Size (E = C/40)	%age (F = D/40)
Rivers (assessed in km)	660.4	274.9	-385.6	-240.2	-9.7	-1.5
Rivers (assessed in ha)	882.1	555.1	-327.0	-158.9	-10.9	-0.9
Farming/Vegetated Floodplains (ha)	12,426.9	26,024.8	+13,597.9	+47.8	+340.0	+2.7
Bare Sand surfaces/ mudflats (ha)	10.8	471.9	+461.1	+2.3	+11.5	+106.7

Sources: * = GIS Analysis of the digitized Map; ** = GIS Analysis of the interpreted RS image

Magnitude (Lengths / Areas): Surface waterbodies reduced both in lengths and areas over the 2-time period. The lengths reduced from 660km to 274.9km and the area from 882.1ha to 555.1ha. Respectively, these represent -327km (-37.1%) and 385ha (-9.7%) over the period, and some -10.9km (-3.1%) and -9.7ha (-1.5%) annually. While some of the tributaries reduced in sizes, some others dried up completely. Comparatively, River Sokoto changed more than River Rima. This could be attributed to the larger settlement density, attendant withdrawal for human activities and water withdrawal for anthropogenic activities.

Associated land covers in the catchment benefited from the shrinking waters. They include (i) dry channels of bare sandy surfaces/mudflats which increased by +47.8% and (ii) cultivated/vegetated floodplains which increased by about +2.3% (Table 2). The vegetated areas are of mixture of sedges, marshes and aquatic grasslands. Intervening smaller channels changed more. Meanders are less frequent in 2005 relative to 1965. Rather, seasonal depressions retain waters during occasional floods for some time. The waters are later consumed by herds and/or evaporated eventually.

