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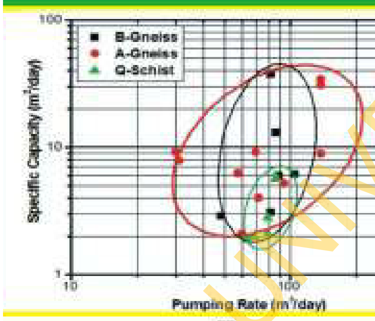

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Embossed cover image

1. Plot of specific capacity (m^3/day) versus the borehole discharge/yield of studied boreholes in parts of Ibadan, SW, Nigeria.
2. Agro-mineral resources sample locations within the framework of geology of Nigeria (modified after Obaje, 2009)
3. Part of the Maijuju Younger granite ring complex showing Lineation on the rock, NC, Nigeria.

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Land-Use Changes And Urbanization Impacts on Livelihood and Groundwater Sustainability of Coastal Areas of Lagos, SW-Nigeria: *Integrated GIS-based, Livelihood and Hydrochemical Assessments*

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Abstract
Water and food security are essential to human survival, livelihood and well-being vis-a-vis sustainable resources management and attainment of the SDGs. This study employed GIS-based, livelihood and hydrochemical assessments of impacts of land use and urbanization on community livelihood and groundwater sustainability with emphasis on the resilience and security of coastal water supply in Lagos metropolis, SW-Nigeria. For the assessment of land-use changes and associated impacts on community livelihood, *Spot 5* satellite imagery of 1984, 2002 and 2017 of Lagos area alongside with *Landsat ETM+* and *OLI* were used to generate the land use / land cover (LULC) changes using *ArcGIS* 10.3 Software. In addition, purposive and random sampling was used to select 500 respondents for the socio-economic assessment of perceived effects of land use changes on livelihood activities of coastal communities in the study area, while the data were analyzed using both quantitative and qualitative approaches. Furthermore, hydrochemical quality assessment of seventy (70) water samples collected from different household water points (wells and boreholes) within study coastal environs were subjected to in-situ physicochemical parameters (pH, Temperature, TDS and EC) followed by laboratory analyses of major cations and anions. GIS-based assessment revealed a significant increase in the built-up areas from 447.3km^2 in 1984 to 951km^2 in 2017 representing 85% increase with corresponding loss of about 5% of the forested coastal wetlands. This is a clear indication of rapid urbanization in the last three decades with attendant impacts on coastal livelihood and water quality. For the livelihood assessment, the average age of respondents was 52±7.7 years while most (66.2%) were males, married, (90.0%), literate (57.7%) with an average 34±5.2 years of residency. Fishing and farming were the major activities while the evaluated data revealed a decline in livestock production by 92.0%, cash crops by 90.0% and food crops by 79.0%. This is also a clear indication of impacts land-use changes as two-third of the respondents diversified into non-farming activities. Hydrochemical assessment revealed elevated electrical conductivity (EC) of >1,000µS/cm alongside with elevated Na (51-230mg/l), Cl (300-980mg/l) and SO_4 (36-88mg/l) concentrations in shallow wells and boreholes tapping the upper unconfined aquifer. This is a clear fingerprint of groundwater vulnerability to saline intrusion and contamination. Therefore, in the face of reality of impacts of anthropogenic land-use and climate-induced changes, there is the need for a clear governance structure to regulate the rate of groundwater abstraction and indiscriminate groundwater development to ensure sustainable groundwater resources management and attainment of SDG-6 and avoidance of water supply crisis. Such crisis can be avoided, if appropriate knowledge-based choices, planning / management options are employed; failure of which will likely be very costly.

Keywords: *Land-use changes, Urbanization, Sustainability, Coastal groundwater, Hydrogeochemistry, Water Quality, Lagos.*

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Introduction

There is no doubt as to the fact that the Earth's ecosystems depend on fundamental environmental cycles such as the continuous circulation of water, carbon, and other nutrients. However, human activities have modified these cycles, especially during the last 50 years with attendant negative impacts on the ecosystem functions and services to man.

Food and water security as well as environmental resources management are essential to human well-being, as the building blocks for sustainable and equitable development and in essence the attainment of the Sustainable Development Goals (SDGs). By and large, these resources are threatened, most especially in the coastal environments due to the damaging impacts of anthropogenic land-use and climate-induced changes, affecting both water and ecosystem resources.

In many parts of sub-Saharan Africa (SSA), the threat of water scarcity can be attributed to several factors, such as urbanization, industrialization, climate change variability, intensification of agricultural activities and indiscriminate use of land and water resources (Cofie, and Amede, 2015; Oteri and Atolagbe,2003). The assertion is consistent with the report of FOA (2009) that the demand for water for agricultural, industrial, and urban needs in Africa will increase by 40% by 2030. In addition, increasing population growth will warrant the need for the agricultural output in SSA to be double by 2050 in order to ensure food security (WWAP, 2015) while there will be attendant increase in consumptive agricultural water demand of 70%–90% by 2050 (Molden, 2007).

In addition, changes in land-use continue to pose a potential threat to the livelihoods of people, especially in coastal communities. Such changes in land use/land cover systems have great impact, among others, on agro biodiversity, soil degradation and sustainability of agricultural production (Lambin *et. al.,* 2003; Sala and Knowlton, 2006) and the overall livelihood of coastal communities. Also, increasing urbanization and industrialization as well as the resultant land-use changes and increasing climate change variability are constraints to water availability and livelihood sustainability of rural populace, especially in the sensitive coastal wetlands, and critical watershed.

Coastal areas are indeed unique places in our global geography and endowed with a very wide range of ecosystems like mangroves, coral reefs, lagoons, sea grass, salt marsh, and estuary. In economic sense, coastal areas are sites for port and harbor facilities with large monetary benefits associated with water-borne commerce and are highly valued and attractive as sites for resorts and as vacation destinations. Studies have shown that land-use changes are associated with large negative impacts on environments in forms of depletion of ecosystems / biodiversity, over-exploitation of fisheries resources, changes in shorelines, degradation of agricultural lands, and poorly managed coastal developments (Churcher, 2006; Gibss *et. al*, 2010; Paterson *et. al*, 2010 and Akinluyi, *et. al*, 2018).

By and large, coastal environments which harbour approximately 20% of the world's human population are said to be under stress as a result of a combination of both natural and human-induced factors - such as increased population pressure, global warming and increased pollution from the atmosphere and from land-based sources (Izrael and Tsyban, 1983; Cohen, et al., 1997; Gommes, et al., 1998). Notable effects and consequences of both natural and human-induced factors are:

- Land reclamation and attendant coastal erosion;
- Increased flooding of low-lying areas and habitat loss;
- Seawater intrusion into coastal aquifers and loss of fresh groundwater resources;
- Encroachment of tidal waters into estuaries and river systems;
- Degradation/pollution of surface and groundwater quality and soil functioning.

According to Intergovernmental Panel on Climate Change (IPCC) report, shallow coastal aquifers are also at risk (IPCC, 2007) as impacts of climate change on local hydrology may offset or increase salinity due to Sea Level Rise(SLR). Under such impacts and threats, sustainable management of natural resources such as water (surface and groundwater resources), agriculture and forestry will require new strategies designed to enable them respond to the changed environmental conditions (Yirsaw, 2016).

Therefore, improving human well-being and meeting the new SDGs should be at the forefront of sustainable developmental efforts in Nigeria and sub-Sahara Africa. In other words, researches geared towards assessment of the vulnerability and impacts of land-use and climate-related changes such as rising sea levels, floods, coastal erosion and associated impacts ecosystem services; sustainable water and land-use management in coastal environments are of relevant priority in the 21st century. Therefore, based on the above background, this study highlights the need to assess the impacts of climate and land-use changes on the livelihood activities of coastal communities and groundwater resources of Lagos area, SW-Nigeria vis-a-vis sustainable resources management, water security and attainment of the SDGs. Furthermore, the emerging infrastructural development in the coastal environment of Lagos-Epe, SW-Nigeria such as Eko Atlantic city and Dangote refinery among others warrant proper understanding of the environmental framework for better planning and sustainable coastal land use and water resources management.

