The Impacts of Urbanization on Kaduna River Flooding

Alayande Adegoke Waheed[1], Agunwamba, Jonah Chukwuemeka[2]

[1]National Water Resources Institute, P. M. B. 2309, Kaduna. Nigeria.
[2]Department of Civil Engineering, University of Nigeria, Nsukka. Nigeria.
walayande@yahoo.co.uk, jcagunwamba@yahoo.com

Abstract: Population growth, urbanization and expansion of structural developments into traditional flood prone areas of urban settlements of Nigeria are challenges requiring dynamic predictions of inundation areas; development of models for the propagation of flood waves on the floodplain; and the development of a rapid response and flood warning systems. In this study the impact of urbanization on geomorphic parameters of the Kaduna River along the City of Kaduna were investigated. The results obtained indicated that increasing urbanization along the Kaduna River floodplain is responsible for the problem of flooding experienced in recent times along the river floodplain and that encroachment into the traditional flood prone areas of the Kaduna River as a result of urbanization has attained 85.31%, 68.47% and 67.54% respectively in Reach 2, Reach 3 and Reach 1 respectively over the period 1962 and 2009. Because the Kaduna River usually attained its bankfull flow capacities in all its sections along the City of Kaduna early August each year, the result further indicated that the 2yr, 5yr, 10yr, 25yr, 50yr, and 100yr floods when occur can cause maximum inundation of between 82.53% to 94.48% of the floodplain area between the Eastern Byepass bridge and the Kaduna South Waterworks with Ungwan Rimi, Kabala Doki and Kigo road extension as the most critical areas where the right banks are lower than the left banks and developments are almost to the right bank of the river. [Journal of American Science 2010;6(5):28-35]. (ISSN: 1545-1003).

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1. Introduction.

The geomorphology of a river system is directly influenced by major variables including channel width, depth, velocity, discharge, channel slope, roughness of channel materials, sediment load and sediment size (Leopold et al. 1964). A change in one variable causes a series of channel adjustments which lead to changes in the other variables, resulting in channel pattern alterations and the manner the channel respond to flood flows flowing through it. Increasing urbanization along the Kaduna River floodplain has led to the problem of flooding which have highlighted the need to understand the consequences of urban developmental activities on the geomorphology of the Kaduna River and the propagation of the flood wave along the river channel.

There have been several cases of floods in Nigeria mostly resulting from heavy downpour and excess releases from dams whose operational capacities could not cope with excessive inflows into their reservoir areas. In most cases these releases are made mainly to safe the dams whose failure could be more catastrophic than the consequences of the releases. Managing flood and other disasters focuses on palate measures and reducing the socio-economic impacts of these disasters through mobilizing relief materials with little investments onto research efforts aiming at understanding the dynamics of these natural events and reducing the impacts of future flood events. In fact a standing National Emergency Management Agency (NEMA) was established by government at the federal level and State Emergency Management Agency (SEMA) at State levels to rapidly respond to the plight of the people in the cases of disasters including flooding. Flood simulations are rarely used in disaster preparations and management either at policy making or implementation levels.

Cases of these floods affects urban centres and rural settlements along the floodplain (Etiosa, 2006; NWRI, 2008), and in all cases houses, property, farm produce and animals were destroyed running into billions of naira each year (Vanguard, 2005 and 2007; The Punch, 2003). Of particular attention and the main focus of this paper is the Kaduna 2003 flood disaster which occurred on Friday 6th September 2003, when Kaduna River overflew its banks spilling flood waters into the adjoin properties along its flood plain across the city of Kaduna. The water stages in the channel and damages to properties along the floodplain were unprecedented, lives were lost,

properties worth about N500 million were destroyed while thousands of people were rendered homeless in the City by the ravaging flood which brought the socio-economic activities of the city to standstill for three consecutive days before the flood waters recedes. In this study, the impact of urbanization on the channel geometry variables of the Kaduna River including channel width, depth, velocity, discharge, channel slope, and roughness of channel materials were investigated in relation to the 2003 flood event.
The Kaduna river took its source on the Jos Plateau, flows northwest across the Kaduna plains cutting several gorges through rugged terrain between Kaduna and Zungeru. Finally, the river flows southwards through the broad, level Niger valley, and enters the Niger River near Wuya in Niger State having drained about 70,200 square kilometers of land area in a 550km long main river course (MNS Encarta 2007) covering Kaduna, Niger, FCT, parts of Plateau, Nasarawa, and Kano States. Major tributaries joining the Kaduna along its course include rivers Karami, Galma,Tubo, Sarkin Pawa and Mariga in that order from source. Kaduna is the only state capital the main channel passes through and Shiroro hydropower reservoir is the only major dam across the main.

