

MAPPING OF RIVER WATER QUALITY USING INVERSE DISTANCE WEIGHTED INTERPOLATION IN OGUN-OSUN RIVER BASIN, NIGERIA

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Received 8 July 2013, accepted in revised form 27 September 2013

Abstract

Sustainable management of water resources involves inventory, conservation, efficient utilization, and quality management. Although, activities relating to quantity assessment and management in terms of river discharge and water resources planning are given attention at the basin level, water quality assessment are still being done at specific locations of major concern. The use of Geographical Information System (GIS) based water quality information system and spatial analysis with Inverse Distance Weighted interpolation enabled the mapping of water quality indicators in Ogun and Ona catchment of Ogun-Osun River Basin, Nigeria. Using 27 established gauging stations as sampling locations, water quality indicators were monitored over 12 months covering full hydrological season. Maps of seasonal variations in 10 water quality indicators as impacted by land-use types were produced. This ensured that trends of specific water quality indicator and diffuse pollution characteristics across the basin were better presented with the variations shown along the river courses than the traditional line graphs. The production of water quality maps will improve monitoring, enforcement of standards and regulations towards better pollution management and control. This strategy holds great potential for real time monitoring of water quality in the basin with adequate instrumentation.

Keywords: GIS, Water quality maps, Ogun-Osun, river basin

1. Introduction

River basins are the geographic area contained within the watershed limits of a system of streams and rivers converging toward the same terminus, generally the sea or sometimes an inland water body (Subramaya 2006). Due to the largeness and complexity of hydrological, geological, environmental and social data needed to be gathered in management of natural resources at such a spatial scale, there is always a challenge of integration of these volumes of data (Mtetwa et al. 2003). Secondly, the cost of generating these data has also become a challenge, hence, the inability of government especially in

developing countries to evolve a holistic and reliable river basin management practices. Nevertheless, integrated management of variables at the river basin, catchment or watershed scale must be the primary approach to addressing sustainable natural resources management generally and water resources in particular. This has been clearly underscored in the principles of Integrated Water Resources Management (Rosana et al. 2007). Geographical Information Systems (GIS) is being recognized as a powerful tool in addressing issues and managing geographical information in holistic manner without losing the spatio-temporal variability which

are often critical in assessment and decision making (Mtetwa et al. 2003; ESRI 2005). The GIS technology integrates common database operations such as query and statistical analyses with the unique visualization and geographic analysis benefits offered by maps and spatial databases. It also provides capabilities to analyze and simulate this complex phenomenon, thus, it has become a support tool for researchers and natural resources managers (Mitasova - Neteler 2004; Xingmei 2006).

Harley et al. (2009) used GIS platform in their study to identify natural and anthropogenic sources of metals in urban and rural soils. The use of spatial interpolation, a procedure that enables the prediction of events from known or observed event to possible scenarios is a major strength of GIS. Mtetwa et al. (2003) used GIS to monitor nutrient pollution loads and their spatial distribution in an agro-rural catchment in South Africa. The systems enabled the delineation of impacts and patterns of pollution across the catchment. The deployment of GIS interpolation methodology could aid the understanding of extent, pattern, distributions and risk assessment of diffuse pollution. Use of GIS in river basin related activities are documented by Xihua et al. (1999), Li et al. (2004), and Balakrishnan et al. (2011), and have also demonstrated the potential of GIS interpolation in their work on mapping environmental variables at watershed level.

Unabated pollution of surface water have been recognized as an environmental disaster and improved management and control is directly related to effective monitoring, assessment and enforcement of standards (Aelion - Conte 2004; Chaosheng 2006). There is still much to be done in development of protocol and methodology on the use of GIS in river basin management, river water quality monitoring, evaluation, data analysis and presentations in Nigeria. This study is an attempt aimed at deploying this technology in environmental and natural resources management in Nigeria.

2. Materials and Methods

2.1 Base Map and Land-use Classification

The Ogun and Ona sub-basins of the Ogun-Osun River Basin (OORB) were the area of interest in this study (Fig. 1). Geographic details (drainage density, topography, and geomorphology) and socio-economic data (population density, household distribution and demographic data) were collected from Ogun-Osun River Basin Development Authority (OORBDA), Oyo State Water Corporation and the International Institute for Tropical Agricultural (IITA).

The land use land cover map (LULC) of the targeted sub basin in OORB, was produced from classification of Landsat ETM image of the area acquired in 2009 from the IITA open resources database and processed using Erdas Image version 8.7 software. Reconnaissances were done in 2009/2010 before carrying out image classification. Supervised classification scheme was used following the procedure described by Kiage et al. 2007 and Seto et al. 2002. The pixel categorization process was done by specifying to the computer algorithm, numerical descriptors of the various land cover types present in a given scene. Thus, representative sample sites of known cover type (called training parcels) were used to compile a numerical characteristics key that best describe the spectral attributes for each feature type of interest. Each pixel in the image data set was then compared numerically to each category in the characteristic key and labeled with the name of the category it most resembles. In order to increase the accuracy of the categorization and classification, many representative sample sites that are well distributed over the scene for each category were trained.

2.2 Water Quality Assessment

Rivers Ogun, Ona, Ofiki, Ogunpa, Ewekoro, Opeki, Omi, and Ibu were monitored monthly for 12 months at 27 locations which corresponded to the gauging stations