Consequently, this study employed integrated GIS-based land-use change and hydrochemical assessments of coastal environment of Lagos-Epe axis, SW-Nigeria to enhance a better understanding of relationship between human development activities and climate related environmental change vis-a-vis sustainability of water resources management. The overall aim is to contribute to the understanding of the impacts of land use and urbanization on groundwater resources vis-a-vis vulnerability and resiliency of groundwater supply in Lagos and environs, while other specific objectives include:

a) assessment of variations of land-use changes using GIS-approach vis-a-vis impacts on coastal ecosystem and groundwater quality degradation
b) assessment of vulnerability or and impacts of saline water intrusion on the quality of the resiliency of the coastal groundwater resources in relation to land-use and urbanization using hydrochemical approach.

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c) Assessment of the interconnectedness of land-use changes and the perceived effects on livelihood activities of coastal communities in the study area.
d) assessment of the overall impacts of uncontrolled land-use changes and urbanization on the coastal groundwater resources of Lagos and implications for sustainable water management.

By and large, assessment of changes that occur in the coastal environments and ecosystems of parts of Lagos State, Nigeria, would form a major milestone for effective coastal groundwater resources management and leads to sustainable utilization of coastal resources.

Location and Geology of the Study Area

The study area is located within Lagos state situated between Lat. 6° 22'N to 6°52'N and Long. 2° 42'E to 3°42'E covering Lekki, Aja and Epe, which are fast developing coastal areas of Lagos (Fig.1).The southern boundary of the study area is defined by the Atlantic coastline and the northern boundary is characterized by the Lagos Lagoon. In addition, the area is typical of the coastal low-lands that dominate the Lagos landscape and form part of the wider stretch of coastal zone of South-western Nigeria characterized by a dendritic drainage pattern. However, the major landforms in the area are lagoons, swamps and marshes with a low-lying topography characterized by loose sandy soils with elevations ranging between 24m to 64m above sea level. The study area is moderately well-drained with streams and rivers flowing into the Creeks, Lagoons and then to the Atlantic Ocean (Gulf of Guinea).

The climate is wet equatorial type, characterized by freshwater mangroves and swamps. The swamp forests are a combination of mangroves and coastal vegetation developed under the brackish conditions and while freshwater swamps are dominated the lagoons and estuaries. However, much of the vegetation had given ways to rapid urbanization (Tijani, *et al.,* 2005). The mean monthly temperature ranges from 22.1°C to 33°C resulting in a low evapotranspiration. However, the phenomenon of global warming has made temperature to be as high as 35°C for Lagos and its environs in recent times giving rise to somewhat higher evapotranspiration at some locations in Lagos State (Federal Department of Meteorological Services).

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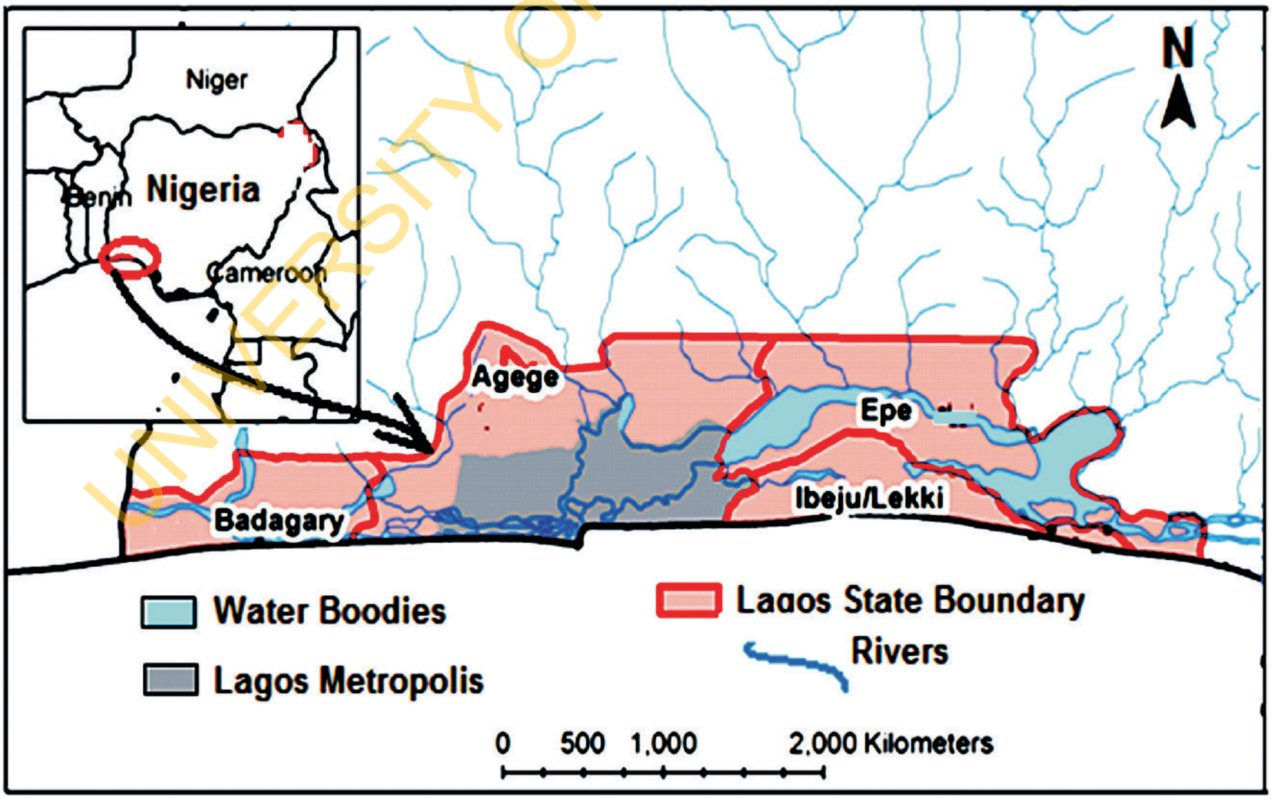

Fig. 1: Location map of the study area

By and large, two main seasons exist in the study area; a short dry season (November to February) and a dominant wet season (March - November). The average annual precipitation is about 1,500 mm and serves as a major source of groundwater recharge in the study area. Nonetheless, the dry season, has been observed to witness light showers probably due to closeness to the sea. Geologically, the study area is underlain by the extensive sedimentary sequences of Dahomey Basin (Fig.2). The tertiary sedimentary succession of the Dahomey Basin is characterized by a major marine transgression in the south-western part of Nigeria during the Maastrichtian (Kogbe, 1975) while the progressive subsidence of the Basin lead to the accumulation of over 2000m thick sediments from Maastrichtian to recent as revealed by Afowo Well-1 off the coast of Badagry (Fayose, 1970).