2. Existing Development with Kaduna River Floodplain.

The project area covers the reaches of the Kaduna River extending between the confluence with the Kangimi River located upstream and the Western Byepass at Nasarawa downstream Kaduna city respectively. For the purpose of this study, the part of the Kaduna city adjoining the Kaduna River as it flows past the city was divided into three distinct reaches namely Upper, the middle and lower reaches. The Upper reach extending between the confluence of the Kaduna River with the Kangimi to just upstream the Kaduna Eastern Bye Pass Bridge at Malali. Important settlements along this reach include Raafin Gusa, Angwan Dosa, part of Malali and the Makarfi new town. In this reach we have the Kaduna North Waterworks, Federal Government College and substantial parts of the Malali Government Reserve Areas developed for residential accommodation were located within the floodplain. The Kaduna basin especially upstream this reach has a large concentration of small to medium scale dams for water supply and irrigation and which regulates the flows into this reach and with the potential to generate flash floods during raining season. The Galma River, one of the major tributary discharges into the Kaduna River some 30km upstream this reach has two major dams on its main channel. The Kangimi reservoir is about one kilometer upstream this reach and releases its flow into the Kaduna River to augment the flow in the main channel during the low flow period. The middle reach extends from the Eastern Bye Pass Bridge at Malali to the main Kaduna Bridge by the Stadium. The reach is the most developed of the three reaches in terms of physical developments within the floodplain and host to the Ahmadu Bello Stadium, Angwan Rimi GRA, Kigo, Living Faith Church, Kabala Doki and Barnawa. The 2003 flood has its devastating impacts concentrated in this reach. The lower reach extends downstream the main Kaduna Bridge to the Eastern Byepass Bridge This reach adjoins the Zango, Kudenda Industrial layout, Kakuri, Nasarawa, Abattoir, and Moslem burial ground. Hydraulic structures along this reach include, the railway Bridge, the Kaduna South Waterworks, three intake pumping stations belonging to the Nigerian Breweries Plc, the United Nigerian Textile and Arewa Textiles while the Western Bypass Expressway Bridge crosses the Kaduna River within this reach. This reach is usually characterized by very low flow and almost dry situation at the peak of the dry season and many industrial effluents are discharged into this segment of the river. Physical development activities are fast emerging in the floodplain within this reach especially around Zango, Angwan Muazu, Kakuri, and Kudenda industrial layout. The reach profile is characterized by visible rock rapids causing braiding and flow bifurcations at various segments of the reach.

3. Materials and Methods.

3.1 Hydrological Analysis.

3.1.1 Analysis of Rainfall and Streamflow Data.

A comprehensive hydrological investigation aimed at determining the causes, level and the probability of occurrences of flooding in the Kaduna River valley along the City of Kaduna was carried out. Statistical analyses of the rainfall data for the period 1955 to 2004; daily Streamflow data for the period 1967 to 1992 and daily water stages record for the period 1993 to 2004 available for Kaduna River at Kaduna South Waterworks were carried on Microsoft EXCEL to create four extreme rainfall and streamflow databases maximum daily, maximum annual, five days and seven days moving averages. Both data sets were characterized by several months of missing records due to gauge not operational or wash away by flood. No discharge measurements were conducted at the station for the period 1993 to 2007 because of obsolete equipment and the data for these periods were converted to discharge using the 1994 rating table. Available data were examined for "spurious peak" and suspicious record verified.

The Kaduna River was completely ungauged during the 2003 flood and in order to reconstruct the 2003 flood level, eye witness account by the author and interview made during the field survey indicated that stage record data corresponding to 2003 flood level marks at the Kaduna Railway Bridge is 0.61m below the top of the central pier of the bridge. The top level of the bridge is at 574.55m amsl and the top of the pier is 0.65m to the top level of the bridge. Therefore the 2003 flood level measured at the railway bridge is (574.55-0.65-0.61)m or 573.29m amsl. With a right bank valley slope of 0.042% and distance of 905m to the cross section at the Kaduna South Waterworks, the corresponding level at this cross section is 573.29-0.042%*905 or 572.91m amsl. Extending the rating curve at Kaduna South Water Works to 572.91m gives the corresponding discharge for the 2003 flood as 3,485.31m^3/sec.