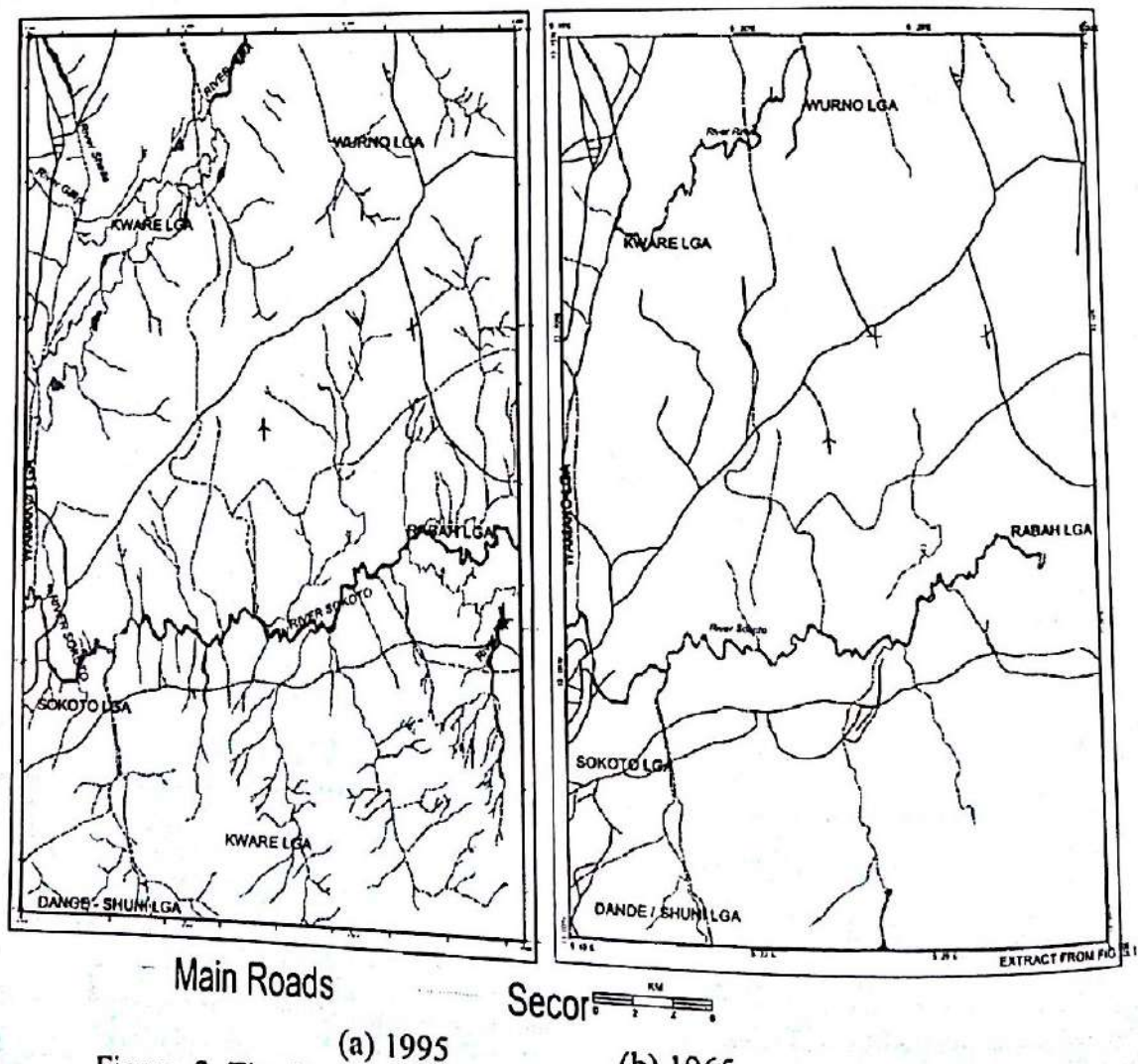


Figure 2: The Surface Drainage Characteristics in 1965 /1995

Stream Order: Five (5) distinct orders were established for the watershed in 1965. They reduced to 3 in 2005. The respective numbers of segments in each order and their changes over the period are analyzed in Table 3. Order O_2 diminished most. A total of 161 segments disappeared over the 40-year period. This implies an average of 4 segments annually. It is followed by Order O_1 with -212 segments over the period and -0.8 annually. Higher density of headwaters in 1965 suggests higher runoff and coefficients as at then. It also means that intensity of rainfall, the main contributor, was higher. The cumulative lengths of respective segments are shown in Figure 3

Table 3: Static and Temporal Changes in the Number of Segments per Stream Order and Bifurcation Ratio

Measurement		1965* (A)	2005** (B)	Change ('65 to '05)		Average Annual Change	
				Size (C = B - A)	%age (D = C/B%)	Size (E = C/40)	%age (F = D/40)
Order (O_i)	O_1	219	7	-212.0	-30.3	-5.3	-0.8
	O_2	164	3	-161.0	-53.7	-4.0	-1.3
	O_3	64	3	-61.0	-20.3	-1.5	-0.5
	O_4	19		-19.0		-0.5	0.0
	O_5	6		-6.0		-0.2	0.0
Bifurcation Ratio (B_{ri})	B_{r1}	2.1	2.3	0.2	0.1	0.0	0.0
	B_{r2}	1.6	1.0	-0.6	-0.6	0.0	0.0
	B_{r3}	3.4		-3.4		-0.1	
	B_{r4}	3.2		-3.2		-0.1	
Drainage Density(m)		0.88	0.37	-0.51	-137.84	-0.01	-3.45
Drainage Density(km ²)		1.18	0.74	-0.44	-60.07	-0.01	-1.50

Sources: * = GIS Analysis of the digitized Map; ** = GIS Analysis of the interpreted RS image

Density: The channels were more distinct and regular on the surface in 1965. The density was 88m of length per km² of the area of study as at the period. The 2005 period has 0.37m per km², indicating that many of the tributaries in 1965 had ceased to exist by then (Table 3). The streams disappear around floodplain agriculture lands in the basin.