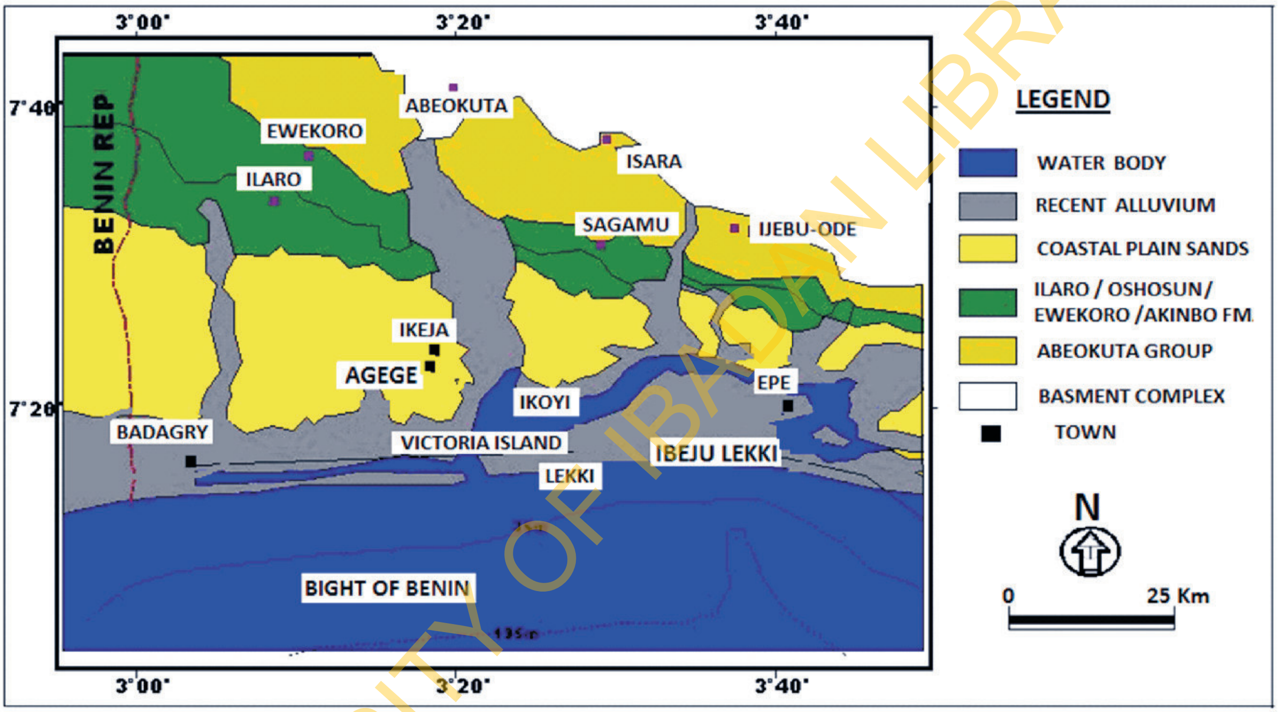

Fig. 2: Geological Map of the eastern Dahomey Basin including Lagos Area.

These sediments have been classified into several lithological formation and sub-units (Jones & Hockey, 1964; Adegoke and Omatsola, 1981). The exposed portion of the sedimentary sequence in most parts of Lagos is the Quaternary Alluvium underlain by virtually in all places by the Quaternary Coastal Plain Sands (CPS). From hydrogeological perspective, Onwuka (1990), outlined three main regional hydrostratigraphic units in Lagos:

a) Upper Aquifer (alluvium and coastal plain sands intercalated with siltstone / clay horizons);
b) Middle Aquifer (Ilaro and Ewekoro Formations); and
c) Lower Aquifer (Abeokuta Formation, lying directly over the Basement Complex).

In most parts of Lagos, including the study area, the main hydrogeological units are those of the Quaternary Alluvium and Coastal Plain Sands (CPS). The Quaternary coastal plain sands (CPS) are underlain in places by the Eocene Middle Aquifer of Ilaro / Ewekoro Formations. By and large, the Coastal Plains Sands Aquifer is the most significant in terms of water supply for local, urban, agricultural, and industrial uses. Locally, it can be subdivided into three distinct aquifer units: a shallow unconfined unit, an intermediate semi-confined unit, and a deeper confined unit. The unconfined unit is exploited by hand-dug wells and shallow boreholes and is vulnerable to pollution from surface activities while the deeper confined aquifers are semi-confined and confined aquifer units are exploited by boreholes.

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In terms of groundwater development, the choice exists, in Lagos, between the tapping of shallow aquifers and deep confined aquifers. However, most boreholes were drilled without detailed hydrogeological studies. However, groundwater use is widespread, although much of the extraction is from domestic hand-dug wells and boreholes that are largely unmonitored.

Methodology

In this study, integrated remote sensing and hydrogeochemical approach were employed in the assessment of the impacts of human induced land-use changes (urbanization and industrialization) on the coastal environments of Aja, Lekki and Epe axis in Lagos, SW-Nigeria (Fig.3). For the assessment of land-use changes and associated impacts on community livelihood, a GIS-based examination involving the integration of *Spot 5* satellite imagery of 1984, 2002 and 2017 of Lagos area (Epe, Lekki and Aja) alongside with *Landsat ETM+* and *OLI* were employed in order to generate the land use / land cover (LULC) changes using *ArcGIS* 10.3 Software. The analysis and evaluation of the satellite images was based on the assumption that the recorded electromagnetic radiation, which is the basis of categorizing land covers, is altered as the land cover/land use of the same geographical area changes (Gonzalez-Trinidad *et. al.,* 2017).

The imageries were geometrically corrected, and the projection was set to Universal Transverse Mercator (UTM) projection system. A false color composite operation was carried on the different bands and then combined to obtain a composite image followed by supervised classification using the maximum likelihood classification algorithm. Finally, a change detection analysis was carried out using the land change modeler in *IDRISI* software to observe the difference in land-use change for the study periods.

For the livelihood assessment, three villages (Iworo, Povita and Etasa) which are farming communities were purposively selected from Badagry area. A multi-stage sampling technique was employed to arrive at the selection of individual respondents. The first stage involves the purposive selection of Iworo, Povita and Etasa villages from Badagry LGA, while the second stage involved systematic sampling technique to select the individual farming households.Structured interview schedule was undertaken with a total of 500 household heads. Interview / questionnaire schedule was used to collect quantitative data while focus group discussion was used to obtain qualitative data. Descriptive statistics comprising of frequency distribution, mean and percentage were used to describe the social economic characteristics of respondents.

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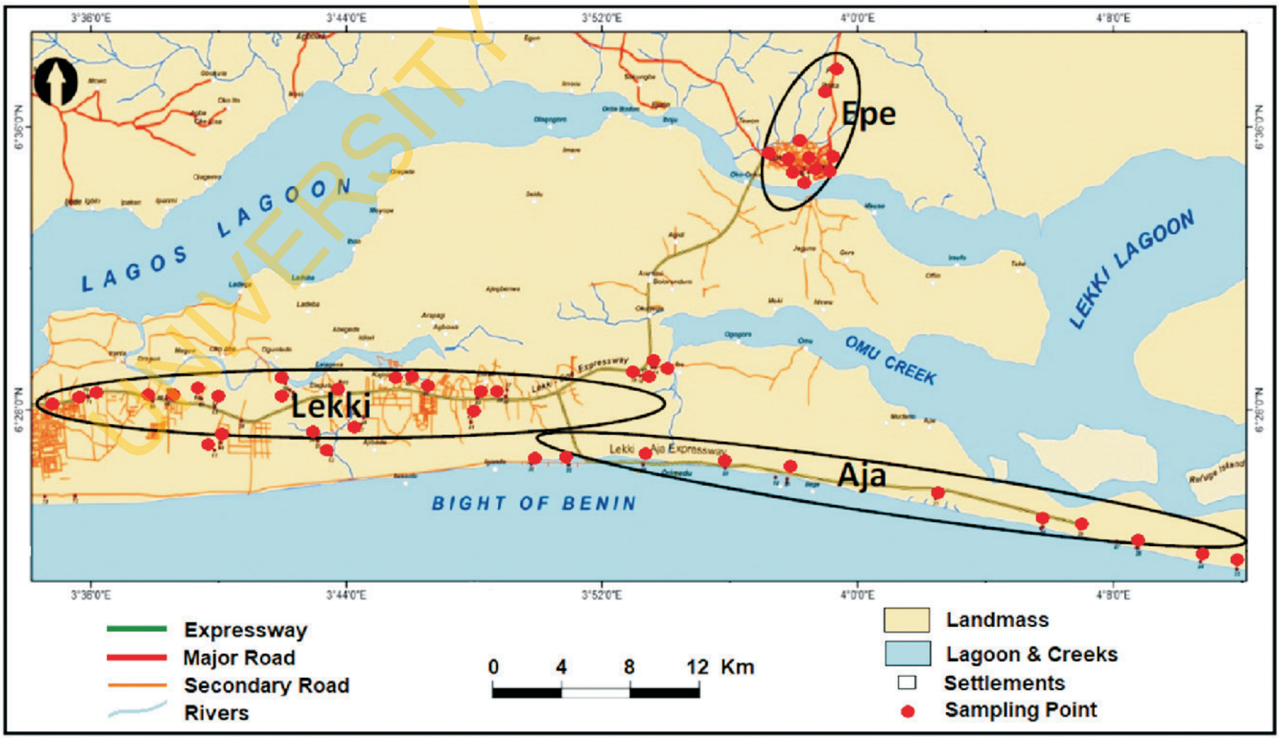