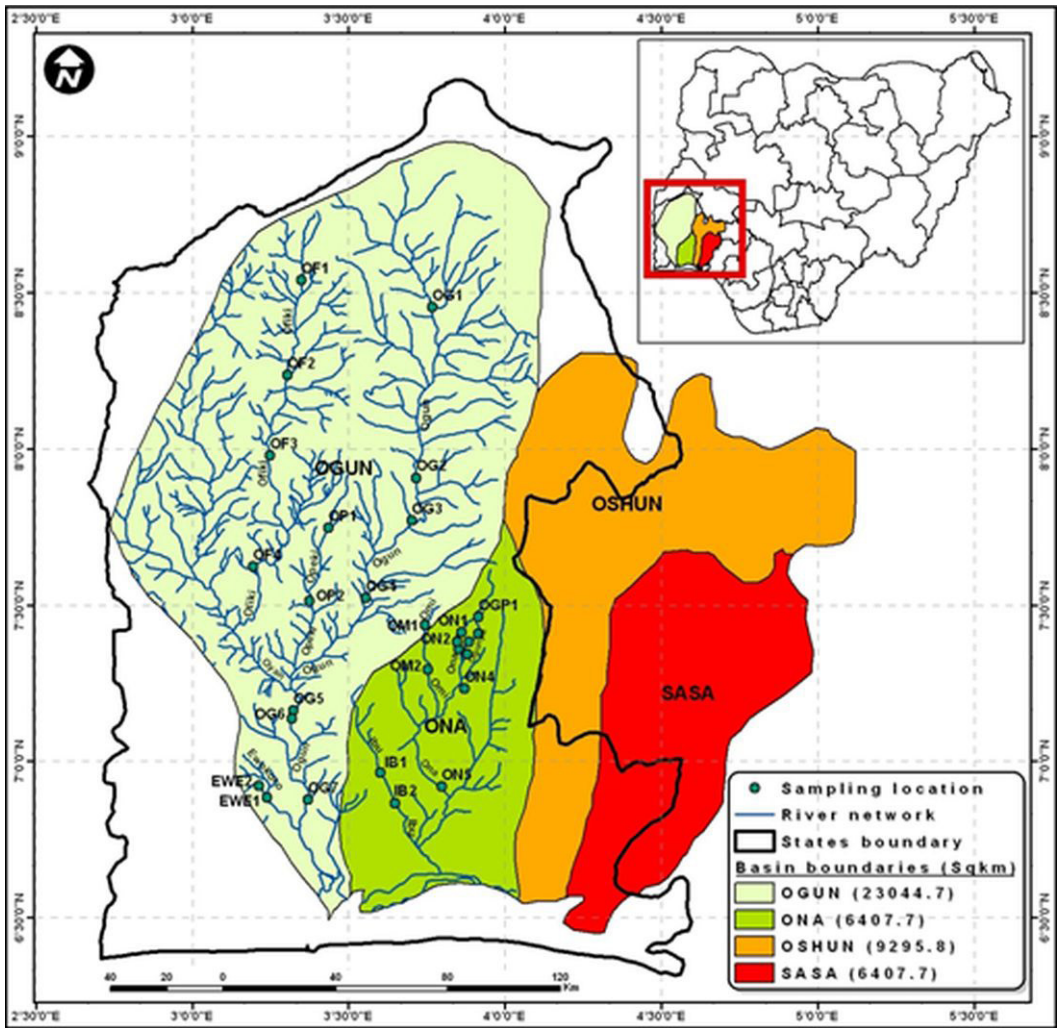


Fig.1. Base map of the study location: Ogun Osun River Basin catchments

established on the rivers for discharge measurement (Fig. 1). Using ArcGIS 9.3@ capabilities, a Water Quality Information System (WQIS) was built as database of water quality indicators for the basin. Thirty two (32) physical, chemical (including heavy metals) and microbiological water quality indicators were monitored to provide baseline information on quality status of the rivers in the catchments (GEMS 2007). Students' t-test at $p < 0.01$ was used to compare the catchments' mean values of the indicators with the Maximum Allowable Limits (MAL) set by WHO (2011) for drinking water. Drinking water objective was taking because some of the rural dwellers across

the basin with poor access to safe water still depend on the river water for their domestic need without any treatment. For this reason, Cadmium (Cd) and Lead (Pb) were chosen as major indicator in the water quality survey. Ten (10) of the mapped water quality indicators discussed in this article are: Sodium Adsorption Ratio (SAR) with its computation integrating Na^+ , Ca^{2+} and Mg^{2+} , 5 - day Biochemical Oxygen Demand (BOD_5), Total Nitrogen (TN), Total Phosphorous (TP), Nitrate Nitrogen ($\text{NO}_3\text{-N}$), Phosphate ($\text{PO}_4^{3-}\text{-P}$), Cd, Pb, Escherichia Coliforms (E. Coli) and Fecal Coliform. The laboratory analysis followed Standard Methods for Water and Effluents Analysis (APHA 1992). Laboratory

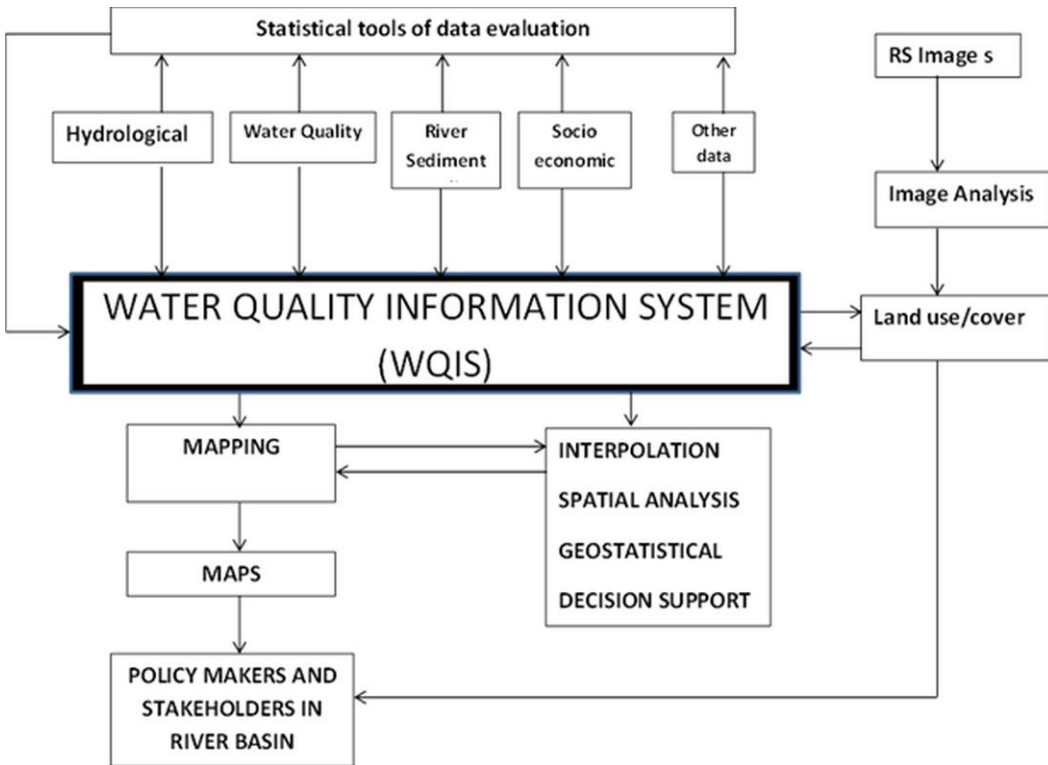


Fig. 2. Framework for the GIS based Water Quality Information System (WQIS)

analyses were done at the Central Analytical Laboratory of the Institute of Agricultural Research and Training, Ibadan, Nigeria. The data of the selected water quality indicators were stored in fields and attribute tables of the river network shapefile in the WQIS

2.3 GIS based Water Quality Information System

ArcGIS 9.3 software was used in creating the Water Quality Information System (WQIS) for storage, retrieval, data analysis and mapping. The WQIS is an assemblage of database of hydrological, water quality indicators, river sediment, socio-economic and images that were remotely sensed using ArcCatalog in ArcGIS 9.3. Base maps of area boundary and river network were collected as paper maps from OORBDA and were converted to GIS shapefiles through process of georeferencing and digitization using ArcGIS 9.3 software. The socio economic data were collected in GIS shapefiles from the

spatial laboratory of IITA Ibadan open access resources. Using ArcGIS 9.3 extensions, analysis, queries and interpolations were achieved. The framework of the WQIS is shown in Fig. 2.