3.1.2 Flood Frequency Analysis

The extreme rainfall and streamflow databases analysis indicated that flooding along the Kaduna City adjoining the Kaduna River are rainfall induced and the river channel are expected to be on higher risks of flooding when the channel is flowing bankfull capacity coincides with high rainfall. Consequently the flood frequency analysis was carried out separately on the extreme flow and rainfall databases by fitting the Log Pearson Type III distribution to the database to determine floods levels corresponding to 200, 100, 50, 20, 10, 5 and 2 years annual recurrence intervals.

The Log-Pearson Type III distribution is a statistical technique for fitting frequency distribution data to predict the design flood for a river at some site. The Log-Pearson Type III distribution is calculated using equation (1).

$$\log x = \overline{\log x} + K\sigma_{\log x} \qquad (1)$$

where x is the flood discharge value of some specified probability, $\overline{\log x}$ is the average of the *log x* discharge values, *K* is a frequency factor, and σ is the standard deviation of the *log x* values. The frequency factor *K* is a function of the skewness coefficient and return period and can be found using the frequency table. The flood magnitudes for the various return periods were found by solving the equation (1) on Microsoft EXCEL. The analysis results are presented in Tables 1 and 2.

Table 1 Flood Frequency Analysis for Kaduna River at Kaduna South Waterworks
Log Pearson Type III Estimated Flood Flows (m3/sec)

	Return Period (years)						
	2	5	10	25	50	100	200
Max Daily Q	1,578.60	2,181.72	2,607.43	3,175.96	3,621.59	4,086.07	4,573.47
Max 5days Q	1,218.57	1,535.55	1,607.96	1,641.22	1,649.64	1,652.41	1,654.22
Max 7 days Q	1,108.94	1,343.03	1,350.97	1,403.08	1,406.81	1,407.59	1,408.20

Table 2 Flood Frequency Analysis of Rainfall at Kaduna Airport
Log Pearson Type III Estimated Rainfall (mm)

	Return Period (years)						
	2	5	10	25	50	100	200
Max Daily	67.73	75.20	79.27	83.75	86.70	89.40	91.91
Max 5-day Total	124.78	134.11	138.97	144.14	147.47	150.43	153.14
Max 7-day Total	150.20	160.53	165.49	170.41	173.38	175.91	178.10
Annual Rainfall	1,235.79	1,317.84	1,346.89	1,368.80	1,378.77	1,385.40	1,389.93

3.2 Geomorphological Characterization and Channel Planform Classification.

The field investigation and topographic surveys were organized in three distinct reaches of the Kaduna River principally to collect project related data on geomorphology, River Mechanics, and channel hydraulic geometry. Instrumentation mobilized for these activities includes **eTrex Garmin GPS** for positioning and distance measurements; **Total Station Instrument** for spot heights and positions**,** and **digital camera** for picture documentation on existing conditions. The entire activities were carried out by traversing the river course while assessing the river and its floodplains for changes in river geomorphology. Survey of the river cross sections were carried out using the **Total Station** instrument and canoe was used to carry the reflector across the sections of the river where water was flowing at the time of survey. A total of fifty nine cross sections were surveyed consisting of 21 in reach 1, 25 in Reach 2 and 13 in Reach 3 and the cross sections were spaced along the longitudinal direction in a manner to capture the changes along the channel and extending across the width of the floodplain at the section.

All the field generated data were analysed using a combination of software including Microsoft Excel 2007, Surface Mapping System Software (Surfer Version 8.01) and AUTOCAD 2007 that facilitated the management of the information collected for the determination of the following Channel Morphology classification parameters (Rosgen, 1996).

- The channel sinuosity which is an index of channel pattern, determined from a ratio of stream length divided by valley length; or estimated from a ratio of valley slope divided by channel slope.
- The entrenchment ratio (ER) is the ratio of the flood-prone area width divided by bankfull channel width.
- The width to depth ratio is the ratio of the bankfull width to the mean depth of the stream channel at bankfull stage elevation.