Fig. 3: Map of the sampling points Locations

For the purpose of assessing the impacts of land-use changes vis-a-vis groundwater quality, about seventy (70) groundwater samples were collected from boreholes and hand-dug wells at different locations at Lekki, Aja and Epe axis of the study area. At each sampling point, two set of water samples were collected in pre-rinsed polyethylene plastic bottles; one set for determination of the concentration of the anions while the other set for the cations were acidified concentrated HNO_3^-. The geographical coordinates of each location were recorded using a hand held GPS and marked on the map accordingly (see Fig.3).

In addition, in-situ measurements of transient physico-chemical parameters such as electrical conductivity (EC), total dissolved solids (TDS), salinity, temperature and pH, were also undertaken using a potable handheld multi-parameter meter. The follow-up laboratory analyses involved determination of cations (Ca,Mg, Na, K, Fe and Mn) using ICP-AES at ACME laboratories, Vancouver, Canada and anions (HCO_3^-, Cl^-, SO_4^{2-} and NO_3^-) using spectrometry method at the Department of Agronomy, University of Ibadan, Nigeria.

Finally, data evaluation and interpretations were undertaken using appropriate software packages such as MS-Excel for bi-variate plots and statistical summary of the data and Rockworks for characterization of the water samples using standard Piper (Piper, 1953) and Schoeller (Schoeller, 1967) diagrams.

Results, Interpretation and Discussion

Results of GIS-based Land-use changes Assessment

There is no doubt that remote sensing data facilitates the synoptic analyses of earth-system functions, patterning, and change at local, regional, and likewise global scales over time (Pullanikkatil, *et al.,* 2016). In this study, for the GIS-based assessment of land-use land cover (LULC) changes, three classification maps were generated for the years 1984, 2002 and 2017 and five (5) land cover classes were delineated i.e. built-up area, forested wetland, sand-fill area, water body and agricultural land (Fig. 4).

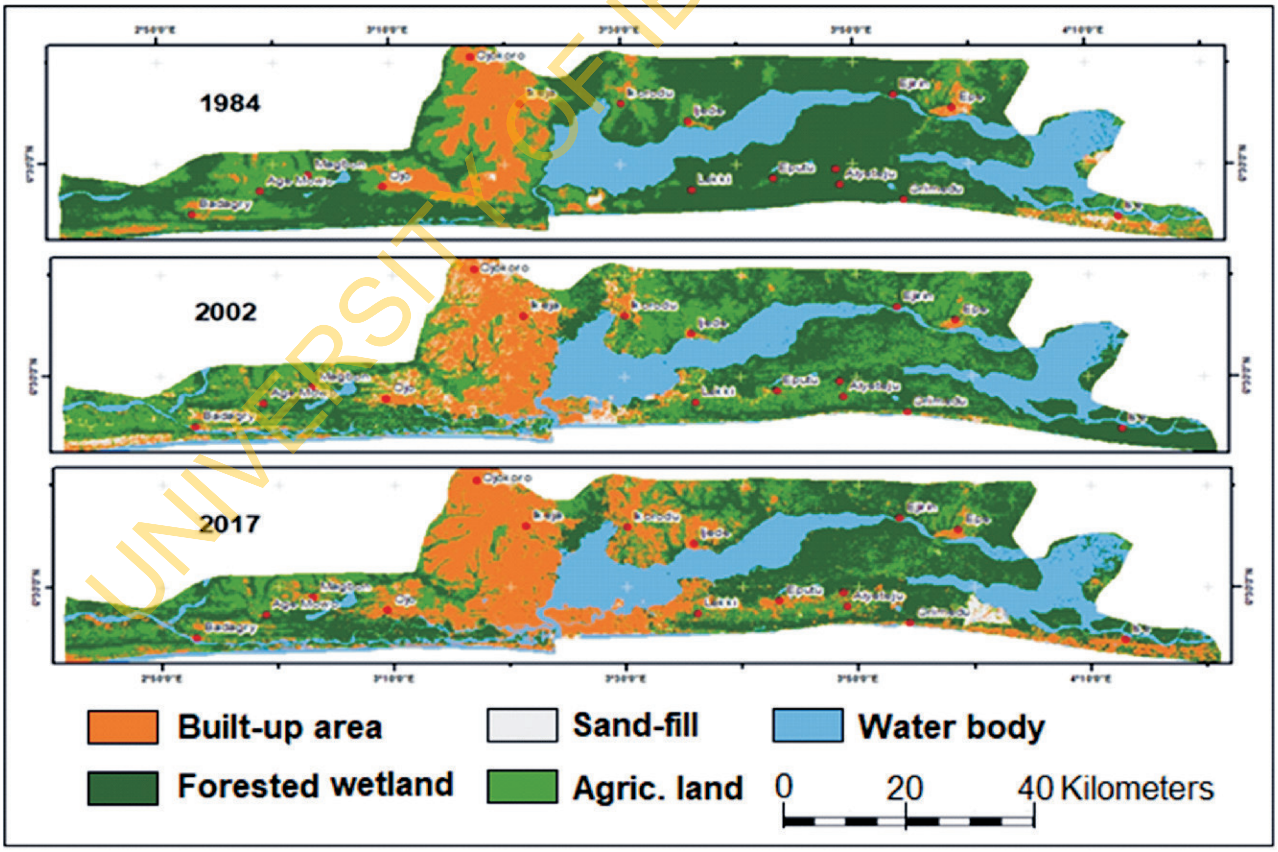

Fig. 4: Land Use Cover Changes Map in Lagos Area, 1984, 2002 and 2017.

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The change detection statistics for the different land-use types for the three years are summarized in Table1 alongside graphical presentation of the relative changes in the different land-uses (Fig.5).

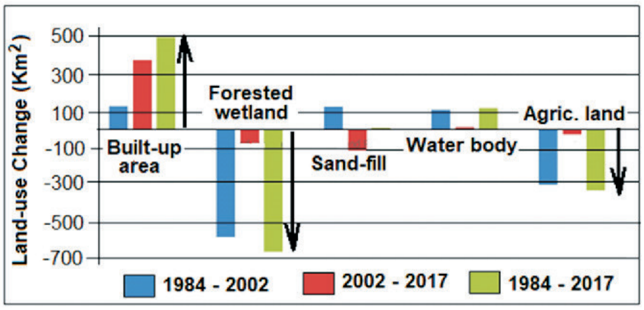

Fig. 5: Percentage Change in the Land Use Cover in the Area.

As presented in Table 1, the results of the GIS-based assessment of land-use / land cover (LULC) changes revealed five (5) types of land use classes for the years 1984, 2002 and 2017 in the study area. Data analyses revealed significant increase in the built-up areas of the study areas from 447.3km^2 1984 to 951km^2 in 2017 with cumulative increase of 503.7km^2 accounting for an increase of about 85%. However, the most significant change for built-up land for the thirty-three (33) years duration occurred between 2002 to 2017 with an increase of 378.4km^2 giving rise to 66.1%. The trend is a clear evidence of population growth and urbanization that drives infrastructural development inform of housing, roads and related facilities.

Agricultural land and forested areas were reduced by 32% and 28% respectively between 1984 and 2002. This is a clear indication of urbanization and associated deforestation consequent to housing and infrastructural developments. For the agricultural lands, agricultural land decreased significantly by -27% between 1984 and 2017 with the largest reduction of 304.6km^3 from 1984 to 2002 accounting for 28% decrease (Table 1).