2.4 GIS Interpolation

The Inverse Distance Weighted (IDW) interpolation is a technique which is largely a reflection of Waldo Tobler's first law in geography which state that "everything is related to everything else, but near things are more related than distant things" (Tomislav, 2009). The IDW is a mapping technique which is an exact, convex interpolation method that fits only the continuous model of spatial variation. The IDW derives the value of a variable at some new location using values obtained from known locations (ESRI, 2005). This is expressed mathematically in the equations given below (Tomislav, 2009):

$$\hat{z}(S_o) = \sum_{i=1}^n \lambda_i(S_o)z(S_i)$$

$$\hat{z}(S_o) = \lambda_0^T Z$$

The simplest approach for determining the weights is to use the inverse distance from all points to the new points

$$\lambda_i(S_o) = \frac{\frac{1}{d^\beta(S_o,S_i)}}{\sum_{i=0}^n \frac{1}{d^\beta(S_o,S_i)}} ; \beta > 1$$

Where:

- λ_i - is the weight for neighbor i (the sum of weights must be unity to ensure an unbiased interpolator).
- $d(s_o, s_i)$ - is the distance from the new point to a known sampled point
- β - is a coefficient that is used to adjust the weights
- n - is the total no of points in the neighbourhood analysis

2.5 GIS mapping procedure

The IDW method of the spatial analyst extension in ArcGIS 9.3 was used in the mapping of the variables. All the measured points (water quality data) were used in the calculation of each interpolated cell (water quality grid). A feature dataset (river network) was used for the mask. Only cells that fall within the specified shape of the feature data (river network) received the values of the first input raster (water quality grid) on the output raster (water quality

result). The output raster is the extraction of the cells of the water quality grid (input raster) that correspond to the routes defined by the mask (Fig. 3). Seasonal classifications were based on Dry season (November, December, January and February), Early rain season (March, April, May and June) and Wet seasons (July, August, September and October) with the map legend according to the data range for the season

3. Results and Discussion

3.1 Land-use map of the study area

The land-use classification showed that agriculture, grazing/grassland, grass woodlands/shrubs, forest and urban are the major land-use types in the basin. The agricultural land-use was 18 793 km² (63.88 %) of the land area while urban/sub-urban land-use (built-up areas) was about 524.9 km². Grazing grassland, forest and grass woodland is 19.04%, 7.53% and 6.11% respectively. Land-use is among the major factors driving river water quality since the runoff that discharges into rivers are implicitly from land surfaces (Rosana et al. 2007). Agricultural, grazing and urban are the predominant land-use in the catchments (Fig. 4). However, land cultivations are scattered across the basin with little or no regulation on the use of chemicals, fertilizers and organic manure which are essential inputs in crop production. The uses of organic and inorganic fertilizers as well as agrochemicals

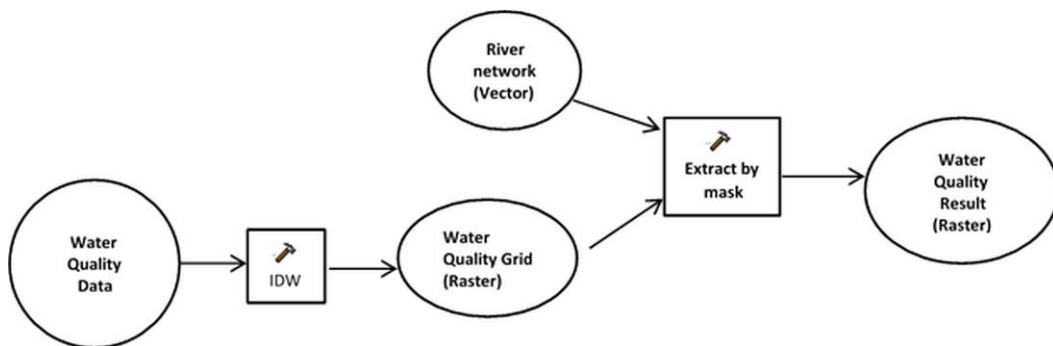


Fig. 3. GIS Mapping procedure

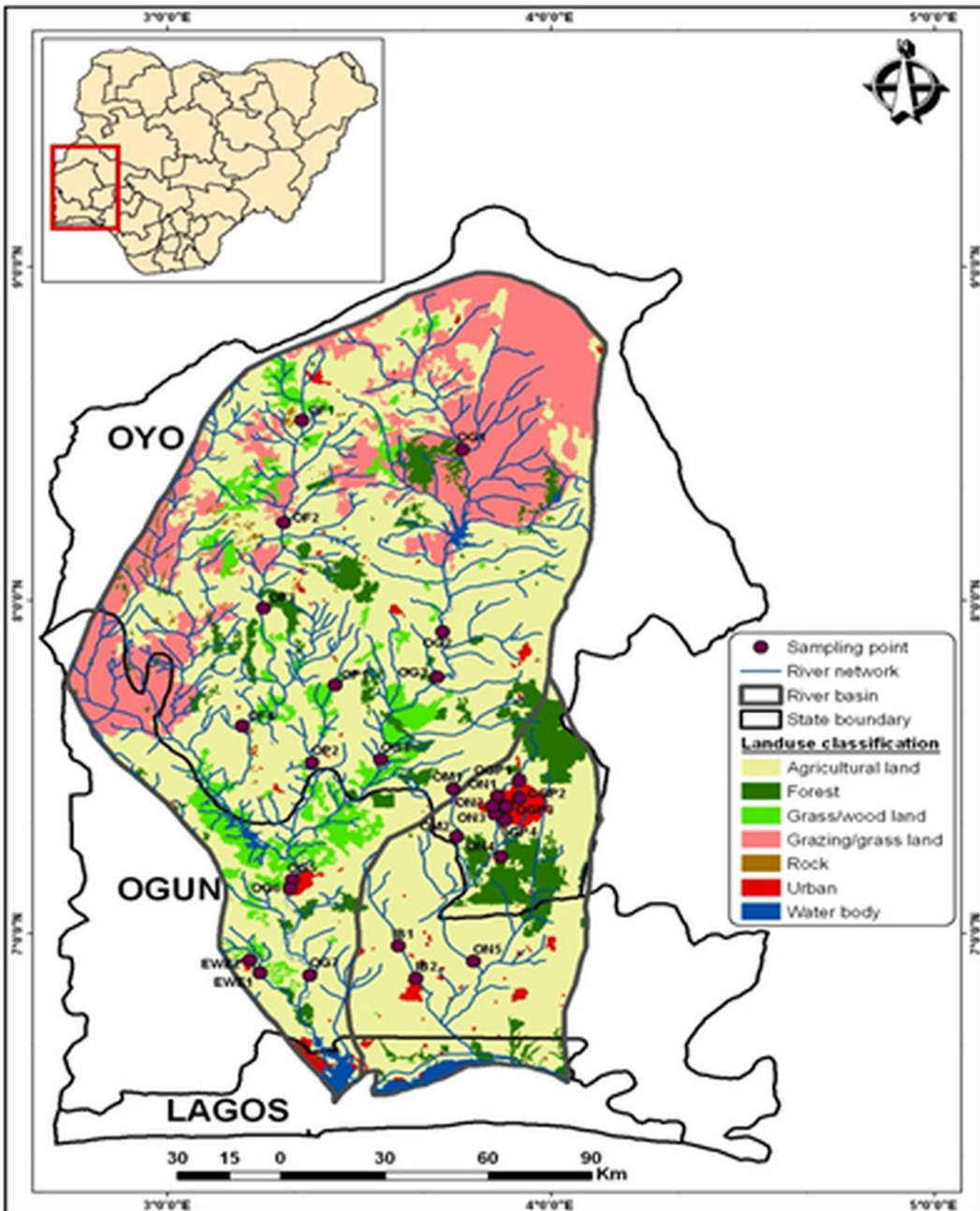


Fig. 4. Land-use map for the Ogun and Ona catchments

have been known to contribute significantly to water resources impairments and general environmental pollution (Chaosheng 2006). This has a major implication for environmental management, more importantly the risks of diffuse pollution (Janwal et al. 2008). Also, farmers who live in dispersed huts, hamlets