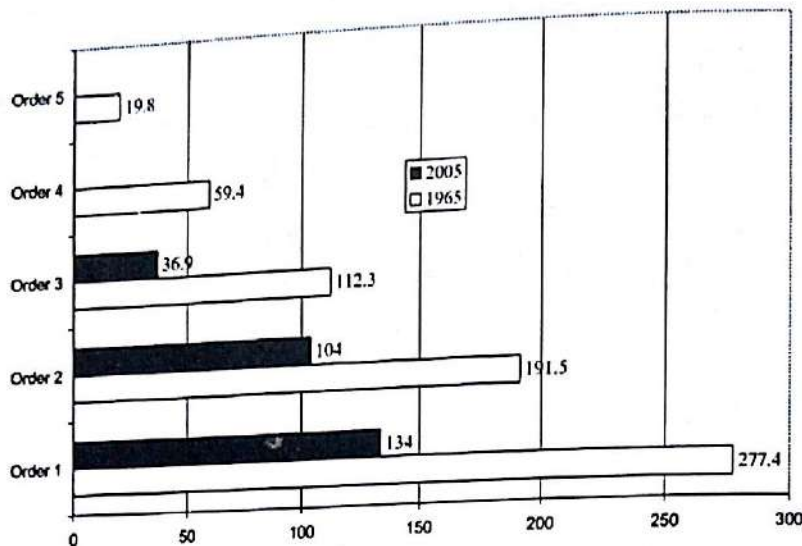


Figure 3: Number of Stream Segments in the Basin per Order; 1965 - 2005

Conclusion

The study evaluated a typical environment sudano-sahellian region being threatened by drainage basin and surface water losses. The results suggest that the floodplains are shrinking and the natural resources are depleting at alarming rates and that surface water losses in the fragile environment is alarming and that access for both domestic and socio-economic needs is critical. The situation is more worrisome for the dominant subsistence farmers especially in the longer dry season when floodplain farmlands and grazing areas for animal pasture are almost elusive. The adaptation strategies include large proportion of the farmers resulting to cultivation of less water-demanding and lower significant grains such as sorghum and millet instead of vegetables, rice and maize; pastoral farmers migrating southwards with their heads of animals to wetter vegetation belts where they are faced with resource conflicts with indigenous farmers, and, residents migrating to cities in search of employment seasonally.

It is inevitable that Rivers Sokoto and Rima floodplains will continue to recede and the natural resources will decline. Increasing population growth and concentration, climate change and plummet rainfall variability and uncoordinated human activities within the region result to unilateral surface water withdrawal for numerous needs (Coe & Foley, 2001). Recent experiences of climate change and environmental degradation globally are reported to be capable of engendering food security and trigger socio-political conflicts over access to natural resources. The shift is tilting towards ground water abstraction through tube wells and boreholes to balance demand which outweighs the supply which depletes the resources more.

The study identified that sustainable water and natural resources conservation in the region requires a holistic understanding of the static and temporal status of the basin characteristics and hydrological cycle with a view to adequately appreciate the challenges and design policy and management approaches. The need for relevant baseline data for such steps are reported in the literature (Jeje, 1976; Eze & Efiog, 2010). The impetus of remote sensing techniques for data collection and monitoring as well as geographic information technology for analysis cannot be overemphasized therefore. GIS is capable of accommodating relevant data from numerous sources and at varied scales to explore hidden attributes and design robust models on the water resources environment spatio-temporally (Anderson & Ames, 2011; Kienzle, 2004; O'Callaghan & Mark, 1984).

While mitigation is vital, it is suggested that regions of similar experiences require firm commitment from every stakeholders including the government at various levels, private sector, civil societies and development partners. Public policy anthropogenic-induced climate change, water control and supply by dams upstream and withdrawal for various functions must be based on objectivity, sound policies and sense of responsibility. This will consider long-term water security plans and policy choices that aim to improve resource allocation, efficiency of management systems and environmentally sound philosophy. Stakeholders must adopt robust techniques that can balance investments to reduce risks and to prepare for increasing crises. Spatial-based technologies will support the implementable *strategies* for knowledge-based audit, planning and development as well as monitoring and intervention more sustainably.

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