The influence of precipitation and landuse change on flood incidence in Lagos Metropolis, Nigeria

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Abstract

This study investigates the flood impact of precipitation increase and land use change in Lagos megacity. It simulates the runoff, peak flow and area inundated for different climate change scenarios on systems 1, 2 and 5. This was achieved by using Precipitation Water Inundation Model (PWIM) that integrates projections of precipitation from regional models and urbanization drivers from land use change to analyse future flood scenario of 25 years and 50 years return periods. Using 2008 as base year, future climate scenarios of 50 and 100 years medium and high changes were analysed for three urban catchments in Lagos (system 1, system 2 and system 5). The urbanization driver of transforming storm runoff to flood in central Lagos was determined using trend analysis while projection of precipitation driver was based on statistical downscaling of CAM-EULAG regional climate model. The results revealed that runoff and peak flow on system 1 will increase by 6.34%, 14.24%, and 20.36% for 50 years medium climate change MCC, 50 years high climate change HCC and 100 years HCC respectively, 10.88%, 13.52%, and 19.26% for 50 years MCC, 50 years HCC and 100 years HCC respectively on system 2 and 6.13%, 13.31%, and 18.91% for 50 years MCC, 50 years HCC and 100 years HCC respectively on system 5. On the average, 20% to 25% increase in urban flash flood due to high climate change will be recorded in the next 50 - 100 years. Adaptation and Mitigation measures through urban renewal and integration of future fluxes from climate change are imperative in reducing the vulnerability of people and property to flooding in Lagos.

Key words: Urban Flooding, Climate Change, Lagos

INTRODUCTION

Water sustains life on earth and ties land, oceans, and atmosphere together into an integrated system. The movement of water, in its various states (gaseous, liquid, solid) across the earth's surface and its integration of the land, oceans and atmosphere, constitutes the global hydrological cycle. The exchange of energy associated with these states' changes is a fundamental driving force for weather and climate systems. The global land surface-atmospheric interactions, with respect to human population and activities with air, water and land in concentrated settlements, induce changes in the hydrological fluxes of water balance components. As development is intensified within the urban environment, the impact of land use changes on hydrological fluxes also increases. One of the major hydrological consequences of urban development is flooding.

Flood may be defined in a variety of ways, according to type, origin and magnitude. Generally, it is an unusual high stage of water in a stream channel (Ward, 1974). It is also that stage at which the stream channel becomes filled and above which it overflows its banks. When it causes damage to goods and properties or impairs human activities, it becomes a hazard. In urban areas, flood hazard occurs when there is sufficient overland flow of urban drainages over the streets to cause significant property damage, traffic obstruction and nuisance, as well as health hazards. Urban flooding is a serious disaster in the world, which not only causes serious damage, disturbs normal life and working conditions, but also pollutes the city and causes sanitary problems (Chen, 2004). It may even lead to loss of life. Urban floods include river flood, flash floods and flood pondages within an urban setting. Douglas *et al.* (2007) identified four types of urban flooding which include;

- localized flooding due to inadequate drainage,
- flooding from small streams whose catchment areas lie almost entirely within the built-up area,
- flooding from major rivers on whose banks the town and cities are built and
- coastal flooding from the sea, or by a combination of high tides and high river flows from inland.

Climate change works in both direct and indirect ways to aggravate urban flooding. Intergovernmental Panel on Climate Change IPCC, 2007 report on Impact, Adaptation and Vulnerability noted that there is evidence of a broadly coherent pattern of change in annual runoff, with some regions experiencing an increase, particularly at high altitudes, and others a decrease. UNEP/WRC (2008) identified high level of variability and uncertainty in the rainfalls over the coast of Guinea and projected general increase in precipitation for this area and a decrease in precipitation over the Sudano-Sahelian inter land region of West Africa. Climate change will have direct impacts by aggravating urban flooding of towns and cities located in regions of increase rainfalls especially in the tropics where rainfall intensity is high. Climate change also works in an indirect way to aggravate urban flooding. Douglas *et al.* (2007) noted that droughts and floods in rural areas have left many rural people in such difficulties that they have migrated to towns and cities, often adding large new populations to the existing slum communities. These refugees from the rural areas increase the size of built-up areas and add to the urban activities that increase the speed of flow of rainwater to rivers and thus the intensity of local flooding. If climate change worsens rural drought and flood situations, increasing numbers of displaced rural people may move to cities and indirectly add to the urban flood problem.

Also, the four identified urban flooding types by Douglas *et al.* (2007) are prominent in Lagos with floods of the first and second types more frequent. However, the cumulative effect of these flooding on the socio-economic, environment and proper functioning of the supporting systems such as the informal economic activities, road network, communication, small scale and other service industries within the megacity is monumental. Therefore a proper understanding of the processes governing the flow of Lagos urban storm as it relates to the existing spatial arrangement of land utilization as well as the ability to properly identify the risk zones are essential for urban flood control and urban renewal of the city. Also, in most Lagos urban catchments, the concentration of people and development is very high and the rate of growth remains high, such that some exposure to storm hazards is expected, solely on random probability basis (Oyebande, 1974). Rainstorms of short duration, high intensity and high spatio-temporal variability occur frequently. This constitutes important factor of perennial drainage problem that creates critical flood conditions being experienced over most watersheds in the Lagos megacity. The high intensity short duration rainfalls are further enhanced in flood generation by the tropical coastal low lying location of the city a situation that promote the fourth type of urban flooding identified by Douglas *et al.* (2007). The low topography of the metropolis retards the flow of storm runoff during rainfalls. The coastal location, low topography and high rainfall intensity enhance the occurrence of high water table, which reduces the infiltration process and the natural absorption capacity of the sub-surface soil. All of these factors promote excessive flood runoff during and immediately after rainfalls. The effects of these natural factors are believed to be aggravated further by a number of anthropogenic factors, the most significant being violation of planning regulation, indiscriminate use of wetland, encroachments into floodplain, inadequacy of the hydraulic capacity and refuse dumping into the drainage systems (Oyebande, 1990). The efforts by the Lagos state government in bringing the flood situation of Lagos megacity under control over the years have always prove abortive. One major reason for this is inadequate estimation of the peak flow from major systems. This mostly results into under estimation of the channels size during design and lack of integration of future precipitation characteristics due to climate change in the design criteria. Consequently this study investigates the flood impact of precipitation increase arising from climate change and increase in urban imperviousness arising from land use change. Using *Precipitation Water Inundation Model (PWIM)* it integrates projections of precipitation and urbanization drivers to simulate peak flow and analyse future flood generations (Odunuga, 2009) over some drainage systems within the Lagos megacity.

STUDY AREA

Lagos is located along the coast of guinea. It extends from about latitude 6^0 15' N to 6^0 55' 30'' N and longitude 3^0 00' E to 3^0 56' 52'E. Specifically system 1 is about 4235.7ha, system 2 is about 2746.65ha while system 5 is about 2409.89 ha. Figure 1 shows systems 1, 2 and 5 in Lagos megacity.

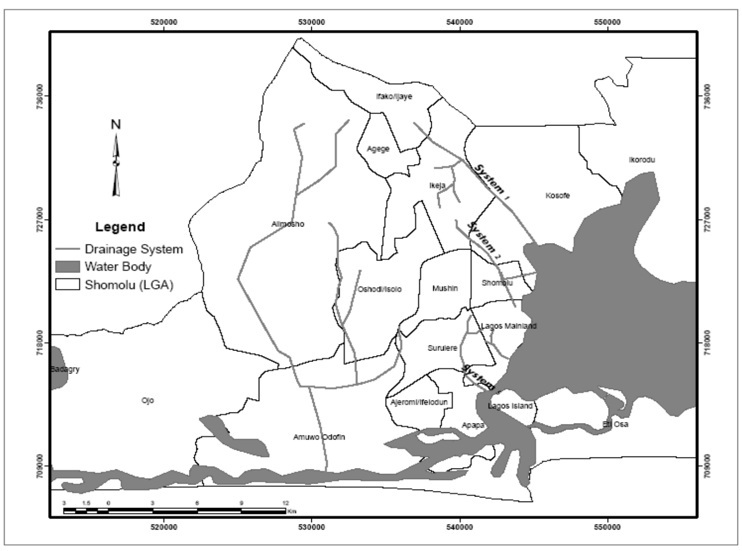

Fig 1: System 1, 2 and 5 in Lagos Megacity

Lagos occupies a low-lying site generally below 20 meters with many parts of the metropolis below sea level (Federal Survey, 1978). The terrain is flat with some noticeable undulation. The relative flatness of the terrain reduces the velocity of surface water delivery during rainfall and promotes surface water retention, a situation that aggravates the flooding process in many parts of the city. Surface lithology is entirely made up of sedimentary formation with sandy loam composition. It is located within the humid tropical climate with moisture index range between –19.5 and +18.5 based on Thornthwaite classification scheme. It's coastal location, the position of inter-Tropical Convergence Zone (ITCZ) relative to the apparent location of the overhead sun and the prevailing winds at different periods of the year, all combine to determine the observed weather and climatic characteristics. However, human activities especially urbanization and industrialization caused the removal of the forest cover. This human activities, of Lagos Megacity with population of over ten million (NPC, 2007) and annual growth rate of about 5% in turn resulted in the modification of the climatic parameters especially evapotranspiration, humidity and temperature.