and villages across the cultivable commands are known to lack adequate sanitation infrastructures for disposal of human wastes and this also contribute to the pollution load. In the urban environment, generally, there is the challenge of sanitation and especially the problem of waste disposal has also been

identified (Sangodoyin – Cooker 2002). The influx of pollutants in the river system was observed to be related to the observed land-use patterns.

3.2 Statistical comparison of River Water Quality with Maximum Allowable Limits

Table 1 gives the Maximum Allowable Limits (MAL) of the water quality indicators and the level of significance ($p < 0.01$) in comparison with MAL using the mean values of the selected indicators in the catchments.

Table 1: Comparison of the averages of water quality data with the Maximum Allowable Limits

	WHO	level of significance
SAR	-	ns
BOD	3.0	↑
Total N	1.0	↓
Total P	5.0	↑
PO ₄ -P	0.02	↑
NO ₃ – N	50	↓
E-Coli (10 counts/100 ml)	0	↑
Fecal Coliform (10 counts/100 ml)	0	↑
Cd	0.003	↑
Pb	0.01	↑

The SAR was not significantly different from the range given for irrigation water quality requirement (Ayers and Westcot 1994). The river water systems are fit for irrigation purposes across the basins. This is unlike BOD5 which is significantly high and indicated high level of organic load in the river system. Generally, irrespective of seasons, TN, and NO₃-N are significantly lower while TP, PO₄-P, E. coli, Fecal Coliform, Cd and Pb are significantly higher across the basin.

The maps of these water quality indicators showing trends and critical areas within the catchments are presented in Figs. 5–12.

3.3 GIS Mapping of the river water quality variables' trends in the basin

The IDW interpolation techniques enabled the visualization of the variations of a parameter along the river course. The river shapefile in the ArcGIS followed polyline and not polygon as it is the case in GIS interpolation in soil research (Xiangdong et al. 2004). The interactions between neighboring points along the line were the basis for predictions in IDW. The variations were reflected along the river course. Thus, predictions were made along the river system beyond the specific sampling points. This is a major advantage in the evaluation of spatio-temporal river water quality and it is an improvement on the traditional location specific monitoring techniques which may not offer reliable data beyond the point of investigation.

3.3.1 Sodium Adsorption Ratio

Sodium Adsorption Ratio (SAR) is a measure of the suitability of water for use in agricultural irrigation, as determined by the concentrations of solids dissolved in the water. Its computation integrates Na⁺, Ca²⁺ and Mg²⁺ ions. The maps showed a clear difference in observed SAR across the catchments (Fig. 5). The SAR ranged between 0.74–1.17 in the dry seasons and 0.53–0.90 in the wet season. The SAR levels irrespective of the season are still within the acceptable limits for irrigation (Ayers – Westcot 1994). Specific areas with elevated SAR across the seasons were identified in the maps. During the dry season, SAR was highest across the majorly urban

and sub-urban areas. Elevated SAR levels were observed in Opeki, Ofiki, Ogun Omi and Ona river systems that drain this mix of agricultural and urban land-use. This was in contrast to areas like Ebiti drained by Ofiki river in the upstream of the basin, Ewekoro and Ogun in the downstream of the basin which are low in SAR in the dry season. This pattern was similar to what obtained in early rainy seasons. However, river system within agricultural areas (Fig. 4) in Iseyin (OG1), Igangan (OF3) and Igboora (OF4) had highest SAR during the wet seasons. The dilution

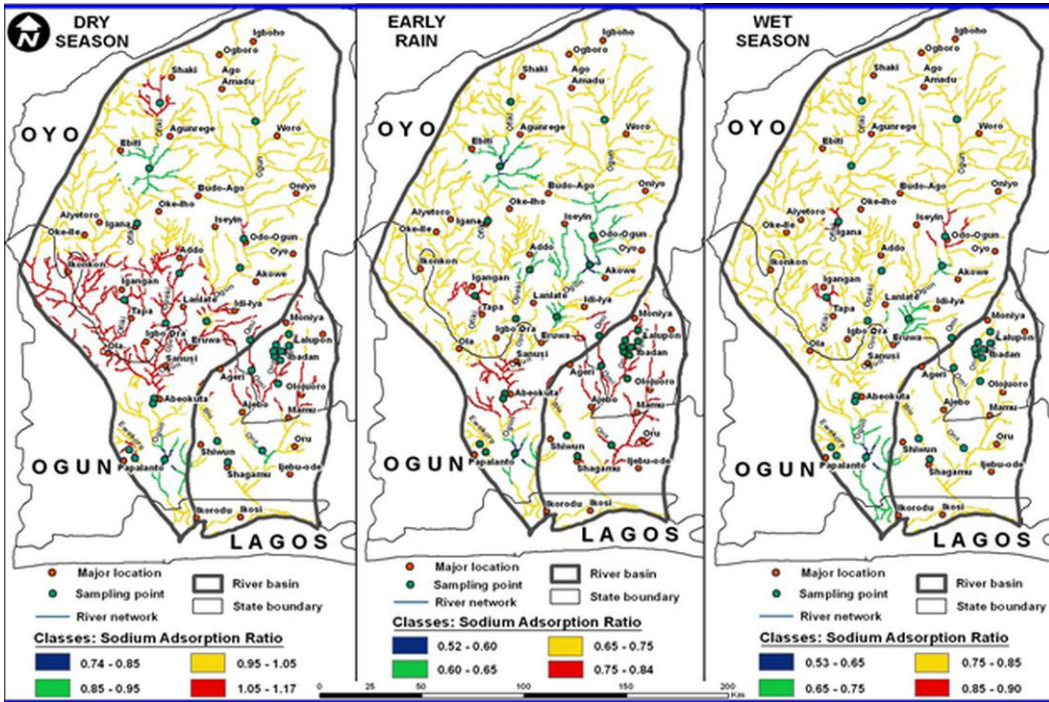


Fig. 5. SAR distribution in Ogun and Ona catchments

resulting from increased runoff during wet season accounts for reduction in the average SAR during the wet season as compared with the dry and early rain season. In terms of water quality for irrigation, the water quality meets the SAR requirement for irrigation purposes across the catchments.