The bankfull width is the width of the stream channel at the bankfull stage elevation in a riffle section. The mean depth is the depth of the stream channel at the bankfull stage elevation in a riffle section. The maximum depth is the depth of the bankfull channel cross-section, or vertical distance between the bankfull stage and thalweg elevations, in a riffle section. The flood-prone area width is measured at an elevation that is twice the maximum depth at the location that the maximum depth was determined. Table 3 presents the summary of the geomorphological parameters for the three reaches while the channel geometry parameters related to bankfull and flood dimensions for selected cross sections, presented in Table 4 for Reach 2, were calculated at each cross section and averaged over each of the three reaches provides the baseline data upon which the changes in geomorphology of Kaduna River arising from anthropological changes were evaluated.

3.2.1 Planform Description

The Google Earth images of reaches of Kaduna River under investigation were downloaded and employed for the channel pattern description. In Reach 1 which is the uppermost portions under investigation the river channel exhibits a regular sinuous meanders at its downstream portion while at its uppermost portion, the channel exhibits braiding and mild meanders with several aggregation and degradation points. Commercial mining of good quality aggregates for infrastructural development in Kaduna City has been going on for years in this reach and still a daily activity.

Table 3 Summary of Gemorphological Parameters.

Parameter		Reach 1	Reach 2	Reach 3
Channel Plan View		Single Threaded	Multi Threaded	Single Threaded
Average water surface slope (S) m/m		0.000109671	8.45557E-05	0.000306698
Stream or channel length (SL) m		21,097.14	24,032.93	4,650.63
Stream or Channel Slope		0.00038	0.00051	0.00157
Valley length (VL) m	Left Bank	20,898.43	24,708.42	4,561.13
	Right Bank	21,097.14	22,483.18	4,802.10
Valley slope (VS) m/m	Left Bank	0.000306281	0.00064	0.00140
	Right Bank	0.000375634	0.000515	0.001142501
Sinuosity (VS/SL)		0.907686209	1.13997	0.809256879
Sinuosity (SL/VL)		1.004731857	1.018525	0.993382274
Entrenchment ratio (W_{fpa}/W_{bfl})		2.057847328	1.795573	1.936598257
Width / Depth Ratio		103.074	221.600	142.171
Stream Power (N/m/s)		2.41	1.49	2.67

Table 4 Channel Geometry Parameters Related to Bankfull and Flood Dimensions for Selected Cross Sections, for Reach 2

PARAMETER	X-14	X-21	X- 22	X- 15	X- 16	X- 23	X--32	X-38	Eastern Bye Pass
Bankfull Dimensions									
X-section area (m.sq.)	484.29	162.42	1,130.9	637.66	404.27	345.14	367.75	345.21	877.78
Width (m)	145.89	167.36	341.85	277.70	204.88	223.82	240.81	169.37	276.70
Mean depth (m)	1.30	1.15	2.97	2.10	0.84	1.20	1.29	2.86	1.99
Max depth (m)	2.74	2.13	5.18	3.35	3.96	2.13	2.44	5.18	4.27
Flood Dimensions									
Flood prone area Width (W_{fpa}) m	262.22	283.43	364.80	379.19	247.98	238.47	294.24	275.25	137.39
Width Left Floodplain	209.75	158.19	106.40	106.40	232.04	483.35	470.00	604.69	589.98
Width Left Floodplain Encroached (m)	144.10	124.08	106.40	106.40	206.18	457.19	0.00	0.00	0.00
Width Right Floodplain	499.95	492.86	439.41	437.02	571.30	494.42	488.50	415.81	638.44
Width Right Floodplain Encroached (m)	480.68	409.96	386.89	395.87	544.63	479.89	432.50	343.50	599.85
Low bank height	571.50	570.89	572.41	571.80	573.02	574.55	583.39	579.12	584.00
Max riffle depth	568.76	570.59	569.98	569.98	570.59	573.02	580.95	579.12	579.73
Bank height ratio (LBH/max riffle depth)	1.0048	1.0005	1.0043	1.0032	1.0043	1.0027	1.0042	1.0000	1.0074
Flood prone area Elevation (EL_{fpa}) m	574.24	574.85	580.34	576.68	578.51	577.29	585.83	589.48	588.26
Maximum Level in the Cross Section	573.94	573.94	575.16	575.46	574.85	575.46	585.22	588.87	591.62

Reach 2 is the most urbanized of the three reaches and the river channel is multi channeled characterized by heavy braiding and heavy anastomosing occasioned by heavy concentration of rock outcrops all across the river length and cross section. The river width and its flood plain is greatest in this reach most especially between Malali and Kigo road extension where the 2003 flood unleashed the most devastating effect on the city. Two other left side tributaries confluence with the Kaduna main channel within this reach which makes this reach very critical for this study. The river and its floodplain narrowed to just 269.13m at its exit into Reach 3 due to construction of the Kaduna River main bridge and fences by properties owner around.