Rain falls for about 8 months of the year in Lagos Megacity. The Megacity is characterized by two seasons – the dry and wet seasons. The rainy season (April/October) is bimodal, with the highest peak occuring during May – July and separated from the lower peak by the August, little dry season. Rainfall regime or the pattern of rainfall distribution over the seasons is determined by the two major air masses dominating the area: the moist tropical maritime (TM) with its associated westerlies and the dry tropical continental air mass (TC) with its associated easterlies. The movement of the Inter Tropical Convergence Zone (ITCZ), a quasi-stationary boundary that separates the TC from the TM, further modifies the process.

Rain falls in more than 7 (i.e. > 23%) of the days in every month of May to October and with just less than 5 (i.e. < 16%) of the days between November and February. Overall a total of about 1970 mm of rain is recorded annually. As shown in Table 1, this gives an average of 164.22 mm per month. The minimum rainfall amount (24.25 mm) is received in the month of December while the maximum rainfall amount (320.42 mm) is received in the month of July. Of the total amount, about 1,792.49 mm is recorded during the wet season (April to October) while only 178.45 mm is recorded in the "dry" season (November to March). The long wet season is characterized by a short break in August as the sun passes over the equator on its way from the Northern to the Southern Hemisphere. The wet season rainfall is mostly torrential and a mixture of short and long durations with high intensity. This probably explains why rainfalls are accompanied by flooding in Lagos.

Table 1: Climatic Characteristics of Lagos Computed from 30 years Records (1975-2005)

	Temperature (°C)			Rainfall (mm)	Relative Humidity (%)	
	Min	Mean	Max	Mean	10:00Hrs	16:00Hrs
January	21.56	25.75	29.94	26.12	93	66
February	26.42	27.21	28.00	25.89	87	64
March	24.52	26.32	28.11	101.89	79	71
April	25.78	27.31	28.84	162.02	89	70
May	21.85	25.93	30.00	210.21	92	74
June	23.58	25.28	26.98	291.54	91	83
July	22.69	24.85	27.01	320.42	96	77
August	24.11	25.48	26.85	192.54	95	81
September	23.25	25.18	27.10	287.25	94	80
October	22.98	25.20	27.41	250	92	79
November	22.70	25.91	29.12	78.51	95	75
December	24.11	26.53	28.95	24.25	92	65
Total	**283.55**	**310.93**	**338.31**	**1970.64**	**1095.00**	**885.00**
Mean	**23.63**	**25.91**	**28.19**	**164.22**	**91.25**	**73.75**
Min	**21.56**	**24.85**	**25.30**	**24.25**	**79.00**	**64.00**
Max	**26.42**	**27.31**	**29.00**	**320.42**	**95.00**	**83.00**

Source: Nigeria Meteorological Agency

METHODOLOGY

The analysis of climate change connection with intra-urban watershed flooding was based on the analysis of change in two of the most important drivers of climate and urban flooding. These are urbanization (Land use change) and precipitation. Increment in urbanisation driver was adopted from Odunuga 2008 analysis of land used changes of System 6c of Lagos drainage master plan. The study investigated urban land use change and developmental activities in central Lagos between 1965 and 2005. A follow up study by Odunuga (2009) reveals that only marginal increase of imperviousness will be recorded in most parts of central Lagos. Based on this expected marginal increase, multiplying factors for urbanization driver contribution to transforming storm runoff to flood in central Lagos was determined using trend analysis. Table 2 shows the multiplying factor for Urbanization drivers in future flood generation in Lagos based on trend analysis of land use developments. For instance, 0.05 (50 years) for scenario (High) means that, flooding emanating from rainfall of same characteristics will increased by 5% in the next 50 years when compared with 2008 base year. The increment is as a result of increase in area impervious due to urbanization.

Table 2: The multiplying factor for Urbanization drivers (Imperviousness):

Scenario	50 years	100 years
High	0.05	0.75
Medium	0.01	0.025

Source: Odunuga (2010)

With respect to change in precipitation there is considerable uncertainty in deducing changes in precipitation over short periods in small urban areas from predictions of global climate models (GCM) as well as regional climate models (RCM). The uncertainty is even much higher for maximum rainfall (extreme-value) analysis (Oyebande, 1983). Based on precipitation projected derived from statistical downscaling of CAM-EULAG regional climate model (Abiodun *et al., 2011*) the incremental rate of rainfall amount and intensity due to climate change in West Africa sub region was derived for 50 and 100 years medium and high climate change scenarios. Table 3 shows the multiplying factor / percentage of increments for precipitation drivers.

Table 3: The multiplying factor / percentage of increments for precipitation drivers

Scenario	Year			
	50		100	
	Amount	Intensity	Amount	Intensity
High	7.5	15	10	20
Medium	5	10	7.5	15

Source: Odunuga (2010)

Four storm rainfall events were selected from amongst series of rainfalls between June 2008 and July 2008. The rainfall selected were those whose total amount is more than 45 mm with intensity of at least 20 mm/h. Simulation of runoff, peak flow and area inundated arising from the precipitation and land use drivers were achieved using Precipitation Water Inundation Model (PWIM). PWIM is a model that synthesis hydrological processes on urban surface characteristics generated in a GIS environment and simulate runoff, peak flow and area inundated from rainfalls (storm event) (Odunuga, 2008). It has four major components based on urban drainage system models.

1. Rainfall Runoff Model Component: this determines the runoff and peak flow from rainfall;
2. Infiltration Component: to determine soil equilibrium beyond which runoff will start accumulating on the pervious surfaces;
3. Digital Surface Component: calculates the surface area within the watershed that will accommodate the volume at peak flow;
4. Stochastic Component: integrate rainfall intensity as a factor in inundation analysis of storm rainfall of urban environments.

Future runoff, peak flow and area inundated of the measured rainfalls were generated for two climate scenario; medium and high for 50 years and 100 years scenario.

In terms of overall performance, however, an examination of relationship between the measured and simulated peak flow for system 5 and year 2008 situation using regression model, reveals 0.867 as degree of relationship (R) with 0.75 as coefficient of determination (R^2). This indicates a strong direct relationship with over 75% of the observed variance being explained by the linear relationship. The standardized estimate of beta coefficients and the relationship between the simulated flow and the observed flow for system 5 and year 2008 situation is shown in equation 1 below.

$$\text{Simulated } Y = 10.42 + 0.908 X \qquad (1)$$

where Y is simulated peak flow and X is measured peak flow

RESULTS AND DISCUSSION

Projected Land use Scenario

The results of the land use and land cover reveals that as at 2008, 3346.203 ha (78%), 2417.052 ha (88%) and 2193 ha (91%) of the total land area of system 1, system 2 and system 5 respectively have been built-up (table 4 and table 5). This shows a general lack of regard for open spaces and wetlands. However, if the trend of developments continues at the high level of change scenario, about 96% and 98.5% of the total area of system 5 would be impervious by 50 years and 100 years respectively. This has a serious implication for flood generation due to spontaneous increase in runoff generation from impervious spaces (Adeniyi and Omojola, 1999).

Table 4: Future Area Impervious for different Scenario

Watershed	Area	Area Impervious				
		2008	**50 Years Scenario**		**100 Years Scenario**	
		Base year	**High**	**Medium High**	**High**	**Medium High**
System 1	4235.7	3346.203	3557.99	3388.56	3663.88	3452.10
System 2	2746.65	2417.052	2554.39	2444.52	2623.05	2485.72
System 5	2409.89	2193	2313.49	2217.10	2373.74	2253.25

Source: Satellite Imagery Interpretations (2008) and Projection Analysis

All the watersheds have distinctive and peculiar characteristics of high proportion of initial wetlands. The fragile wet lands were never taken into consideration during developmental activities; this however resulted in the current annual flood scenarios being experience on system 2 and system 5.

Table 5: Percentage of Future Area Impervious of different Scenario

	2008	**50 Years Scenario**		**100 Years Scenario**	
Watershed	**Base Year**	**High**	**Medium High**	**High**	**Medium High**
System 1	79	84	80	86.5	81.5
System 2	88	93	89	95.5	90.5
System 5	91	96	92	98.5	93.5

Source: Data Analysis

Also, these unguided developments as displayed by the level of impervious area within the watersheds (as shown in table 4 and table 5) reveals a lack of monitoring and or strict enforcements of the town and regional planning regulations during developments. For instance section 17 (Building coverage) sub section 1a and 1b (residential) of the town and regional plan regulations Lagos State Government stated as follows:

(a) The maximum building coverage permissible under schedule 7 to these regulations shall be fifty (50)% in Victoria Island, Ikoyi, the GRA's in Apapa, Ikeja, Victoria Island annex, Ogudu, Omole, Magodo Scheme, Lekki Peninsula and other Government Residential Schemes.