Likewise, the water bodies have shown a reduction of 1.5% from 1984 to 2017; though, they occupied significant area of 105.6km^2 for 1984 to 2002 with a 15.4% increase and 10km^2 decrease in 2002 to 2017 (1.2%). The decrease between 2002 and 2017 may be attributed to sand-fillings and land reclamation consequent to the development of the Eko-Atlantic City. By and large, the increase in built-up area vis-à-vis decrease in forested wetland and agricultural land as presented in Fig. 6, are clear indication of impacts of urbanization and increasing population growth and the attendant deforestation to accommodate the increasing housing and infrastructural needs.

Hence, for sustainable development and attainment of the SDGs, there is the need for adherence to a proper urban master plan in order to balance the interest of the environment in an integrated resources management and infrastructural development dynamics of a rapidly urbanized city like Lagos.

Table 1: Statistical Summary of the Land Use Changes in the Study Area

	Land-use Change (in km^2)			**Percentage Change**		
Class	1984-2002	2002-2017	1982-2017	1984-2002	2002-2017	1984-2017
Built-up Land	125.26	378.46	503.73	28.00	66.10	84.61
Forested wetland	-588.09	-81.70	-669.79	-32.10	-6.57	-4.46
Sand Fill	124.09	-116.43	7.66	576.42	-79.96	-540.86
Water body	105.61	10.27	115.87	15.42	1.30	1.50
Agricultural Land	-304.6	-28.90	-333.46	-28.34	-3.75	-2.68

Results of Livelihood Assessment

Table 2 reveals the age distribution ranges between 41 and 70 years, while more than half (53.3%) of the respondents fall within the age bracket of 41-50 years indicating that the majority of respondents were within the economically active age bracket, at an average age of 51.8±7.0 years.The percentage distribution of respondents by gender indicates that 76.7% of the respondents were male while 23.2% were female with 0.9% as widowed. This however does not necessarily imply that there are more male than female dwellers in study area, rather it suggests that there are more male-headed households than those headed by female counterparts. The percentage distribution of the respondents, according to marital status, shows that a vast majority (95.8%) of the respondents are married, while 3.3% are single suggesting the fact that married households will have more family labour for agricultural production and this may also be helpful in

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adapting to the effects of land-use and climate changes as there are possibilities of engaging in multiple livelihood choices. This is in consonance with Baruwa, et. al., (2012) who reported a larger proportion of married individual in coastal area of South-western Nigeria.

In terms of educational status, 67.5% of the respondents have one form of formal education or the other, while 32.5% have no formal education which suggests that households in the study coastal communities will be better positioned to make a broader series of choices for effective adaptive measures in the face of land-use and climate changes. This finding is congruent with Adeparusi, et. al., (2003) who reported a high level of literacy among people in coastal communities of South-western, Nigeria. Studies have also shown that improving education and disseminating information is an important measure for stimulating participation in various livelihood options and development of natural resource management initiatives (Kandlinkar and Risbey, 2000; Dolisca, *et. al.,* 2006).

In addition, 83.4% of the respondents have more than 30 years residency in the study area, while only 0.8% have residency of less than 20 years indicating domination of the native or traditional inhabitants in the study rural community. Furthermore, 58.8% of the respondents have household size of 1-5 people; while 41.2% have household size of above 5 persons with a mean household size of 4.8±0.9 persons. In terms of household income, 60.4% of the respondents earned below ₦21,000/month while 39.6% earned above ₦21,000 which is within the bracket of prevailing national minimum wage. Bye and large, the average monthly income of ₦17,212.50 is a clear indication of the fact that the households in the study coastal communities are among the rural poor in Nigeria.

Livelihood Activities engaged in

Fishing, arable crop farming, water transportation service and trading were the predominant occupations in the study area (Table 3). However, about two-third of the respondents engaged in multiple livelihood activities to enhance living standards. There was a general consensus amongst the participants that there are decline in the level of involvement in livelihood activities in recent times compared to thirty years ago. For example, cassava, maize rice, coconut, banana, okra, pepper, melon, plantain and sugar cane were mostly cultivated in the areas 30 years ago, compared to only fewer crops like cassava, rice and maize cultivated in the recent times. The fact that other crops either

Table 2: Distribution of respondents by socio economic characteristics

Variable	Frequency	Percentage	Average
Age			
41-50 years	128	53.3	
51-60 years	72	30.0	
61-70 years	40	16.7	51.8±7.0
Gender			
Male	184	76.7	
Female	56	23.3	
Marital status			
Single	8	3.3	
Married	230	95.8	
Widowed	2	0.9	
Educational Status			
Non –formal	78	32.5	
Primary	23	9.6	
Secondary	131	54.6	
Tertiary	8	3.3	
Years of residency			
≤ 10 year	0	0	
11-20 year	2	0.8	34.4±2.9
21-30 years	38	15.8	
31-40 years	105	43.8	
>40 years	95	39.6	
Household size			
1-5	141	58.8	
6-10	67	27.9	4.8+1.0
11-15	22	9.2	
16-20	8	3.3	
Above 20	2	0.8	
Estimated income			
< 20,0000	145	60.4	₦17,212.38
21,0000 - 40,0000	62	25.8	
41,000 - 60,000	22	9.2	
61,000 - 80,0000	8	3.3	
>80,0000	3	1.3	

decline in quantity or are no more cultivated in the study area is clear indication of the changes in land-use, whereby areas for cultivation of some of the crops gave way for the increasing urban infrastructural development.

Observable changes in climatic parameters

Figure 6 presents the results of some environmental elements with respect to the type of change perceived to have occurred by the respondents over the last 30 years. It reveals that soil fertility (95.2%) was indicated to have declined over time by majority of respondents, while temperature (69.9%), ocean surge (46.7%) and flooding (43.3%)were perceived to have increased over time. This indicates not only an increasing awareness of climate variability and change among respondents, it also shows that majority of the people are experiencing

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Table 3: Changes in different livelihood activities in the study area

Livelihood Activities	30 years ago		Now (2018)	
	Freq	%	Freq	%
On Farm				
1. Arable crop farming	182	75.8	110	45.8
2. Tree crops farming:	186	77.5	162	67.5
3. Cash crop planting	7	3.2	0	0
4. Livestock	41	17.1	16	6.7
5. Fish farming	193	80.4	146	66.1
Off Farm				
6. Processing of farm produce	52	23.5	28	11.7
7. Hunting/gathering of NTFPs	13	5.9	6	2.5
8. Milling of farm produce	7	3.2	13	5.4
Non-Farm				
9. Artisan	8	3.3	30	12.5
10. Road Transportation	17	7.1	42	17.5
11. Water transportation	39	16.3	45	18.8
12. Clergy	5	2.3	16	6.7
13. Traditional health services	9	3.8	9	3.8
Local trade				
14. Civil/public service	3	1.4	9	3.8
15. Petty trading	57	23.8	25	10.4
16. Sales of Agric. Products	8	3.3	10	4.2
Local formal employment				
17. Teaching	20	9.0	3	1.3
18. LGA civil service	6	2.7	6	2.5
19. Night guard	0	0	0	0
20. Migratory wage services	5	2.3	48	20.0

the negative effects of climate change in their livelihood activities. This assertion is clearly supported by perceived increase in rainfall (96.7%) and erosion (82.9%), which are clear indications of combined effect of climate variability and land-use change. This is further buttressed by the result of the focus group discussion, as there was a general agreement among discussants that there has been a change in climatic condition over a period of time. For instance, participants in one of the focus group discussions reached the following consensus:

> *"We do experience flood now especially around July when the intensity of rainfall is high compared to thirty years ago".*

Another discussant also argues:

> *"It is amazing to us that the water is increasing this time compared to thirty years ago as areas that were spared initially, are now submerged".*