The Kaduna river flow into Reach 3 with a very sharp U shaped meanders around the Moslem burial ground and characterized by heavy braiding and major flow bifurcations occasioned by occurrences of two vegetated bars just downstream the Kaduna South Waterworks Intake.

3.2.2 Flood Plain Encroachments and Flood Risk Zone Delineation

Urban expansion in all the communities located near the main stream channel of the Kaduna River has caused floodplain areas to be developed. High rise hollow block wall fences had been placed to allow the use and development of areas that originally provided zones for natural floodwater storage and conveyance. As a result, channel floodway zones have become constrained most especially in the middle reach where the 2003 has caused severe damages. Consequences of these developments are many for instance flood passage through these areas may results in higher stages and low velocities and shortage of flood attenuation potential. In other reaches, encroachment may impede the downstream progression of the floodwave such that backwater effects may cause high local flood levels.

To determine the extent of encroachments into the floodplain consequent to urbanization development, the surveyed cross section data was overlaid with the topographical map of the area taken in 1962. The two extremities of the cross sections are limits of floodplain development as at the time of surveys March 2009. The limit of the floodplain as delineated by contour elevation 1900feet was compared with the width of the cross section surveyed to quantitatively give the extent of floodplain encroachment between 1962 and 2009. Table 5 presents the extent of floodplain development between 1962 and 2009 while Figure 1 shows typical cross sections and floodwall at section in Reach 2.

Table 5 Extent of Kaduna River Floodplain Development

	Reach 3		Reach 2		Reach 1*	
	Left	Right	Left	Right	Left	Right
Area of floodplain (ha) as at 1962	124.41	130.48	388.55	455.48	453.46	406.20
Developed Area (ha) as at 2009	85.19	36.04	68.06	388.55	0.00	274.35
Developed Area as % of 1962 Coverage	68.47	27.62	17.52	85.31	0	67.54
Undeveloped Area (ha)	39.23	94.44	320.50	66.93	453.46	131.85
Undeveloped Area as % of 1962 Coverage	31.53	72.38	82.48	14.69	100	32.46

*Measured to Rafin Gusa (Limit of Kaduna City)

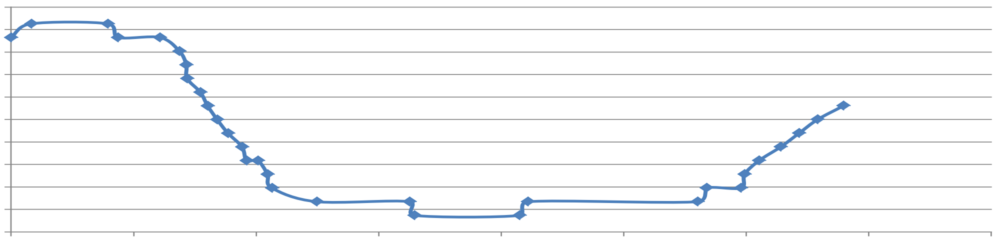

Figure 1 Typical Cross Section in Reach II and Floodwall Protection Structure
(Source: Alayande, 2010)

The extent of flood risk zones corresponding to the 2yr, 5yr, 10yr, 25yr, 50yr, 100yr and 200yr flood levels were determined by reading off the water stages corresponding to these flood levels discharges on the rating curves established for each of the 59 cross sections. These levels were compared with the floodprone area elevation and the maximum elevation in the cross section. Where maximum elevation in the cross section is less than the flood level elevation, or the flood level elevation is greater than the floodprone area elevation then there is the risk of flooding.