3.3.2 5-Day Biochemical Oxygen Demand in the Ogun and Ona catchments

The map of BOD₅ in the catchments is heterogeneous across the basin and within the season (Fig. 6). There are distinctions in the levels BOD₅ of across the seasons. The lowest levels of BOD₅ were observed in the Early Rain season (16.6–25.6 mg/l) while highest level of organic load was observed in the wet season (43.2–58.9 mg/l). As earlier reported (Table 1) the organic load in the river system is significantly high. However, areas like Addo with 45–52.1 mg/l in dry season, Abeokuta and Sagamu with 24–26.6 mg/l in the early rain season as well as Ewekoro, Abeokuta and Ibadan with 55.0–58.9 mg/l during the wet season were shown to be hot spot during these seasons. The BOD₅ in the

dry season may be related to the oxidation of organic materials which use up the available oxygen in the rivers and the wet season surge in concentration may be related to the influx from the runoff from anthropogenic activities (Emmanuel et al. 2012). It was also noted that higher concentration were observed within locations with urban land-use. For instance, the river system within Abeokuta Metropolis, areas within OG5 and OG6 (Fig. 4.) reported the highest BOD₅ during the Early Rain and Wet seasons. The map of BOD₅ gave insight into the distribution of organic load deposition into the river system which is an indication of sanitation level in the study basin.

3.3.3 Nitrate-Nitrogen characteristics in the Ogun and Ona catchments

The map of Nitrate-Nitrogen (NO₃-N) is shown in Fig. 7. As earlier observed, the NO₃-N in the basin was statistically lower (P<0.01) than the MAL of 50 mg/l which showed that nitrate level in the basin did not pose any risk in the river systems. In terms of distributions, there is a clear variation across

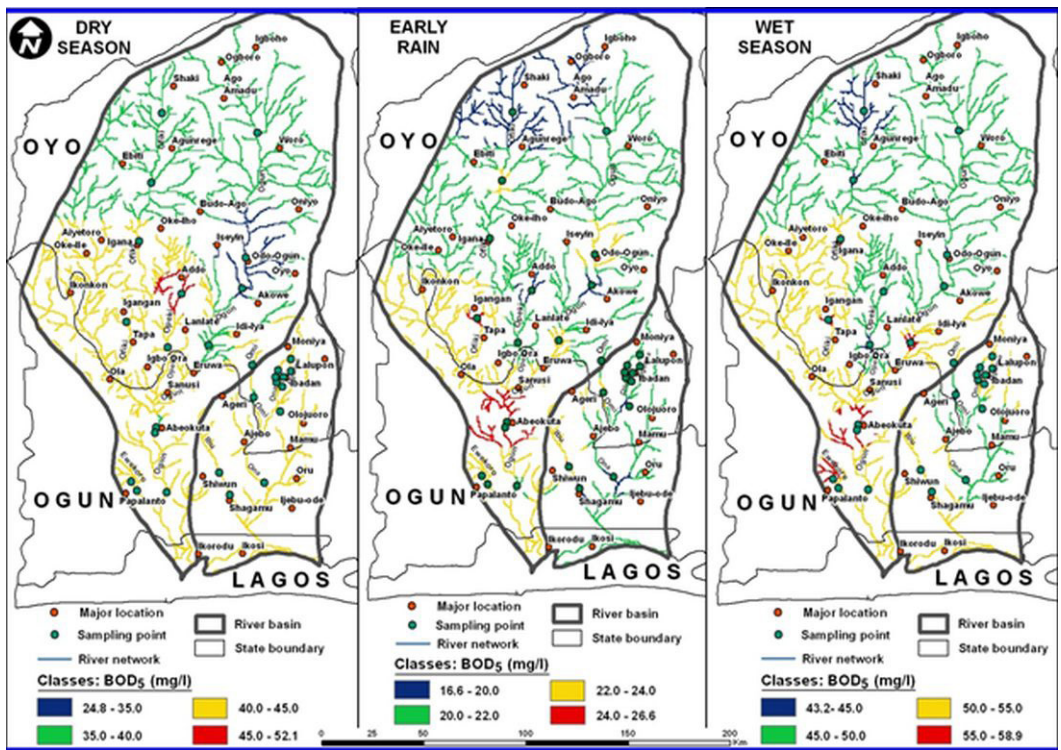


Fig. 6. BOD₅ in the Ogun and Ona catchments

the seasons. The dry season with increased decomposition of organic waste in the river system returned highest NO₃-N values (0.048–0.078 mg/l) while the lowest levels of NO₃-N were observed in the early rain. This reduction during early rain season may be related to the reduction in DO (because of low river turbulence) which increase river system’s tendency towards anaerobic condition. Under this condition, denitrifying bacteria are capable of reducing NO₃-N into NO₂ and N₂ as part of the Nitrogen cycle. (Gilbert 2006). During the early rain season, uniform level of NO₃-N ranging between 0.01–0.10 mg/l was observed across the river systems except for area within Shiwun town on the Ibu river which recorded twice the concentration (0.20–0.23 mg/l). This suggested a major influx of organic materials pollutant within that area. In the wet season, when there were increased runoffs and consequently high pollutant load, the level of NO₃-N increased southwards (downstream) with significant elevated levels observed in

the urban environment of Ibadan, Sagamu, Abeokuta, Igbo-ora, Eruwa, Ijebu-Ode among others. All the rivers draining these areas (Opeki, Ogun, Ibu, Ewekoro, Ona, Ogunpa and Ogunpa) have NO₃-N levels ranging between 0.045–0.059 mg/l (Fig. 7). The map showed the impact of urban land-use as well as peri-urban agricultural activities within this urban environ on the nitrate level in the river system. This predisposes reservoir within such environment to high level eutrophication (Gilbert 2006).

3.3.4 Total Nitrogen characteristics in Ogun and Ona catchments

Similar to what obtained with the NO₃-N, the level of TN in the basin was below MAL (Table 1), it was highest in the dry season (0.19–0.28%/100 ml) and lowest in the early rain season (0.09–0.014%/100 ml). In the wet season, along Ogun river system from Odo-Ogun to Eruwa and in the downstream end within Abeokuta area, TN level was lower than what was observed in Ofiki, Ewekoro,