Perceived effects of climate change on land use for livelihood activities

Data in Table 4 reveals that exotic species (93.8%), farmlands availability (83.3%), soil water quality (86.3%) and soil fertility (74.3%) were perceived to

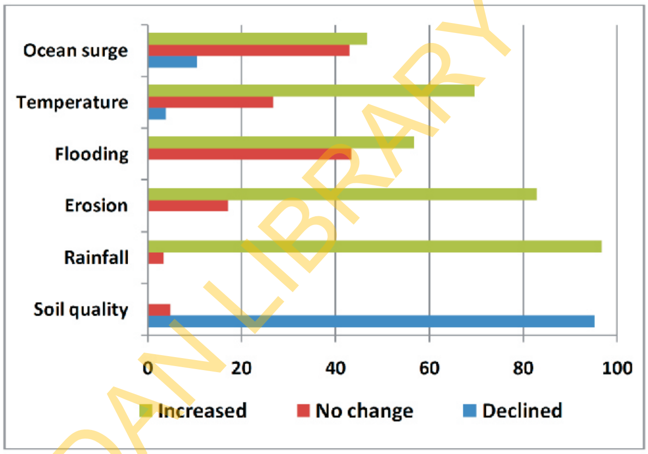

Fig. 6: Percentage distribution of respondents by observable changes in climatic parameters

have declined over the past 30 years by respondents in the study area. These are indications of combined impacts of environmental degradation and land-use changes which obviously suggests that the livelihood, local economy and hence well-being of the study coastal communities, might be under the threats of climate and land-use changes. The result which revealed that damage of building and infrastructure (93.5%) arising from increased coastal storm intensity, land pollution (89.6%) and land conflicts (62.5%) had increased over past 30 years. While these can be regarded as combined effects of environmental degradation and land-use changes, the implication is that the difficulties in access to arable lands do results in increased tendency and reality of land-use conflicts leading to loss of income / livelihood among dwellers in study coastal areas.

Perceived effects of changes on livelihood activities

As shown in Table 5, the respondents cited different effects of changes in land-use and climate on their livelihood activities. Most of the respondents indicated a decline in food crop productivity (96.7%), livestock production (90.0%), cash crop production (83.8%), access to snail (83.7%) and reduction of size of fish (83.3%) leading to general reduction in income generation (90.0%). These could be clearly attributed to shift in seasonal and erratic weather patterns as corroborated by majority of the respondents who

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Table 4: Percentage distribution of respondents by perceived effects of climate change on land use for livelihood activities

Items	Decline	No change	Increase
Soil fertility / quality	74.3	5.3	20.4
Farmland availability	83.3	16.7	0.0
Soil water quality	86.3	10.4	3.3
Spread of exotic and invasive species	93.8	3.3	2.9
Non-farm Land availability	72.5	27.5	0.0
Displacement	35.6	0.0	64.4
Land conflict	20.4	17.1	62.5
Land pollution	0.0	10.4	89.6
Damage of building / infrastructure due to coastal storm intensity	3.8	2.9	93.3

Table 5: Percentage distribution of respondents by perceived effects of changes on livelihood activities

Items	Declined	No change	Improved
Food Crop productivity	96.7	3.3	0.0
Cash crop production	83.8	16.2	0.0
Livestock production	90.0	10.0	0.0
Quantity of fish	76.3	23.7	0.0
Fish species	63.3	36.7	0.0
Size of fish	83.3	16.7	0.0
Fish processing	39.6	60.4	0.0
Marketing of produce	36.3	17.1	46.6
Income generation	90.0	6.7	3.3
Access to bush meat	77.1	20.0	2.9
Access to snails	83.7	16.3	0.0

Source: Field survey, 2018

affirmed that climate change have impacted negatively on their livelihood activities. In tandem to this finding, one of the participants during the FGD reported thus:

> *"There has been a drastic reduction in the quantity of fish caught in present time compared to what was obtained thirty years ago. Our water bodies have been polluted and most of the fishes have gone into extinction and the ones we manage to catch self are just too little".*

In addition, most of the participants reiterated that there has been a significant difference in travelling distance before getting fish to catch 30 years ago and now. The result of the FGD further corroborates this:

> *"Thirty years ago, we used to walk about 5-7 km and in just 20-30 minutes, we would have caught so much fish. However, now, a lot of things have changed. We spend close to 10-15 km and spend close to 3-5 hours before we catch any and at the long run we may not even catch any. There are even some types of fish we used to catch before but which are no more available".*

This finding affirmed the position of Rarieya, et. al., (2010), which established a strong nexus between climate change and agricultural production and hence, food insecurity.

Coping Strategies to Climate Change Effects on Livelihood

Table 6 shows that respondents generally used a combination of strategies, as no single strategy is enough to effectively adjust to climate change effects. Nine strategies were identified, out of which livelihood diversification ($x = 1.40$) and alternating livelihood activities ($x = 1.37$) and feeding pattern adjustment ($x = 1.00$) were the mostly employed by the respondents. This further affirms the fact that land-use and climate changes have constituted threat to agricultural productivity, livelihood and well-being of the people in the study area. Other coping strategies used by the respondents are borrowing from relative and friends, migration, sending children to relatives/friends to reduce expenses. Furthermore, the fact that many of the respondents have to rely on family, relatives and even religious organization for financial supports further reflects the impacts of land-use and climate variability on their livelihood.

Results of Hydrochemical Assessment of Water Quality

Hydrochemical characteristics of groundwater system can serves as an indirect indicator of geochemical processes in the course of water evolution via interaction with the subsurface environment. Also it can provides evidence of natural and human induced quality degradation arising from factors such as sea level rise (eustasy), flooding, irrigation returns, mining activities, uncoordinated industrial waste discharge and salt water intrusions in coastal areas (Tijani, *et. al.,* 2005). In this study, the summary of the results of hydrochemical quality assessment of the water samples collected from

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Table 6: Percentage distribution of Coping strategies to climate change effects on livelihood

Coping strategies	Never	Occasionally	Always	Mean*
Adjust feeding pattern	0.4	99.2	0.4	1.00
Alternate livelihood activities	11.7	40.0	48.3	1.37
Diversification	17.1	25.8	57.1	1.40
Borrow from friends	44.2	55.8	0	0.56
Borrow from relatives	20.0	80.0	0	0.80
Migration	31.3	68.7	0	0.69
Send children to relatives/ friends	26.7	73.7	0	0.73
Depend on religious organization	46.7	53.3	0	0.53
Remittances from relatives from cities	50.8	49.2	0	0.49

Source: Field survey, 2018
*Mean derived from the average of the frequency of responses (i.e. Never =0, Occasionally =1, Always =2)

different sources (mostly boreholes and hand dug wells) across the study area are presented in Table 7. Except for NO_3, the results across the study area revealed that the major cations and anions are within the acceptable limit of WHO/SON standards.

As summarized in Table 7, the pH of the water samples range from 4.0 – 7.3 with average of 5.5, 6.0 and 6.5 at Epe, Lekki and Ajah areas respectively suggesting a mild acidic to neutral groundwater system. The measured EC and TDS are generally below the recommended value of 750 µS/cm and 1,000 mg/l respectively with exception of a contaminated dug-well at Awoyaya (Lekki axis) with EC of 1,883µS/cm. The generally low TDS (36 – 683 mg/l) and mild acid nature of the groundwater across the study area implies low mineralized water with capacity to promote weathering and leaching of geologic materials with possible impacts of corrosiveness of groundwater system and solubility of slightly soluble compounds leading to increase the dissolved ions, even at shallow depths (Bilgehan and Ali, 1990).