(b) In other areas, building coverage shall not exceed sixty (60) % percent except where otherwise stated in this regulation.

System 1 drained areas under section 17 (1) a and b, System 2 and System 5 drained areas under section 17 (1) b. However, field verification shows that most buildings do not meet these requirements as more than (85) % of most plots have been developed in all the three urban watersheds. The reasons for gross violations of the laws range from corrupt practices of government officials to lack of effective and efficient monitoring strategies. Also, section (15) of the same regulation titled 'Setback to public Utilities', sub section (5) d 'Gorge/Canal/Drainage' stated that: The distance between any building and a gorge/canal/drainage shall not be less than ten (10) metres, or as may be specified by the relevant statutory body. Field verification also reveals that not only that the setback to major waterways are less than 10m, some structural developmental activities have actually moved into the channels of the drainages. A situation that further compound the free flow of water, create unhealthy environment and exacerbate the flooding process during raining season.

Analysis of Observed Rainfall under Climate change scenario

Four rainfall events that resulted in serious flooding in most parts of Lagos during the months of June and July 2008 were selected for analysis under different climate change scenario. Percentages for projection were based on statistical downscaling of CAM-EULAG regional climate model on South Western Nigeria. The results of CAM-EULAG regional climate model reveal a sustained minimal increase in precipitation over the region. The percentage increase for the scenarios was used as multiplying factors (table 3) for projecting the four selected storm rainfall. Table 6 shows the result of the projections for the rainfalls under different climate scenario. However, going by the results of the projections, rainfall will increase by about 5%, 7.5% and 10% under the 50 years MCC, 50 years HCC and 100 years HCC respectively.

Table 6: Projected precipitation under different Climate scenario

Date	2008 Observed Precipitation	50 yrs MCC	50 yrs HCC	100 yrs HCC
3/6/2008	48.90	51.35	52.57	53.79
7/6/2008	69.50	72.98	74.71	76.45
13/7/2008	122.40	128.52	131.58	134.64
21/7/2008	66.70	70.04	71.70	73.37

Source: NIMET and Projection Analysis

Urban Flooding and Climate Change

The impact of land use-change and increasing precipitation with high intensity especially in the tropics on flood events can be both positive and negative, so predictions are hard to make for a specific urban watershed. Generally, the removal of forest and other natural cover and the conversion of land to agricultural uses, result in compaction of the soil and reduction of the infiltration rate, leading to high flood peaks (Odunuga, 2009). However, a city will frequently have significant flooding problems that are local in nature, but will be impacted upon by major flood events on large streams or lakes that are not within the urban zone (UN, 2004). This will become more frequent where local sustainability practices built on citizenship participation is not adopted (Selman, 1996). A community's physical environment is a central part of its basic identity. It is the foundation upon which the community is founded and the framework within which it functions. It is, therefore, pertinent to anticipate, at the design stage, the hydrological changes that may be caused by urbanization, with particular emphasis on the extent and consequences of flooding. An understanding of this effect of the ever extending urban environment upon our water resources is essential to proper planning and engineering design in existing and future areas of urban growth. Table 7, 8 and 9 provides the PWIM peak flows and area inundated for different scenarios of cumulative environmental change on three systems (watershed) in Lagos megacity using the 2008 observed situation as the bench mark. The results revealed that runoff and peak flow on system 1 will increase by 6.34%, 14.24%, and 20.36% for 50 years MCC, 50 years HCC and 100 years HCC respectively. On system 2, runoff and peak flow will increase by 10.88%, 13.52%, and 19.26% for 50 years MCC, 50 years HCC and 100 years HCC respectively while on system 5; runoff and peak flow will increase by 6.13%, 13.31%, and 18.91% for 50 years MCC, 50 years HCC and 100 years HCC respectively.

Marginal increase in the area inundated is also expected on each of the three watersheds. On the average, area inundation on system 1 will increase by 2%, 3% and 4% for 50 years MCC, 50 years HCC and 100 years HCC respectively. On system 2, area inundation will increase by 1%, 2% and 4% for 50 years MCC, 50 years HCC and 100 years HCC respectively.

Table 7: PWIM Simulation of Peak Flow and Area Inundated for Different Scenario on System 1

	2008 Situation			50 yrs. HCC Scenario			50 yrs. MCC Scenario			100 yrs. HCC Scenario		
Date	PWIM RO mm	PWIM PF (m3/s)	PWIM AI ha.	PWIM RO mm	PWIM PEAK Qm3/s	PWIM AI ha.	PWIM RO mm	PWIM PEAK Qm3/s	PWIM AI ha.	PWIM RO mm	PWIM PEAK Qm3/s	PWIM AI ha.
3/6/2008	1650.37	194.19	1150.43	1885.60	221.87	1172.04	1754.97	206.50	1164.58	1986.46	233.74	1179.71
7/6/2008	2345.62	276.00	1168.73	2679.94	315.34	1194.67	2494.29	293.49	1185.71	2823.30	332.21	1203.86
13/7/2008	4131.00	486.08	1223.63	4719.77	555.36	1262.54	4392.81	516.89	1249.10	4972.26	585.07	1276.33
21/7/2008	2251.12	264.88	1157.75	2571.97	302.64	1181.09	2393.80	281.67	1173.03	2709.55	318.82	1189.37

(Source: Simulation Analysis)

Table 8: PWIM Simulation of Peak Flow and Area Inundated for Different Scenario on System 2

	2008 Situation			50 yrs. HCC Scenario			50 yrs. MCC Scenario			100 yrs. HCC Scenario		
Date	PWIM RO mm	PWIM PF (m3/s)	PWIM AI ha.	PWIM RO mm	PWIM PEAK Qm3/s	PWIM AI ha.	PWIM RO mm	PWIM PEAK Qm3/s	PWIM AI ha.	PWIM RO mm	PWIM PEAK Qm3/s	PWIM AI ha.
3/6/2008	1196.09	140.74	599.62	1357.82	159.77	607.51	1270.28	149.47	600.08	1426.51	167.85	615.18
7/6/2008	1699.97	200.02	620.67	1929.82	227.07	630.14	1884.94	221.79	621.22	2027.45	238.56	639.33
13/7/2008	2993.90	352.28	683.80	3398.71	399.91	698.01	3319.67	390.61	684.63	3570.65	420.14	711.80
21/7/2008	1631.48	191.97	608.04	1852.08	217.92	616.56	1809.00	212.85	608.53	1945.77	228.95	624.84

Source: Simulation Analysis

Table 9: PWIM Simulation of Peak Flow and Area Inundated for Different Scenario on System 5

	2008 Situation			50 yrs. HCC Scenario			50 yrs. MCC Scenario			100 yrs. HCC Scenario		
Date	PWIM RO mm	PWIM PF (m3/s)	PWIM AI ha.	PWIM RO mm	PWIM PEAK Qm3/s	PWIM AI ha.	PWIM RO mm	PWIM PEAK Qm3/s	PWIM AI ha.	PWIM RO mm	PWIM PEAK Qm3/s	PWIM AI ha.
3/6/2008	1086.56	127.85	573.48	1231.13	144.86	595.09	1153.21	135.69	587.72	1292.04	152.02	602.76
7/6/2008	1544.29	181.71	591.78	1749.77	205.89	617.72	1639.02	192.86	608.86	1836.33	216.07	626.91
13/7/2008	2719.73	320.02	646.68	3081.60	362.60	685.59	2886.56	339.65	672.31	3234.05	380.54	699.38
21/7/2008	1482.07	174.39	580.80	1679.27	197.59	604.14	1572.99	185.09	596.17	1762.35	207.36	612.42

Source: Simulation Analysis

where: HCC; High Climate Change, MCC; Medium High Climate Change, PWIM; Precipitation Water Inundation Model, RO: Runoff, PF; Peak Flow, AI; Area Inundated

System 5 area inundations will increase by 3% 6% and 8% for 50 years MCC, 50 years HCC and 100 years HCC respectively. It must be stated that rainfall intensity plays significant role in area inundated by individual storm events, thus the area inundation provided is an average of the four storm events investigated under the different scenarios. Many threatened infrastructures along the flood plain of these watersheds are vulnerable to damage from flooding. The stock of these infrastructures which includes schools, private houses, hospital and so on at risk is increasing rapidly as a result of the continuing growth of the flood plain as well as its usage by the informal sectors such as the road side mechanics and other artisans. In some of the systems within Lagos Megacity, damage costs due to flooding have been estimated (Odunuga, 2008) and are often substantial. For examples, in a city wide survey of the socio-economic impact of flooding in Lagos in 2005/2006, (Odunuga, 2008) reported that the monetary value of loss in business due to flooding from single storm events range from about $84.75 to $8474.58. The survey indicated that small and medium scale industries are severely impacted, and that the low income and female gender are particularly vulnerable. With anticipated increase in flood generation from storm events, especially under scenarios 50 years HCC and 100 years HCC, it can be concluded that the monumental impact of flooding especially on low income vulnerable people will be great. If mitigation plans are not put in place to address the issues, and urban development is allowed to continue in an unregulated manner, it will not be too far before environmental refugees from flooding become the order of the day in Lagos Megacity.