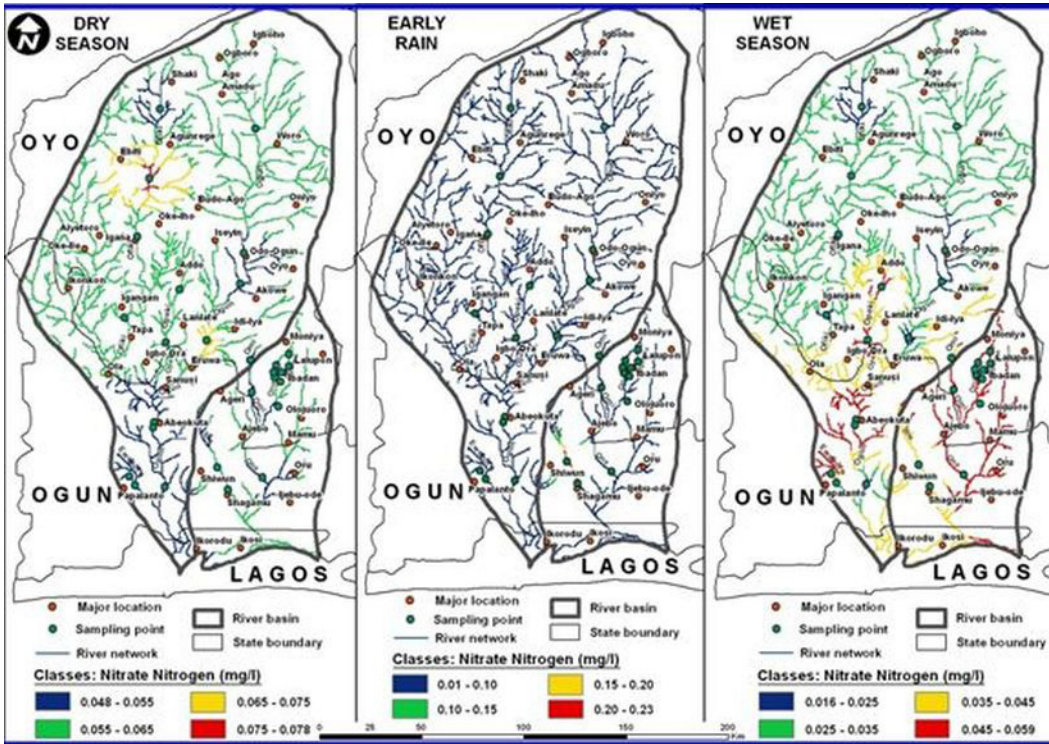


Fig. 7. Nitrate-Nitrogen in the Ogun and Ona catchments

Ibu, Omi, Ona and Ogunpa river system. The distribution of TN in the basin showed that river systems within the agricultural land-use, grazing and urban areas had elevated levels of TN as compared to other land-uses. This is particularly obvious in the dry and early rain seasons. This pattern is related to the deposition and decomposition of nitrogenous organic materials, fertilizers from agricultural fields and cattle excreta from the grazing grassland which are washed into the river system through runoff. Even though the observed level of TN is still within environmentally tolerable limits, the areas with high contribution to the nutrient pollution of river system in the Ogun and Ona catchments are clearly highlighted in the GIS maps.

3.3.5 Phosphorous characteristics in the Ogun and Ona rivers systems catchments

Figs. 8 and 9 are the maps of TP and PO_4 -P in the catchments respectively. The observed concentrations of both TP and PO_4 -P across

the river systems were higher than the MAL (Table 1). This shows that the contributions of phosphorous to nutrient pollution of water systems in the catchments are significant unlike the nitrogenous compounds. Phosphorous pollution is linked to natural deposits, phosphate based fertilizers and waste water discharges into the rivers. During the dry season, the downstream of the basin showed higher levels of TP than the upstream. River Ewekoro near Papalanto was of note. This area is noted for Cement production with Rock Phosphate deposit as a major natural mineral in the area. The Igangan, Tapa area posed an elevated level of TP in the early rain season. The levels are higher in these areas as well as in Addo during the wet season. The Ofiki and Opeki river systems drain these critical areas which are majorly within agricultural land-use. Thus, the elevation in TP is related to fertilizer uses in crop production. The high level of TP and PO_4 -P predisposes the Eruwa Dam reservoir which receives runoff from rivers systems