Table 7: Summary of the Results of Hydrochemical Analyses of the Groundwaters

Parameter	Epe (N=10)		Lekki (N=47)		Aja (N=17)		WHO (2011)
	Range	Mean	Range	Mean	Range	Mean	
pH	4.0–6.8	5.5	4.5–7.3	6.0	5.9–7.1	6.5	6.5-8.5
Temp.(°C)	27.9–31.7	29.3	27.9–30.6	29.2	29.5–37.4	31.1	24
EC (µS/cm)	109–969	499.2	50.3–646	247.8	51.4–401.0	220.3	750
TDS(mg/l)	78.0–683	353.5	35.7–458	168.7	36.7–285.0	157.3	1,000
Sal. (mg/l)	57.0–474.0	244.0	31.3–964	154.3	32.0–285.0	114.7	500
TH (mg/l)	81.2–206.4	136.2	12.9–294.0	201.9	12.0–123.7	55	500
Ca^{2+} (mg/l)	1.9–71.2	33.4	4.4–98.0	21.6	3.8–39.1	19.9	200
Mg^{2+} (mg/l)	0.9–6.8	3.7	0.4–11.8	2.5	0.6–8.2	2.8	50
Na^{+} (mg/l)	11.5–92.8	52.1	4.2–230.7	26.9	3.8–31.0	17.4	200
K^{+} (mg/l)	1.8–43.7	17.9	1.1–68.4	7.9	0.6–15.2	6.5	100
Fe^{2+} (mg/l)	0.07–0.1	0.03	0.0–10.9	0.4	0.01–6.1	1.1	3.0
Mn^{2+} (mg/l)	0.04–0.6	0.23	0.01–0.66	0.08	0.01–0.14	0.04	-
HCO_3^-(mg/l)	12.2–61.1	43.9	6.1–61.1	28.2	24.4–61.0	38.9	250
Cl^-(mg/l)	72.0–518.4	310.8	10.8–986.5	140.5	93.7–367.2	181.6	600
SO_4^{2-}(mg/l)	5.4–35.8	18.2	0.43–302.5	53.5	7.1–68.5	23.9	400
NO_3^-(mg/l)	0.15–1.0	0.37	0.02–1.6	0.26	0.01–1.01	0.21	50
Cl^-/HCO_3^-	5.9–8.5	7.1	2.7–16.2	4.8	3.8–6.0	4.7	<2.4

The cations revealed concentrations of 1.9 – 98.0 mg/l Ca^{2+}, 0.4 – 11.8 mg/l Mg^{2+}, 4.2 – 230 mg/l Na^+ and 1.1 – 68 mg/l K^+. The concentrations of the anions are 6.1 – 61.1 mg/l HCO_3^-, 10.8 – 986.5 mg/l Cl^- and 0.4 – 302.5 mg/l SO_4^{2-}. It is clear that Na and Ca represent the dominant cations while Cl and HCO_3 represent the dominant anions in the water samples. These apparently constitute the greater proportions of the observed total dissolved solid (TDS) as presented in Fig. 7a-d. While NO_3 is generally less than 1.0mg/l indicative of no

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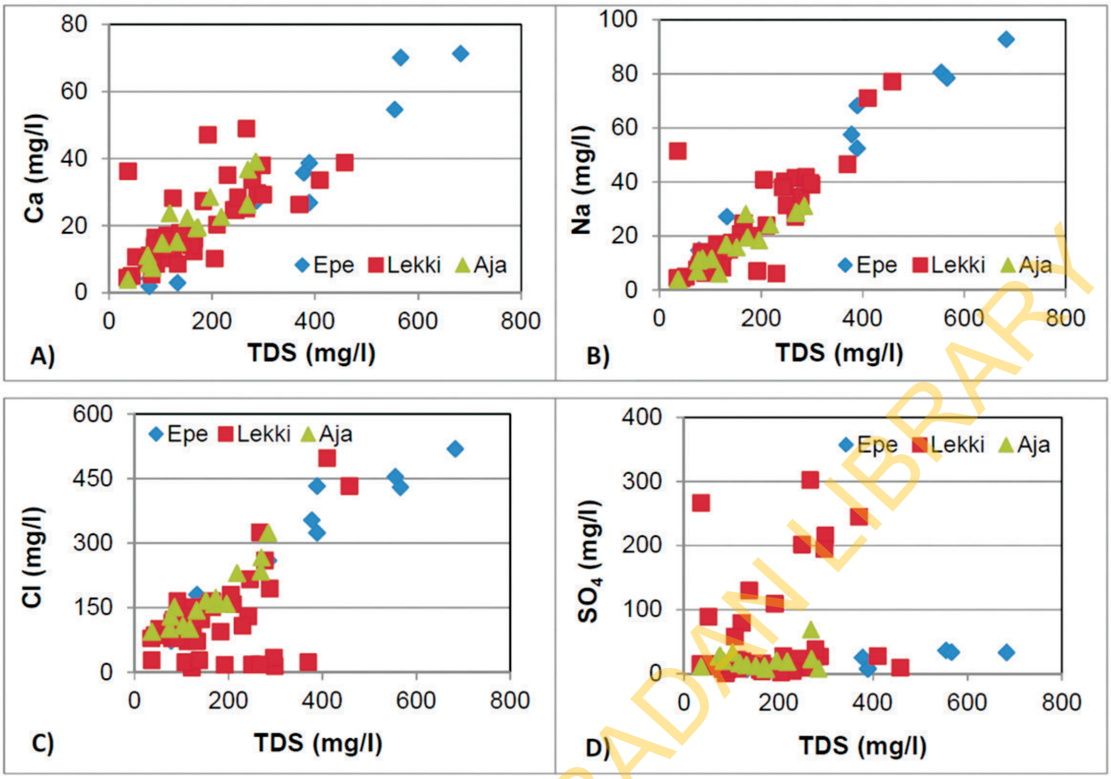

Fig. 7: Plot of TDS again major cations (Ca and Na) and anions (Cl and SO_4)

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anthropogenic contamination, the higher concentration of Fe^{2+} above 3mg/l in a couple of location in Lekki-Aja axis is a clear indication of iron-oxidation and corrosion problems associated with coastal plain sand aquifer in the study area.

Nonetheless, the generally low concentrations of the cations and anions as highlighted above suggest low mineralization of the groundwater in the study area which is indicative of precipitation recharge dominated groundwater system with limited migratory history. Furthermore, a slightly higher TDS (78.0–683 mg/l) of the samples from Epe compared to Lekki and Aja (35–458mg/l) can be attributed to possible leaching and dissolution of the relatively thick lateritic overburden in the area. Nonetheless, most of the water samples can be considered chemically potable and within the acceptable limits of WHO standards.

However, the relatively higher concentrations of Na^+ and Cl^- compared to other ions are indicative of possible impacts of seawater in such coastal environment like the study area. This is consistent with the positive values of rCl^-/HCO_3^- (2.7–16.2) with average of 7.1, 4.8 and 4.7 at Epe, Lekki and Ajah areas respectively are clear indication of the fact that the groundwaters have substantial amount of chloride ion compared to bicarbonate ion. This is an indication of impacts of seawater on the chemistry of the coastal shallow aquifer system apparently due to sea surge flooding and seawater intrusion.

In addition, the hydrochemical characterization of the groundwater using Piper-tri-linear plot (1966) revealed a Na-Cl tainted water type, with Na comprising about 72% of the total cations and Cl comprising about 67% of the total anions (Fig.8). This is, once again, indicative of impacts of seawater. However, the salinization path towards Ca-(Mg)-Cl and Ca-(Na)-HCO_3water types suggests active infiltration and aquifer flushing resulting from mixing and dilution with water of Ca-Mg-HCO_3 dominated recharge (Appelo, 1994; Appelo and Postma, 2005).