Adaptation

Impact of changes in the characteristics of storm events in the tropical coastal area especially in Cities within the guinea coast could be tempered by appropriate infrastructural developments, and by changes in water and land use management (Bate *et al.*, 2008). Coordinated planning involving all stakeholders and relevant government agencies such as the Ministries of Environment, Works and Infrastructure, Physical planning and Urban development is needed to tackle the growing problems of climate change in general and urban flooding in particular. Improved incorporation of current climate variability and projected scenarios into infrastructural developments and water related management would make adaptation of future climate change easier with very high confidence.

CONCLUSION

The paper discussed the impact of 50 years MCC, 50 years HCC and 100 years HCC in flood generation in system 1, 2 and 5 of Lagos drainage master plan. An up scaling of drainage and other infrastructural developments by about 20% would be needed to accommodate future high climate scenarios. Also maintaining green areas and natural buffers around streams in Lagos would also help to reduce the adverse impacts of future heavier storm runoff.

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Effects of landuse changes on the sedimentation rate in the Galma Reservoir in Northern Nigeria

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Abstract

The Galma earth dam was impounded in 1975 to supply Zaria with drinking water and has a maximum storage capacity of 16 million cubic metres, a maximum depth of 14.9m, a dam length of 640m and a total lake length of 40km. The intensification of cultivation, fuel wood harvesting and other landuses within the catchment of the Galma has resulted in increased soil erosion. This study was carried out with the objective of determining the effects of the present landuse/landcover change on the sedimentation rate of the Galma dam. To achieve this objective, Landuse / land cover changes over the catchment of river Galma were assessed from Landsat MSS 50m resolution (resampled) for the 1970s; Landsat TM 30m resolution for the 1980s; SPOT XS 20m resolution for the 1990s and Landsat ETM 15m resolution for the 2000s.The results reveal that cultivated area increased from 2476.25km^2 to 3241.36km^2; built-up area from 4.06km^2 to 13.67km^2 from 1970s to 2000s respectively while forest and water body show a reduction of 1085.35km^2 to 313.52km^2 and 7.12km^2 to 5.81km^2 from 1970s to 2000s respectively. Area statistics of 203.25km^2 was uniform for rock outcrop throughout the decades of 1970-2000. Hydrographic survey of the dam was conducted to determine the level of sedimentation by carrying out depth measurement of the dam from the surface to its bed .The result obtained shows that the dam has lost 7.6m depth to sedimentation; indicating 51% loss in installed storage capacity. The results have significant implications for future water supply to the residence of Zaria.

Key words: Catchment area, Reservoir, Sedimentation, Storage capacity, Landuse

INTRODUCTION

A major problem in the management of freshwater ecosystems is sedimentation. Sedimentation problem in rivers and reservoirs is always one of the key problems to be faced in the construction and operation of hydro-projects (Annandale, 1987). As a result of high temporal and spatial variability of rainfall in addition to extreme fluctuations in river discharges in some climatic regions, river valley projects such as dams were constructed to tap the available water resources to serve various purposes and to control flooding. Sedimentation occurs when rapidly flowing streams burdened with sediment enter a still body of water such as a reservoir, causing the sediment to settle due to the lower flow rate (Salas and Shin 1999). Such reservoirs, capturing the runoff from their upstream watersheds, and often without a method to balance the inflow of sediment with outflow, function as sediment traps (Fan and Morris 1992).

The Savannah ecological region is known to be predisposed to high rate of soil loss, particularly in areas where intense cultivation, overgrazing and unwholesome land use practices dominate. The prolonged exploitation of vegetation within the catchment areas of Galma reservoir has stripped open large areas thereby making the soil susceptible to water erosion at the beginning of the rainy season which is often characterized by high intensity thunderstorms. Sediment generation from the cultivated areas of the catchment is therefore usually high. The end result is often degraded water, disrupted ecological relationships, and diminished aesthetic qualities (Waters 1995). In addition, as reservoirs become filled, their capacity for storage decreases. The continued loss of storage capacity due to sedimentation is diminishing the benefits reservoirs were built to provide including flood control, water supply, and recreational opportunities (Hotchkiss and Huang 1995).

Sedimentation embodies the processes of erosion, entrainment, transportation, deposition and the compaction of sediment at the reception point. During and after a particularly violent storm a river may carry as much sediment as it would in several "normal" years. Mudslides caused by earthquakes and volcanoes can also have a dramatic and unpredictable effect on reservoir sedimentation (Morgan, 1986). The potential for watershed erosion and reservoir sedimentation increases as areas urbanize, exposing bare soil and increasing the amount of impervious surfaces. Since 1980s there has been rapid urbanization and intensification of farming activities in the catchment area of the Galma reservoir. Besides, the changes in the local population density have brought about the conversion of more forest areas to agricultural landuse. Hence, this research is designed to find out the nature of landuses within the catchment area of the reservoir and examine the effects of the present landuses on the sedimentation rate of the Galma reservoir.

The main objective is to assess the effects of landuse/Landcover changes on the rate of sedimentation in the Galma reservoir. However, the specific objectives are to:

i. Characterize the land uses in the study area.

ii. Examine the effect of landuse/ land cover change on the sedimentation rate of the Galma reservoir.

CONCEPTUAL FRAMEWORK

Human activities have had a fundamental and increasing impact on the fluvial system behaviour. Landuse changes have significantly altered the runoff regime of many rivers and the pattern of sediment supply (Starkel, 1991). Vegetation cover is one of the primary controls on sediment supply and catchment hydrology. A major consequence of forest clearance is accelerated soil erosion on hillslopes, associated with which are network extension through gully development and an increase in the amount of sediment supplied to the streams (Trimble, 1974, 1983). Milliman *et al*. (1987) have estimated that the sediment load of the Huang Ho increased by an order of magnitude after the easily eroded soils of the loess plateau had been cleared of forest.

Soil erosion by water or wind is facilitated by lack of vegetation. A cover of trees, bushes, grass or other vegetation prevents the rain from beating the ground, reduces splash erosion, increases infiltration and decreases surface runoff. Therefore, the clearing of natural vegetation and bringing land under cultivation will inevitably increase the risk of soil erosion. Compared to natural conditions most agricultural practices imply a substantial reduction of vegetation cover, at least during part of the year, including loss of surface litter and content of humus. Agricultural practices will also have other effects on soil and ground surface, e.g. physical changes of the soil, including destruction of soil aggregate which makes the surface more erodible by wind and water-sealing of the surface by silt and clay particles, compaction of the soil and the creation of new drainage channels for runoff (Millington, 1988). Soils of forest and woodland vegetation are normally characterized by low surface runoff, high infiltration rates, and insignificant soil erosion due to the protection by leaf canopy and ground cover litter. Forests are cleared for cutting for pulp and paper, timber, production of charcoal, fuel wood for heating and cooking. Also they are cleared to extend or improved cultivation and grazing on rangeland (FAO, 1982). There are numerous reports on erosion hazards and accelerated sediment production from areas with logging activities and deforestation. Large-scale timber harvesting in the Redwood Creek catchment caused storms in 1964 and 1972 (estimated as 1 in 50year events) to have impacts disproportionate to their size (Madej, 1995; Nolan and Marron, 1995). The resultant 20 percent increase in storm runoff triggered extensive landsliding, particularly in the upper basin during 1964 storm, and considerable amounts of sediment were delivered to the valley floor. Megahan (1972) reported that sediment production per unit area in a watershed with logging activities in Idaho, USA, equalled over 150 times the undisturbed sediment production. Most sediment was produced by surface erosion from new roads and road construction works, intended to facilitate logging operations. The effects of grassland practices on hydrological condition and soil erosion depend on climate and grazing intensity. In semi-arid areas over-grazing may cause considerable changes in runoff and may lead to increased erosion activity. In the dry season animals are often bound to live and graze within short walking distance from a water hole or any other water available. Areas that have been destroyed during the preceding dry seasons are now susceptible to heavy rainstorms with severe splash, wash, rill, and gully erosion (FAO. 1976). Mining operations often give rise to a tremendous increase in the activity of erosion and sedimentation processes. As much as 270 million m^3 of sediment were delivered to the Bear River (James, 1991), while the Yuba River received over 15 million m^3 in a single year (Wildman, 1981). Construction sites, in particular, can increase the sediment found in a stream by as much as five times the normal amounts. Such sites are increasingly found to be the primary sources of sediment, with soil erosion rates up to twenty times higher than at comparable agricultural sites (USEPA, 1997 and Faucette *et al*., 2004).