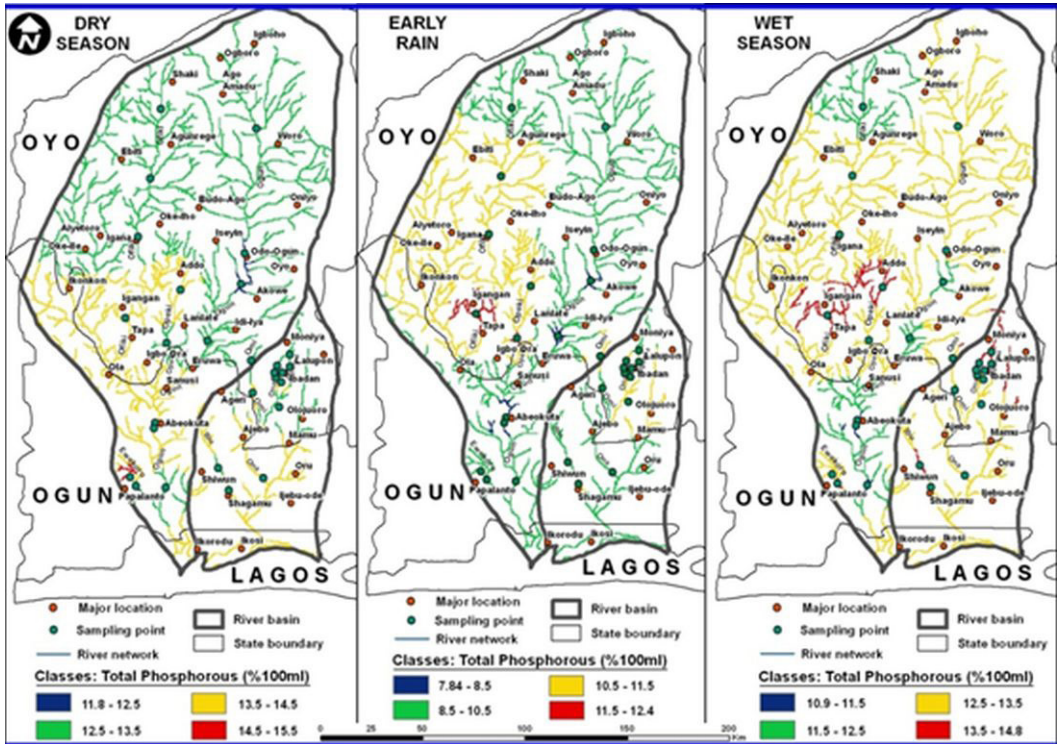


Fig. 8. Total Phosphorous in the Ogun and Ona catchments

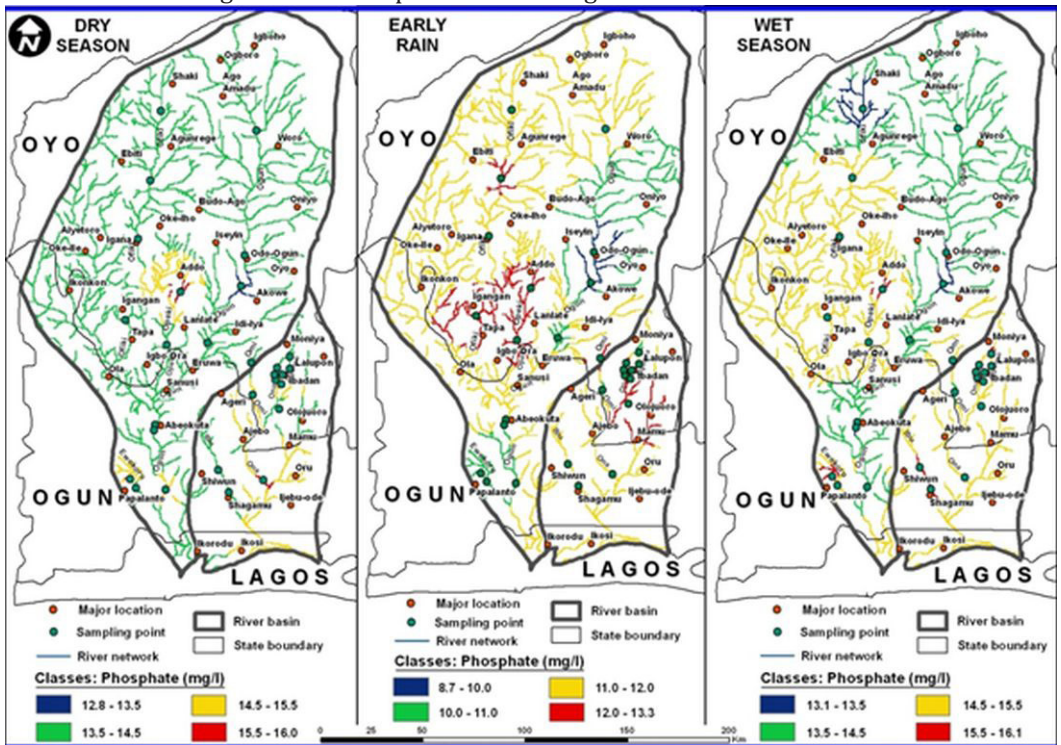


Fig. 9. Phosphate in the Ogun and Ona catchments

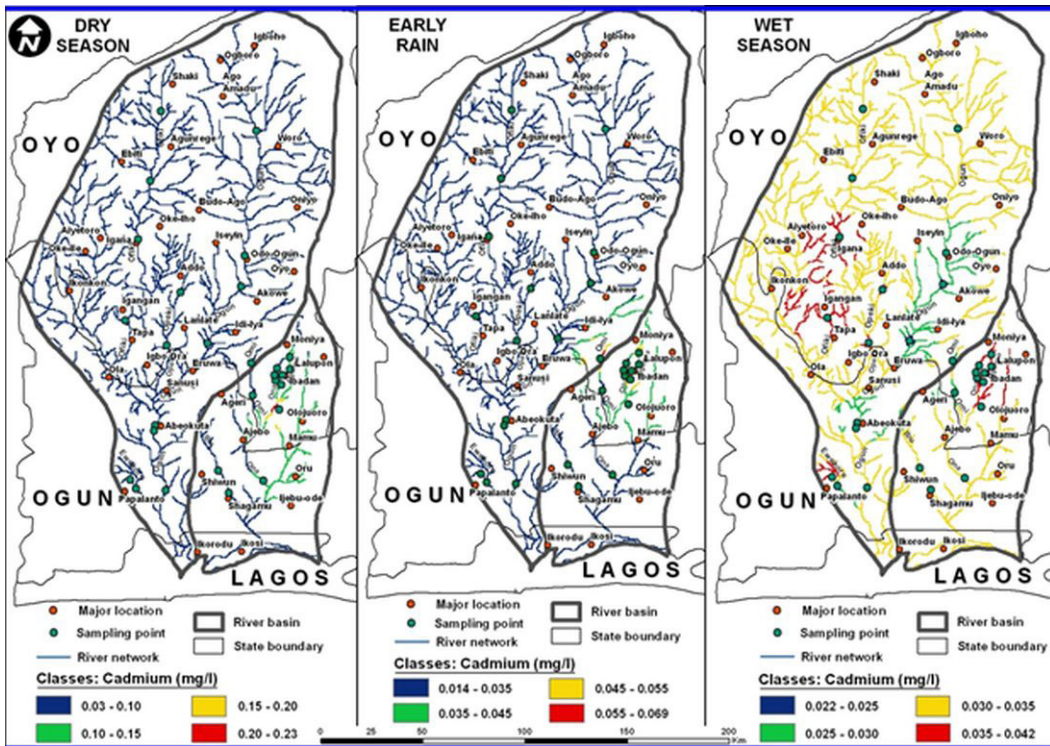


Fig. 10. Cd the Ogun and Ona catchments

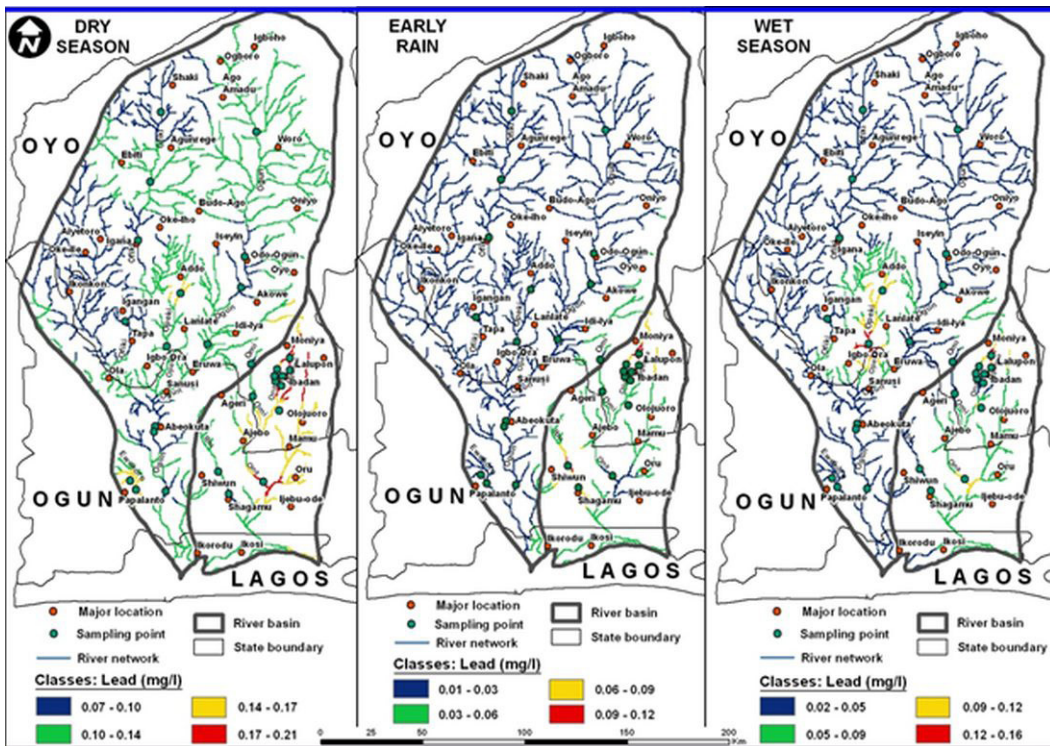


Fig. 11. Pb in the Ogun and Ona catchments

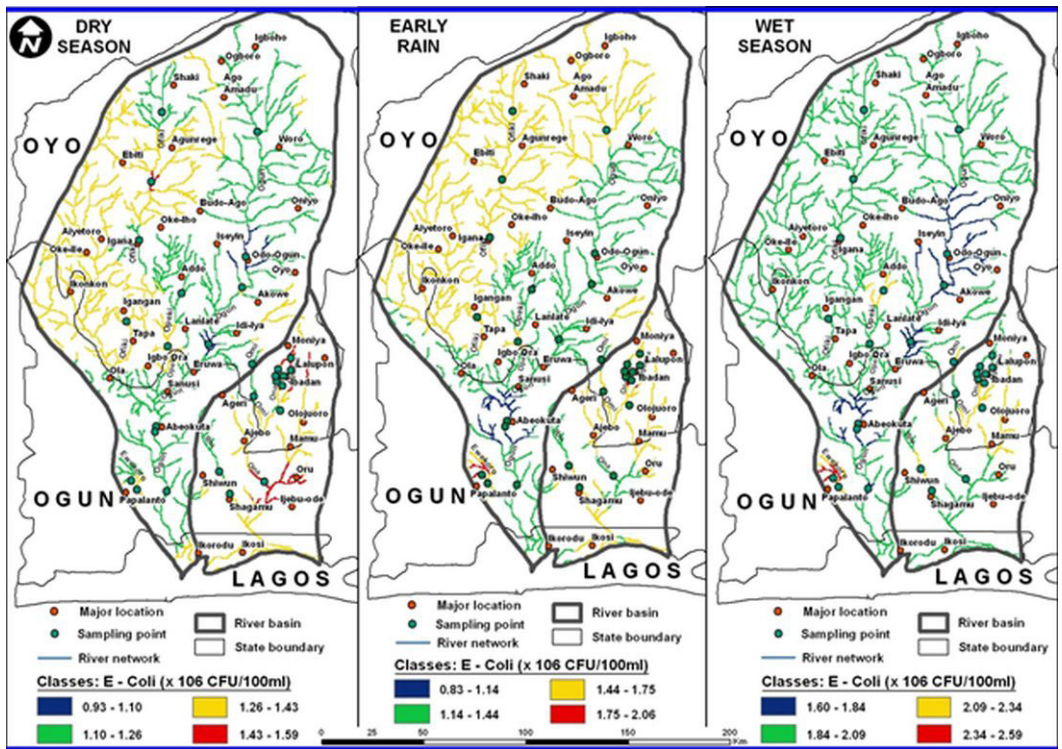


Fig. 10. Cd the Ogun and Ona catchments

in these area to eutrophication or nutrient pollution. Nyenje et al. (2010) also observed the influence of phosphorous in nutrient pollution of rivers in sub-Saharan Africa. The spread as presented in maps shows the extent of diffuse phosphorous pollution in the catchments.

3.3.6 Cadmium and Lead characteristics in Ogun and Ona rivers systems catchments

It was observed that the Cadmium (Cd) levels in the catchments were significantly higher than the MAL (Table 1). The map Cd in the catchments showed a fairly homogenous distribution in the dry and early rain season (Fig. 10). Observed concentrations were higher during dry season and lowest during the wet season. This is due essentially to dilution effects. The map also revealed that river system in the urban environment generally presented elevated levels irrespective of the season. Rivers Ogunpa,

Omi and Ona were more polluted in the dry season as well as early rain season when Cd is highest in the river system. This shows the impact of urban runoff in contrast to the levels of Cd in other river system and land-use types. The distribution during the wet season was found to be more heterogeneous. Iganna, Ayetoro, Igangan, Tapa within Ofiki river systems and Moniya, Ibadan, Lalupon within Ogunpa and Ona river systems draining urban land-use are critical polluted areas. Although, Ogun river system from Odo-Ogun down to Eruwa was less polluted (0.025–0.030 mg/l) as compared to other parts of the basin. The Cd in the rivers is beyond tolerable limits (Table 1). Areas where more heavy metals influx are being released in the river systems are identified.

The distribution of Pb in the river system of Ogun and Ona catchment are presented in Fig. 11. Similar to the pattern observed with Cd, the level of Pb in the river system during the dry season was also significantly higher

($P < 0.01$) than the MAL and it ranged between 0.03–0.23 mg/l. Furthermore, the urban land-use also presented relatively higher level of Pb in the river system irrespective of season. Cd and Pb in the environment are toxic metal at elevated levels beyond background values (Janwal et al. 2008). With the use of the water by farmers and their households within the study area, the risks of exposure to these metals are high which thus call for improved environmental monitoring and pollution control.

3.3.7 E. Coli and Fecal Coliforms distributions in the Ogun and Ona catchments