To further assess the possible controlling hydrochemical process responsible for the observed chemical composition, Chloro-alkaline indices (CAI) by Schoeller (1967) was employed. The estimated CAI $= \{Cl^- - (Na^+ + K^+)\}/ Cl^-$ (ions expressed in meq/l) revealed positive Schoeller indices (0.40 – 0.93) that are indicative of cation exchange reaction whereby the primary Ca+Mg dominated water converted to Na+K dominated water (Liu *et al.,* 2015). This is a clear indication of impact of Na+K dominated seawater on the primary Ca+Mg dominated freshwater as

Water type	Percentage Sample		
	Lekki	Ajah	Epe
Na-Cl	44.4	26.7	100%
Ca-Cl	35.6	73.3	0
Na-SO4	8.9	0	0
Ca-SO4	11.1	0	0

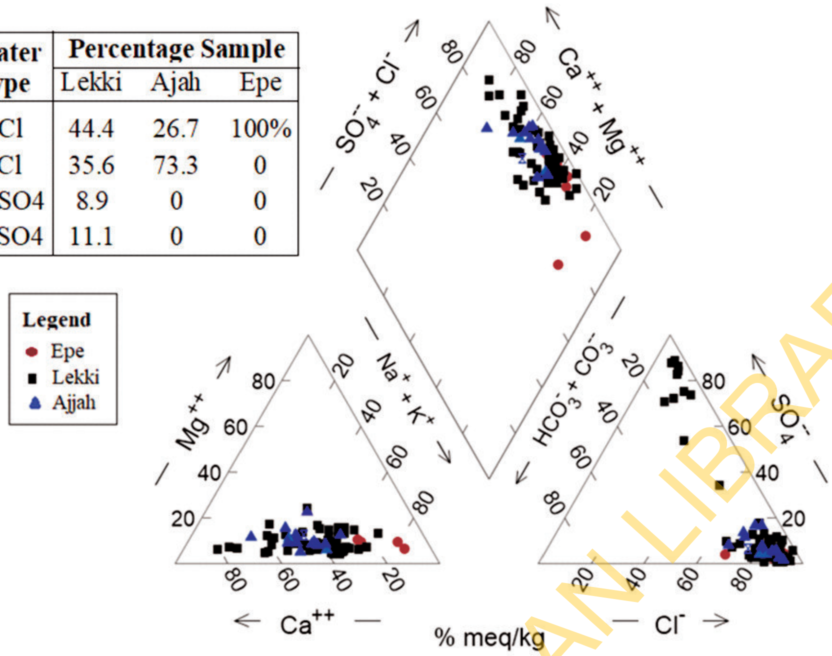

Fig. 8: A Piper diagram showing the Water Types

consequence of seawater intrusion into the coastal aquifer; hence a clear indication of urbanization and uncoordinated groundwater development.

In summary, due to increasing population and development consequent to urbanization on one hand and due to shallow nature of the unconfined aquifer, characterized by loose coastal plain sands on the other hand, the groundwater quality in the study area is prone to degradation. Notable sources of degradation identified are the impacts of seawater and anthropogenic contamination from infiltrating surface waste water and possible leakages from in-house soak-away pits in the study area.

Conclusion and Recommendations

Sustainable development in coastal environments such as Lagos is of utmost important in terms of environmental and resource management in the face of rapid urbanization and threat of emerging climate change. In this study, an integrated GIS-based and hydrochemical and assessments were carried out to investigate/ assess the impact of rapid urbanization cum industrialization on the sustainable groundwater resource development.

The result of the assessment of land use changes via GIS based LULC changes indicates significant changes in the biophysical attributes such as built up area, forested wetlands, sand fill, and water and agricultural land. The increase in built-up area as evidenced of urbanization and industrialization, especially between 2002 and 2017 with about 65% increase suggesting encroachment on the coastal landscape of Lagos. This is manifested in a number of infrastructural developments such as the Eko Atlantic City, Dangote Refinery, Dangote Fertilizer Plant, Lekki Free Trade Zone, Lekki International Airport, Lekki Deep Sea Port, Lagos State Golf Course and Lagos Smart City among others.

It can be concluded that climate change impacted negatively on land use as most of the respondents indicated a decline in soil fertility, land availability, land fragmentation and loss of soil quality. This further gave rise to decline in crop and livestock production, quantity of fish harvested, fish species as well reduction in income. The study also found that the growing need for survival in coastal communities has led to diversification in non-farming activities as most of the respondents engaged in multiple socio economic activities. This suggests that climate change has constituted threat to agricultural productivity, livelihood and well-being of people in coastal communities.

The study thus recommended the need to improve the adaptation capacity of coastal communities as well the need to mainstream these strategies into conservation of natural resources to combat such negative impacts for

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guaranteed sustainable livelihood. Also, there is need to focus on livelihood improvement activities of coastal communities through participatory process and understanding of the social and economic factors of the people. Improvement in the quality of livelihoods and the environment is germane to improving the wellbeing of people in coastal areas. Hence, policies aimed at mitigating unsustainable activities that may induce changes in land use in coastal areas should be promulgated and enforced.

From the hydrochemical assessment, the major cations and anions revealed a fingerprint of seawater-impacted quality deterioration of groundwater in the study area. The unconfined nature of the coastal plain sand aquifers makes it vulnerable to anthropogenic contamination from infiltrating surface waste water and seawater impacts from ocean surge and flooding. The dominance of Na and Cl ions and the observed elevated Cl^-/HCO_3^- are clear indication of salinization and seawater impacts. Piper diagram also revealed evolution of the primary $Ca\text{-}Mg\text{-}HCO_3$water type through active infiltration and aquifer flushing towards Ca-(Mg)-Cl and Ca-(Na)-HCO_3water types suggests salinization and seawater impacts.

Although, the general quality of the groundwater samples from the study area is within the recommended limits of WHO standards, however, the long term sustainability is in doubt due to the rapid population increase, urbanization and associated infrastructural developments. Hence, to ensure sustainable groundwater resources development and management, there is the need to curtail the rate of groundwater abstraction and indiscriminate groundwater development practices that will further trigger degradation (salinization) of the coastal groundwater resources in Lagos area. Therefore for sustainable management of water resources, a more holistic approach should encompass all the components of the local resources (water, land, human and biological resources), socio-economic and climatic factors within the framework of integrated water and environmental resources management as highlighted in Fig. 9.

Nonetheless, with about 10-30% current water supply coverage, the challenge of the existing Lagos Water Supply Master Plan to cover the water demand gap by 2030 is daunting. Therefore, for sustainable resources management and attainment of the targets of the SDG-6 with emphasis on security of the coastal groundwater supply in Lagos metropolis, SW-Nigeria, there are the needs to:

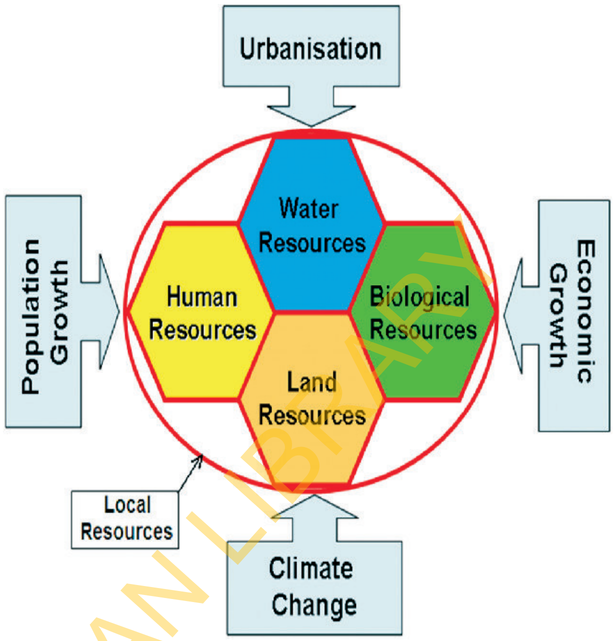

Fig. 9: Concept of integration of components of local resources with social economic and infrastrural development strategies.

a) To formulate plans and strategies that would address all the gaps and challenges of water supply system.
b) To have a clear regulatory structure and governance frameworks to address the issues of monitoring of quantity and quality of groundwater system.
c) To regulate uncontrolled proliferation of private wells (boreholes) development vis-à-vis the protection of coastal aquifer from seawater intrusions.
d) To develop a robust land-use master plan that will integrate both groundwater resources management and environmental protection into the development plans.
e) To focus more on livelihood development assistance of coastal communities and promote natural resource management and conservation.

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