Given the present rate of deforestation in the tropics (10 hectares of rainforest are lost throughout the world every minute of the day) it is hardly surprising that rivers in the region carry enormous quantities of silt. Indeed, in many areas, the increased sediment load of rivers is clearly visible to the naked eyes (Goldsmith and Hildyard, 1982). In comparison with forest clearance, urbanization represents a localized form of landuse change, but its effects may nevertheless be propagated downstream. In general, the creation of impervious surfaces and the installation of more efficient drainage systems in urban areas increase the volume of runoff for a given rainfall and give rise to a flashier runoff regime with shorter lag times and higher peak discharges (Roberts, 1989).

METHODOLOGY

The Study Area

The Galma earth dam is located in the Galma basin $10^0 35^1$N-$11^0 25^1$N and $7^0 42^1$E-$8^0 41^1$E (Fig. 1).The climate of the study area is generally described as Tropical wet and dry. It is characterized by strong seasonality in rainfall and relatively high temperature. Rainfall starts effectively from the month of May and ends in October. The beginning of the rainy season is often marked by high intensity thunderstorms produced by the Tropical Easterlies. Rainfall intensity decreases progressively as the rainy season becomes well established. It ranges from about 25mm/hr to about 125 mm/hr (Kowal *et al*., 1972). Mean monthly temperature is about 27^oC. Daily maximum temperature can be as high as 40^oc in the months of April and May and daily minimum can be as low as 15^oC in January. The seasonality in rainfall is caused by the Tropical Maritime Airmass (mT) over the study area. When the Tropical Continental Airmass (cT) prevail, dry season dominates the study area while the rainy season is ushered into the study area by the incursion of the airmass.

The vegetation cover of the study area is originally Tropical Savannah grassland characterized by tall grass communities and short widely dispersed trees. At present it is only in a few places that this typical Savannah vegetation can be found. In this study area, very little of this natural vegetation can be seen. A prolong period of bush burning, overgrazing, cultivation, tree harvesting for cooking purposes has considerably degraded the vegetation cover to open grassland, bare surface and scattered scrubs. The grass communities sprout up shortly after the onset of the rainy season, blossom and become luxuriant almost completely covering the ground surface towards the latter part of the rainy season. In the dry season, however, the grass communities wither and die. The geology of the study area is underlain mainly by biotite gnesis weathered to various depths. Lateritic crusts occur close to the surface and outcrop in a few places. The soils in the study area are part of the Tropical ferruginous soils, which are commonly called Ferrasols, developed on crystalline basement complex rocks. The soils are characterized by low organic matter content (about 1%), low cation exchange capacity and sandy clay texture (Iguisi, 1996).

Landuse /land cover changes

To characterize landuse and assess land cover changes over the catchment of Galma, Satellite imageries covering the period 1970-2000 were obtained from the GIS unit of Federal Ministry of Agriculture and Water Resources (Livestock House) Mando, Kaduna State.

These include: Landsat MSS 50m resolution (resampled) for the 1970s; Landsat TM 30m resolution for the 1980s; SPOT XS 20m resolution for the 1990s and Landsat ETM 15m resolution for the 2000s. The imageries were analyzed using GIS procedures as follows:

i. **Geo-referencing:** Known points on the imageries were selected and their corresponding ground coordinates were used to perform geo-referencing exercise. This exercise relates the positions on the imageries to their true ground positions.
ii. **Development of interpretation key for imagery interpretation:** This was necessary in order to delineate various landuses by employing imagery characteristics of the various features. Based on the various signatures exhibited by the features, the interpretation was carried out thus: water body appeared blue; cultivated area appeared light tone with specks of red; forested area appeared dominantly red (evidence of green healthy vegetation); built-up area appeared blue tone with coarse texture and streams/rivers appeared as linear features mostly aligned by riparian forest.
iii. **Visual on-screen interpretation of the imageries:** ArcviewGIS 3.2a was used to perform the on-screen interpretation of the imageries. Based on the interpretation key, the various landuse/landcover were discriminated. The direct on-screen interpretation saved the separate process of digitization. The features were interpreted as lines and thereafter polygonised so as to obtain area statistics as well as area symbols.
iv. **Classification and symbolization of the interpreted features:** Different symbols (colours) were assigned to the various landuse/landcover features. This was done following laid down convention. For instance, Blue was used to represent water body; Grey represent built-up area; Green represent forest etc.
v. **Overlay of the various features:** The various features were overlay as they appeared in reality. For instance, rivers flow over the landuse/landcover, so they were place above the landuse/landcover during the overlay process.
vi. **Map composition and production:** Lastly, all maps were composed and produced by placing the overlay on the grids. The grid values were indicated, the scale and the legend were placed in their appropriate positions on the map.

Dam Sedimentation

The conventional tape method of measuring lake sedimentation was adopted (USDA, 1975). The lake surface area was mapped using simple land surveying techniques to fix survey points and grid squares over the lake area. Grid lines were drawn from the south bank to the north bank and from the embankment to the upstream. Eight grid lines labeled P_1-P_8 were drawn between the two banks at 80m intervals. Nine grid lines labeled 1-9 were also drawn between the embankment and the upstream at 20 m intervals. The intersection between these two sets of grid lines were designated sampling points. In all, there were 72 sampling points over the lake area for the purpose of collecting data on lake sedimentation.

A canoe was guided from the theodolite at point P_1. At each sampling point, the researcher measured the depth of the lake by using a rope and medium weight plumb tied to its end. The rope was lowered down from the canoe into the lake bed until it sags indicating that the plumb has reached the lake bed. The rope is drawn up until it is taut and the point of intersection between the rope and the lake surface marked by the researcher was measured with measuring tape and recorded. The same procedure was repeated for all the sampling points over the lake surface to determine the depth of the lake. Lake sedimentation is therefore obtained as the difference between the previous depth and the present depth. This difference is the level of accumulation of silt and sediments in the lake. This is usually referred to as sedimentation.

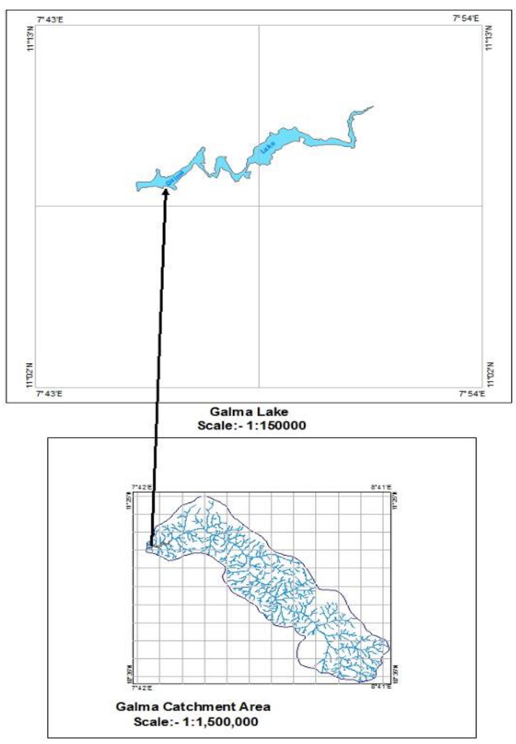

Fig 1: Study Area Showing the Galma Reservoir

RESULTS AND DISCUSSION

Analysis of the satellite imageries shows five major landuse/ land cover classes which include cultivated area, built-up area, forested area, water body and rock outcrop. The proportion of the catchment area occupied by each class is shown in Table 1. The result of the lake depth measurement is shown on Table 2. It can be observed that the deepest point in the lake is 7.3 m. The table shows that sampling points with depths of more than 7.0 m are only three out of the 72 sampling points. The lake is shallower close to the banks and deeper close to the north bank. In 1975 when the reservoir was constructed its maximum depth was 14.9 m during the dry season. The result obtained in this study during the 2007 dry season (February) indicates a maximum depth of 7.3 m. This represents a loss of 0.6 m in 32 years and translates to an annual loss of depth of 23.8 cm, assuming the sediments causing this loss in depth are evenly distributed over these years. The data also indicate that Galma dam has incurred 51% loss in installed storage capacity since its construction in 1975.