The observed levels of E-coli and Fecal coliform in the studied catchment were found to be significantly higher than the MAL irrespective of the season with higher levels observed in the wet season (1.60–2.60 $\times 10^6$ CFU/100 ml). Maps of the E-coli in Fig. 12 revealed that the concentration recorded in the dry and early rain season are higher in the grazing and agricultural land-use types. This pattern as similarly observed with Fecal coliform may be linked to the cattle dung from intensive grazing, disposal of waste from poultry farms as well as indiscriminate organic and human waste disposal across these land-use types. The major areas across the northern part of the Ogun catchment were including communities such as Saki, Agunrege among others are the hot spots across the seasons. These farming communities in the catchments are still sourcing their drinking water from the rivers and streams without basic treatment in most of these villages and towns. With high levels of bacteria counts in the river system, the danger of water borne and water related diseases are high in the study watershed. The population of the 65 local government areas in the study area was estimated to be about 16 729 477 (NPC, 2006). Presently, except in the urban centers where there is pipe borne water, though at very low supply, higher percentage of the population in the sub-urban and the rural agricultural areas use water from the rivers and streams and groundwater for domestic

and sanitary activities which expose them to high pollutant load especially those with high health risks such as Fecal Coliforms, E. Coli, Pb and Cd.

4. Conclusion

The levels of SAR show that water quality is still within the limit required in the river basin. Although, $\text{NO}_3\text{-N}$ and TN were lower than the limits and therefore were not of major environmental concern at these levels, $\text{PO}_4\text{-P}$ and TP were higher across the study catchments. The Cd, Pd and the microbiological pollutants are significantly high which poses challenges to the human health of the rural dwellers who still source for their water supply largely from these rivers without any treatment. Seasonal variation exists among these pollutants which shows that runoff contribute to pollutants influx. This is particularly obvious for BOD_5 , $\text{PO}_4\text{-P}$, E. coli and Fecal Coliform which were highest during the wet season.

The GIS maps based on Inverse Distance Weighted Interpolation clearly showed the hot spots in relation to the spatio-temporal characteristics of pollutants influx and also enabled the estimation of levels of pollutants in all the river systems across the basins beyond the locations where samplings were conducted. The urban, agricultural and grazing land uses were shown to be responsible for elevated levels of pollutants as observed in the maps.

Therefore, this interpolation technique could strengthen monitoring and assessment capacity of river basin management systems towards better pollution monitoring and control.

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