4.0 Results and Discussions

Hydrological analysis of rainfall data 1955 to 2004 revealed that the year 2003 annual rainfall of 1459.4mm was the third historical maximum annual rainfall coming after 1691.34mm and 1674.88mm of 1955 and 1957 respectively. Also the month of August 2003 was fifth wettest month during the period. Available record did not indicated flooding in the basin in 1955 and 1957 but what was certain was that the level of urbanization and structural developments was higher in 2003 than in 1955 and 1957. The analyses of streamflow data for the period 1967 and 2004 indicated that the month of August and September are the wettest months each year producing the maximum daily flow annually for ten and fifteen months respectively during the period under investigation. The historical maximum daily flow of 2,926.31m^3/sec was recorded on the 18th September 1994 followed by 2,871.75m^3/sec and 2,579.50m^3/sec for 1986 and 1992 respectively.

Analysis of 5-days and 7-days consecutive rainfall and average daily flows did not show and significant pointer to the occurrence of flooding in the basin. The flood frequency analysis shows that the basin's 2yr, 5yr, 10yr, 25yr, 50yr, 100yr and 200yr floods are respectively 1,578.6m^3/sec, 2,181.72m^3/sec, 2,607.43 m^3/sec, 3,175.86m^3/sec, 3,621.59m^3/sec, 4,086.07m^3/sec and 4,573.47m^3/sec and what we experienced in 2003 could be as much as 3,485.31m^3/sec . From the hydrological point of view, the Kaduna 2003 was rainfall-induced or as a result of high rainfall aggravated by indiscriminate structural developments in the floodplain that progressively reduces the width of the floodplain.

The geomorphological characterization classify the reaches investigated as class B stream segment defined as moderately entrenched, moderate width-to-depth ratio, moderate gradient, riffle dominated channel with gently sloping valleys; rapids predominates with scour pools infrequently spaced; very stable plan and profile. The average main channel slope is 0.0416% while the longitudinal slope for both banks is 0.042%. The Kaduna River channel develops into several low, medium and high flows braided reaches and five bifurcated reaches characteristically overgrown with forested vegetation, or shrubs while the soils in the bars are consolidated eroded materials from the catchments. Nineteen tributaries flow into the main Kaduna channel with a tributary density of 1.93 tributaries per kilometer.

Impact analysis of urbanization shows that the Kaduna River floodplain is increasing urbanized at a maximum encroachment rate of 85.31%, 68.47% and 67.54% respectively in Reach 2, Reach 3 and Reach 1 over the period 1962 and 2009. The flood risk zones were determined by comparing the floodprone area elevation with the maximum elevation in each of the cross sections. Where maximum elevation in the cross section is less than the floodprone area elevation, there is the risk of flooding. The analysis indicated that 39 out of 59 cross sections are under the risk of overbank spills of flood waters into the adjoin properties with Reach 2 the most vulnerable having 21 cross sections susceptible to overbank spills out of 21 cross sections. Existing floodwalls made of hollow bricks are quite inadequate in capacities for flood control as they can be pulled down under severe flooding. Also these walls are not continuous a situation that can lead to flood water flowing through unprotected sections to inundates properties.

In view of the fact that the Kaduna River usually attained its bankfull flow capacities in all its sections along the City of Kaduna in early August each year, when this situation coincides with the occurrences of the 2yr, 5yr, 10yr, 25yr, 50yr, and 100yr floods, the level of flood plain inundation could be as much as 82.53% to 94.48% of the floodplain area between the Eastern Byepass bridge and the Kaduna South Waterworks with Ungwan Rimi, Kabala Doki and Kigo road extension as the most critical areas where the right banks are lower than the left banks and developments are almost to the right bank of the river.

5. Conclusion

The results from this study indicated that urbanization is progressively modifying the Kaduna River floodplain and its flow. This situation if persisted without proper flood protection works will endanger both lives and properties in the floodplain. Existing flood protection measures cannot and will never put to check the menace of flooding along Kaduna River. A concerted effort in the form holistic approach towards controlling the flood is urgently required. It is therefore recommended that the Kaduna State Government should immediately put in place a policy to regulate infrastructural development along the Kaduna floodplain as a short term measure and construct dyke along the banks to shield already developed area from flood water as a long term measure.

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National Water Resources Institute. Kaduna. Nigeria.

Correspondence to:

Alayande Adegoke Waheed

National Water Resources Institute. P. M. B. 2309. Mando Road. Kaduna. Nigeria.

GSM: +234-803-303-2309, +234-808-211-2400

Email: walayande@yahoo.co.uk

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