Table 1: Landuse/ land cover change in the Galma catchment (1970- 2000)

Landuse/Landcover	Extent in 1970 (km^2)	Extent in 1980 (km^2)	Extent in 1990 (km^2)	Extent in 2000 (km^2)	Change in areal extent from 1970 to 2000 (km^2)	% change in areal extent from 1970 to 2000
Cultivated area	2476.25	2847.16	3089.27	3241.36	765.11	30.90
Built-up area	4.06	8.43	9.01	13.67	9.61	236.70
Forest area	1085.35	707.44	469.47	313.52	771.83	71.11
Water body	7.12	10.64	5.78	5.81	1.31	18.40
Rock outcrop	203.25	203.25	203.25	203.25	0	0

Source: GIS Analysis (Landsat MSS 1970s; Landsat TM 1980s; SPOT XS 1990s and Landsat ETM 2000s)

Table 2: Lake depths at each sampling point (m) Embankment

South Bank

Traverses	1	2	3	4	5	6	7	8	9
P_1	0.7	1.0	1.4	2.6	2.6	2.7	1.2	1.4	2.1
P_2	*0.9*	*1.2*	*2.9*	*3.5*	*3.1*	*4.1*	*3.1*	*3.2*	*3.2*
P_3	1.2	1.8	7.2	7.1	7.3	6.4	3.9	3.7	3.6
P_4	1.5	5.2	6.5	6.9	5.2	5.9	3.8	3.7	1.6
P_5	4.3	4.5	4.3	3.6	3.1	4.0	3.1	2.4	2.7
P_6	1.3	3.2	3.2	3.0	3.1	3.0	2.7	2.5	2.0
P_7	1.5	1.7	3.1	3.8	3.1	1.6	2.0	2.1	1.8
P_8	1.8	1.9	2.0	3.1	3.6	1.4	1.7	1.8	1.6

North Bank

Upstream

Source: field survey, 2007

The magnitude of loss in storage capacity of the dam and its thickness of sedimentation in about 32 years seem to be in conformity with what obtains in similar small earth dams in other parts of the world. One of the causes of the high level of sedimentation is the peculiar design of the reservoir, which makes the reservoir a huge sediment trap into which all sediments enter. The design, coupled with the predominant land use of cultivation, deforestation and built-up area over the catchment area of the dam explain why the rate of sedimentation in the dam is very high. McCully (1996) asserted that the rate of dam sedimentation depends mainly on the design and size of the dam. A small dam on an extremely muddy river will rapidly lose capacity. This assertion relates well with what obtains on the Galma dam. The landuse analysis of the Galma catchment shows considerable change between 1970 -2000. Cultivated area increased by 765.11 km^2 from 2476.25 km^2 in 1970 to 3241.36 km^2 in 2000; built-up area increased by 9.61 km^2 from 4.06 km^2 in 1970 to 13.67 km^2 in 2000; forest area decreased by 771.83km^2 from 1085.35km^2 in 1970 to 313.52 km^2 in 2000 and water body decreased by 1.31 km^2 from 7.12 km^2 in 1970 to 5.81 km^2 in 2000. These show that the trend of landuse change was an increase of cultivated area and built-up area and a consequent decrease of forested area and water body. Increase in the area under cultivation offer little protection against raindrop impact, overland flow, rill erosion and gullying. Sediment yield increases with increasing runoff and with increasing percentage of land under cultivation. Also increase in built-up area leads to higher runoff yield because the increasing construction area extends the impermeable area. The decrease in the forested area reduced infiltration rates thereby increasing overland flow. The loss of storage capacity of the Galma dam could be attributed to landuse / landcover changes since the 1980s.

CONCLUSION AND RECOMMENDATIONS

Conclusion

The study has shown that the Galma reservoir has lost a substantial part of its depth to sedimentation. Reservoir sedimentation remains a serious problem in many parts of Nigeria. The situation has been exacerbated by the intensification of agricultural production and the encroachment upon marginal lands by settlements as a result of population pressure.

Recommendations

In view of the importance of water to our national development, it is important to determine the useful life of a reservoir periodically by assessing its sedimentation rate. With the updated information on sedimentation processes taking place in a reservoir, remedial measures can be undertaken well in advance and reservoir operation schedules planned for optimum utilization of water. The following specific recommendations are made to control the problems of sedimentation in the Galma reservoir.

1. Watershed management including afforestation and the promotion of farming practices which reduce soil erosion is a sure way of cutting sediment deposition in reservoir.
2. From the viewpoint of integrated sediment system management, check dams should be put in place to prevent excess sediment flow to downstream areas.
3. Projects on stabilization of embankments should be put in place.
4. Long term monitoring of reservoir on a regular basis is ideal to ascertain the level of sedimentation.
5. Dredging can be applied to the problem of excessive sedimentation in reservoirs.

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Estimation of runoff from Chanchaga River Basin using soil-water balance approach

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Abstract

This paper presents the estimation of runoff in an ungauged watershed in Chanchaga River Basin in Guinea Savannah region using semi arid moisture balance technique (SAMBA). The SAMBA model is a single layer soil water balance model that estimates daily surface runoff using daily rainfall, evapotranspiration, vegetal cover and soil moisture deficit (SMD). The model estimate was validated with discharge measurements taken in 2009 and 2010 with a rectangular weir across a stream at the outlet of the basin. Annual runoff for the year 2009 was 167.7 mm, which is 14.5% of the annual rainfall of 1157.1 mm. Maximum runoff occurred on 1st September, coinciding with the high rainfall that occurred between 29th August and 1st September. Similar result was obtained for the year 2010. It was also found that SMD was as high as 49.8 mm during the dry season. The result is useful in understanding and management of water resources in the region.

Keywords. Runoff, Soil Moisture Deficit; Ungauged catchment; Guinea Savannah

INTRODUCTION

The excess water flowing on the soil surface after the infiltration, percolation, recharge, and interception have been satisfied is called runoff. In the water balance, runoff is a very significant component for its input in the water balance procedure. Surface runoff depends on many factors, among which are, surface gradient, soil characteristics, vegetation, rainfall intensity, and the soil moisture conditions, which is represented in this study by soil moisture deficit, SMD. The estimation of runoff of a catchment is required for various water resources projects. Once the demand of evapotranspiration, interception, infiltration, surface storage, surface detention, and channel retention are satisfied, runoff will occur. Based on this note, runoff is defined as the portion of precipitation that makes its way towards stream channel, lakes or ocean as surface or subsurface flow (Schwab, 1993). When all the factors affecting precipitation are kept constant, equal amount of precipitation will produce different amount of runoff. This is actually dependent on the size of the watershed, the larger the size, the larger the amount of runoff produced. Watershed can simply be defined as a topographical area drained by a stream or a system of connecting streams such that all outflow is discharged through a single outlet. Perevia (1998) also defined watershed as the area to water course. The topography or orientation of watershed defines its shape. Watershed either promotes or demotes runoff. The topography of the watershed influences the mean travel time of a drop of water from its point of impact on the surface thereby influencing flood intensities to the point of exit in the main stream.

Various methods have commonly been used in the past for the estimation of surface runoff in the catchment. These include the rational method and the Natural Resources Conservation Service (NRCS) method. The rational method is very simple in concept but relies on considerable judgment and experience to evaluate all factors properly. It is used primarily for small drainage areas (less than 20 ha). The NRCS method offers a more accurate approximation of runoff, particularly for areas larger than 8 ha. Another technique is the soil water balance methods account for all water entering and leaving the soil zone based on the quantification of the individual physical processes (the inputs and outputs), without representing all the physical soil physics and their interactions which describe the movement of water within the soil (Eilers, 2002). This approach is based on fewer physical processes and it is not subject to the uncertainties of the mechanisms of a full soil physics analysis. Eilers (2002) and Rushton *et al*. (2006) among others, discussed the merits and demerits of the soil water balance techniques over other methods such as empirical rainfall-recharge expression, lysimeters, zero flux plane, and numerical solutions based on Darcy's law. Specifically, soil water balance method is favoured for semi-arid region because of its physical credibility at daily or less time scale, and its simplicity with less uncertainty in spatial variability in hydraulic soil properties. In addition, the technique is favoured because model parameters are few. As the number of parameters increases, the level of data required for parameter estimation increases. In semi-arid areas, the availability of complex information (e.g. soil-vegetation system) is poor and there are financial and technical limitations involved in gathering a large amount of data.

In this study, we have used a daily soil water balance (the Semi Arid Moisture Balance Accounting - SAMBA) to estimate the groundwater recharge and runoff in a small watershed in Minna, Nigeria. Runoff from the outlet of the watershed was measured for different rainfall events. The field data were used to validate the SMABA estimates.

MATERIALS AND METHOD

The study area is the Chanchaga river basin located between Latitude $10^{o}15^{'}$ and $10^{o}\ 45^{'}$N and Longitude $6^{o}15^{'}$ and $6^{o}\ 45^{'}$E (Fig. 1). The topography is shown in Fig. 2. The vegetation of the area is classified as Guinea Savannah. Characteristic vegetation in the area includes shrubs with scattered shear butter and locust bean trees. The climate is characterized by wet and dry seasons. The wet season lasts between April and October with annual rainfall ranging between 1000 mm to 1200 mm and the temperature between 20°C and 40°C. The nature of vegetation varies from one season to another with shrubs at the early period of the year showing what the vegetation looks like when the soil moisture deficit, *SMD*, is high.

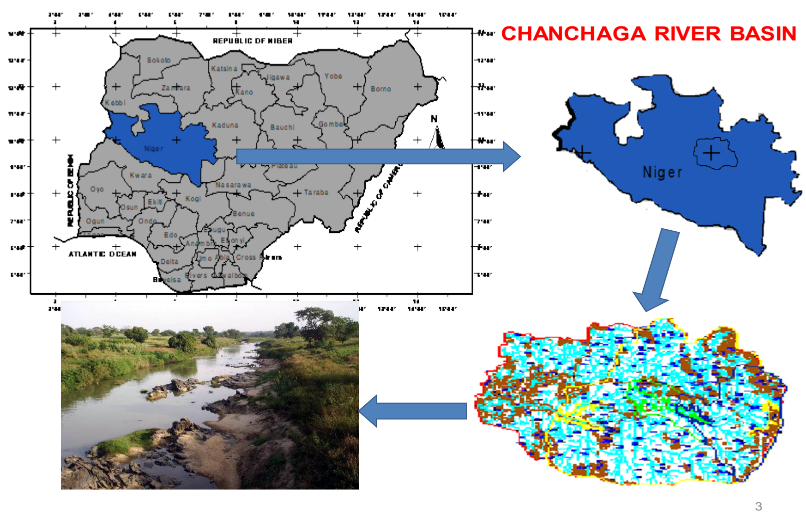
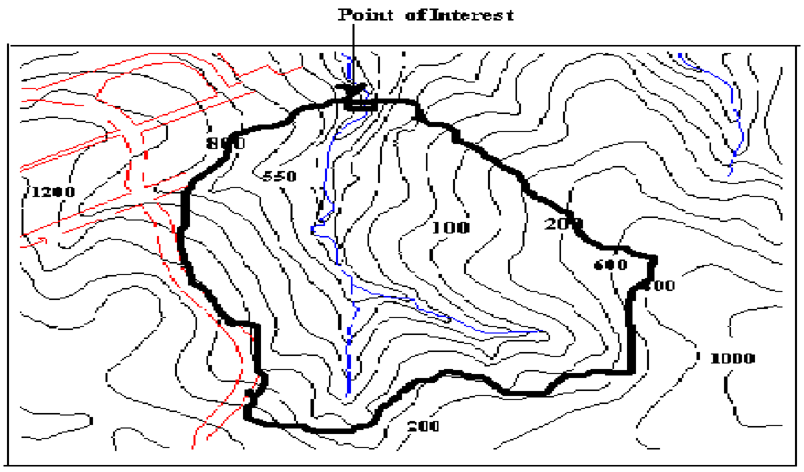


Fig. 1: Location of study area



10^oN6^oE

Fig. 2: Topography of the study site showing the catchment boundary

THE MODEL AND ITS COMPUTATIONAL METHOD

There are various models available for the estimation of the runoff and some other hydrological components. There are conventional single layer model; the CROPWAT model which was developed by the Food and Agriculture Organization of the United Nations (Smith, 1992); a two layer model which was developed to estimate daily soil water balance for cropped or un-cropped surface; and the four root layer model (FRLM) developed by the Institute of Hydrology, UK for the estimation of soil moisture deficits in sites under permanent grass cover (Ragab *et al*., 1997). The model used in this study is a single layer soil water balance model that incorporates the physical processes (rainfall, surface runoff, soil evaporation, crop transpiration, root growth, soil water distribution following rain event and potential recharge). It is termed SAMBA model and has been applied in various areas in northern Nigeria. Grema *et. al.* (1994) adopted the model for Maiduguri where a detailed field investigation was carried out for a complete rainy season and Nguru where daily rainfall and potential evaporation data are available for several years. Though there is difference in the vegetation between these two locations and the study area, the successes recorded in these two locations encouraged the application of this model to Guinea Savannah regions. The features of the model are presented in Fig. 3.

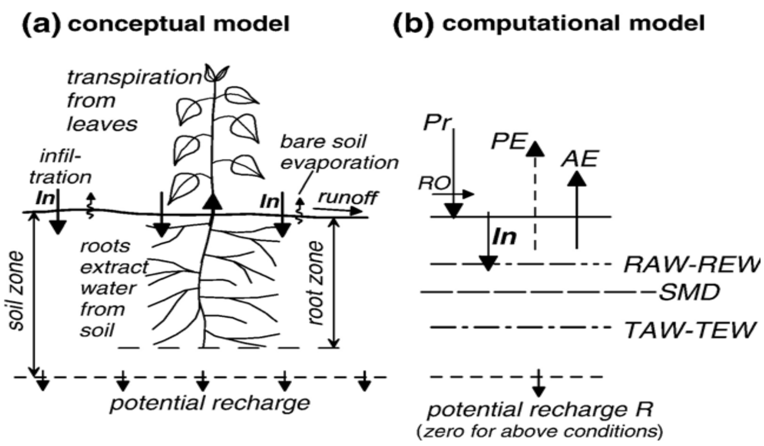


Fig. 3: Features of the model

The computational procedure (Senarath and Rushton, 1984; Rushton *et al*., 2006) on daily time step is summarised below.

(i) Get daily rainfall
(ii) Compute reference evapotranspiration (ET_o). The Blaney-Morin-Nigeria technique (Duru, 1984) was adopted for this study.
(iii) Use *SMD* at the driest season as initial soil moisture deficit - SMD
(iv) Compute runoff coefficient, using a runoff matrix
(v) Compute the Runoff = Rainfall * Runoff coefficient
(vi) Determine Available water for evaporation (AWE)
If SMDpr < 0, AWE = Rain – Runoff
(vii) Compute crop coefficient Kc using information on planting date and crop duration
(viii) Potential evapotranspiration = Kc * ETo
(ix) Determine root depth Zr based on growth stage
(x) Determine Total available water, TAW as:
TAW = max[(FC-WP)*1000*Zr, (FC-WP/2)*1000*Ze]
Ze is the soil evaporative surface
(xi) Readily available water, RAW = TAW * ρ (a constant between 0.2 and 0.7, Allen *et al*., 1998)
(xii) Determine soil stress coefficient, ks as follows:

If $\text{SMDpr} \geq \text{TAW}, \ \text{ks} = 0$

If $\text{SMDpr} > \text{RAW}, ks = \dfrac{\text{TAW} - \text{SMDpr}}{TAW - RAW}$

If $\text{SMDpr} \leq \text{RAW}, \ \text{ks} = 1$

(xiii) Compute actual evapotranspiration, AE:

If $\text{SMDpr} < \text{RAW}, \ \text{AE} = \text{PE}$

Else If $\text{AWE} \geq \text{PE}, \ \text{AE} = \text{PE}$

If $\text{SMDpr} \geq \text{TAW}, \ \text{AE} = \text{AWE}$

Else AE = AWE + ks(PE – AWE)

(xiv) Determine the near surface storage (NSS)

If $(\text{AWE - AE}) > \text{SMDpr}, \quad \text{NSS} = 0$

Else, NSS = max((AWE-AE)*NSSfactor, 0)

(xv) If $\text{SMDpr} \leq 0, \ \text{SMD} = \text{AE} - \text{AWE} + \text{NSS}$

Else $\text{SMD} = \text{SMDpr} + \text{RECHpr} + \text{AE - AWE} + \text{NSS}$

(xvi) Compute recharge:

If SMD < 0, Rech = -1* SMD + NSS

Else, Rech = 0

where: SMD denotes soil moisture deficit at the end of day t, while SMDpr denotes previous day SMD.

Rech denotes recharge at the end of day t, while Rechpr denotes previous day recharge

NSS is near surface storage at the end of day t and NSSpr is the previous day NSS

NSSfactor is the storage fraction of near surface storage.

FIELD EXPERIMENT AND DATA COLLECTION

Hydrological data such as rainfall, evapotranspiration, and actual evapotranspiration, AE were all collected from a meteorological agency and used in the model for the purpose of the runoff estimation. Figure 4 shows the time series of the rainfall depth. Soil moisture deficit in the catchment was determined and used in the model and daily moisture content estimation of the soil in the catchment was carried out for the whole length of the study period. Field and laboratory tests were carried out to describe the soil characteristics, infiltration capacity of the soil, runoff, and particle size analysis of the soil. For the discharge measurement in the catchment, a wooden weir was mounted at the outlet of the basin considered and firmly braced at the downstream to withstand the built up pressure from the impounded water. The weir was buried into the soil at about 0.7 m and clay materials were used to brace the wooden weir by pressing to avoid water leaking through underneath and sideways. Record of water level above the weir crest was recorded. Measurements were taken on four days with appreciable rainfall. The weir discharge formula (equation 1) based on Larry (1993) was used to convert the recorded water level to discharge.

$$Q = 0.0184\ (b-0.2H)\ H^{3/2} \qquad (1)$$

where, Q = discharge in cm^3/s, b = crest width (cm)
H = head (difference between the crest and the water surface) at a point upstream usually 4 times the maximum head of the crest, k = constant. The resulting runoff peaks are labeled Q_1, Q_2, Q_3, and Q_4 for respective measurements for the years under study.

RESULTS AND DISCUSSION

Weekly record of rainfall depth for the year is presented in Fig. 4. The variation of rainfall with time is noisy. The highest rainfall depth, 150 mm, was in week 34. The seasonal variation of the collected data of Potential evaporation, PE, Actual evaporation, AE, and Reference evapotranspiration, ETo is presented in Fig. 5 with PE recording the highest values in most part of the season. Figure 6 shows the hydrographs obtained from the field measurements carried out. Figure 6a shows the hydrograph of the measurement made on 28th July, 2009 with effective rainfall depth of 28.6 mm. From the hydrograph, the runoff depth was 2.0 mm (volume of runoff was 1344.6 m^3) while the value obtained from SAMBA model on same date was 2.86 mm. However, on the 18th August, 2009 (Fig. 6b) the measured runoff depth was 1.2 mm as compared to 5.1 mm obtained from the SAMBA model. The runoff depth on the 17th September was 4.88 mm, while that of 21st September, 2009 was 19.89 mm respectively. The annual runoff was 168 mm, equivalent to 14.5% of the total annual rainfall of 1157 mm in the year. It was found that runoff estimated by the model is similar to the runoff obtained from field measurements in two occasions (Fig. 6) while the remaining two estimates differ by 21% and 24% respectively.

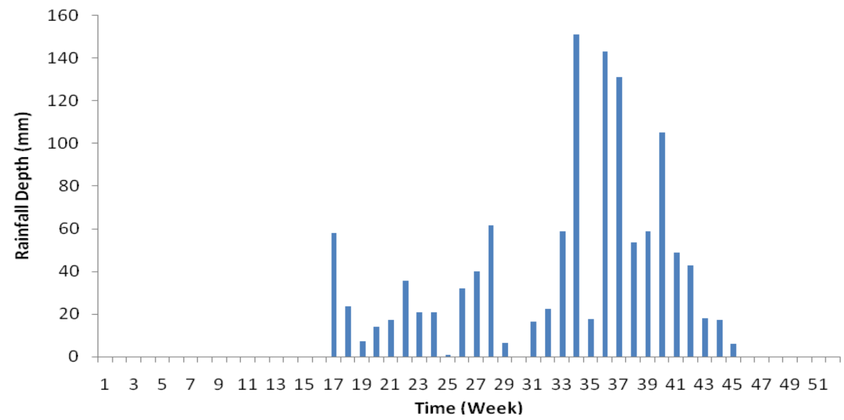


Fig. 4: Weekly records of rainfall depth for the year 2009

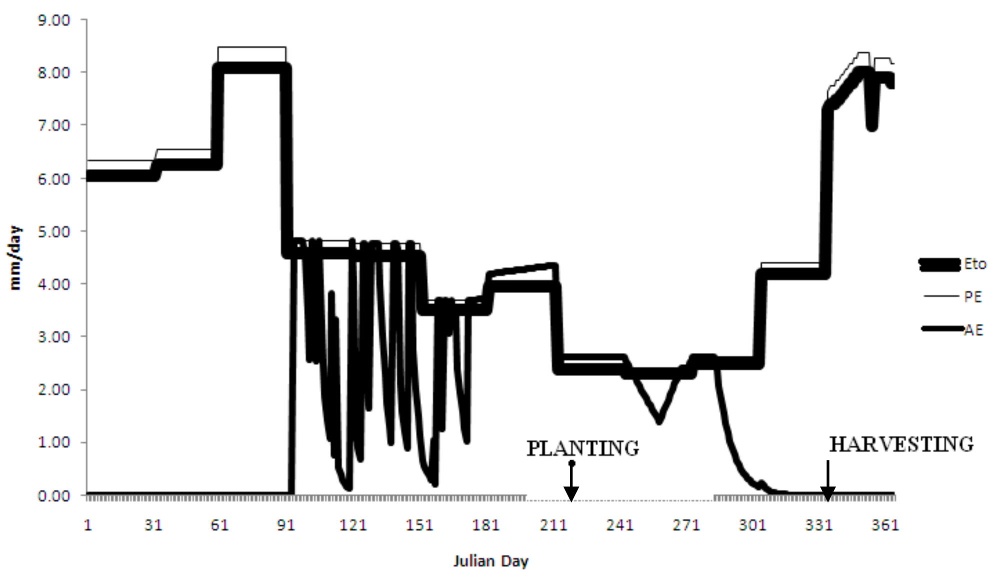
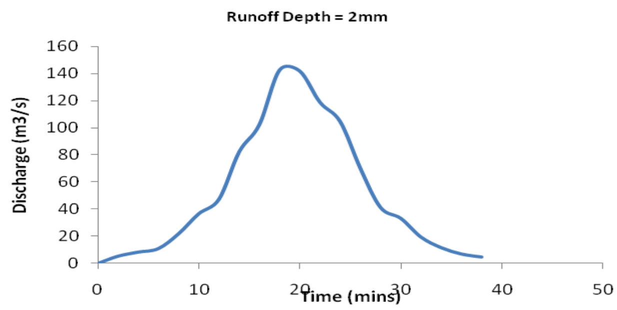
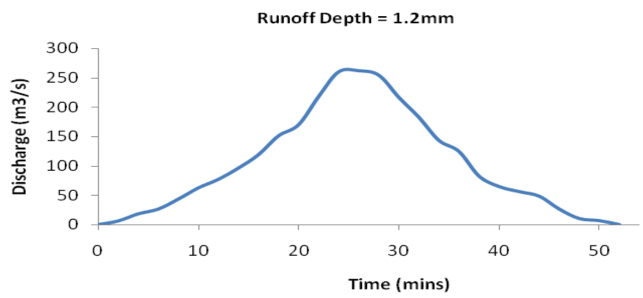


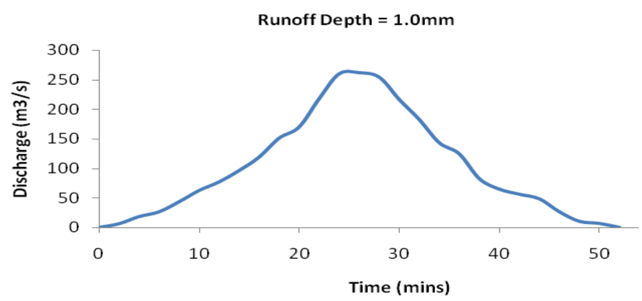
Fig. 5: Seasonal variation in Evaporation



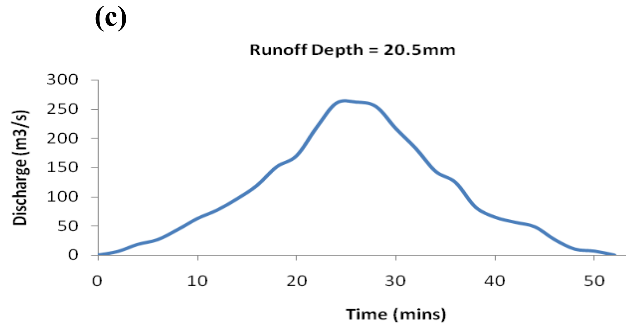
(a)



(b)



(c)



(d)

Fig. 6: Hydrographs for the field discharge measurements.

Figure 7 shows the relationship between rainfall and runoff depth for 2009 and 2010. In 2009, highest rainfall depth was 95.2 mm on Julian day 244 and the highest runoff depth was 26.88 mm on Julian day 241. Unlike in 2009, the highest rainfall depth in 2010 was 63.3 mm on Julian day 253 while the highest runoff depth was 18.99 mm on the same day. Figure 8 shows the SMD and runoff, where for the first 91 days into the year the SMD remained constant at 49.8 mm, and no runoff was experienced during the period. Subsequently, as rain falls, the SMD was reduced to 29.8 mm on Julian day 216. Groundwater recharge was obtained on Julian day 216. Figure 9 shows the relationship between the rainfall and the resulting runoff. For year 2009, annual rainfall was 1157.7 mm and runoff was 167.65 mm, while for the year 2010, total annual rainfall and runoff were 1120.6 mm and 137.91 mm respectively. The estimated recharge is similar to that of Rushton (2006).

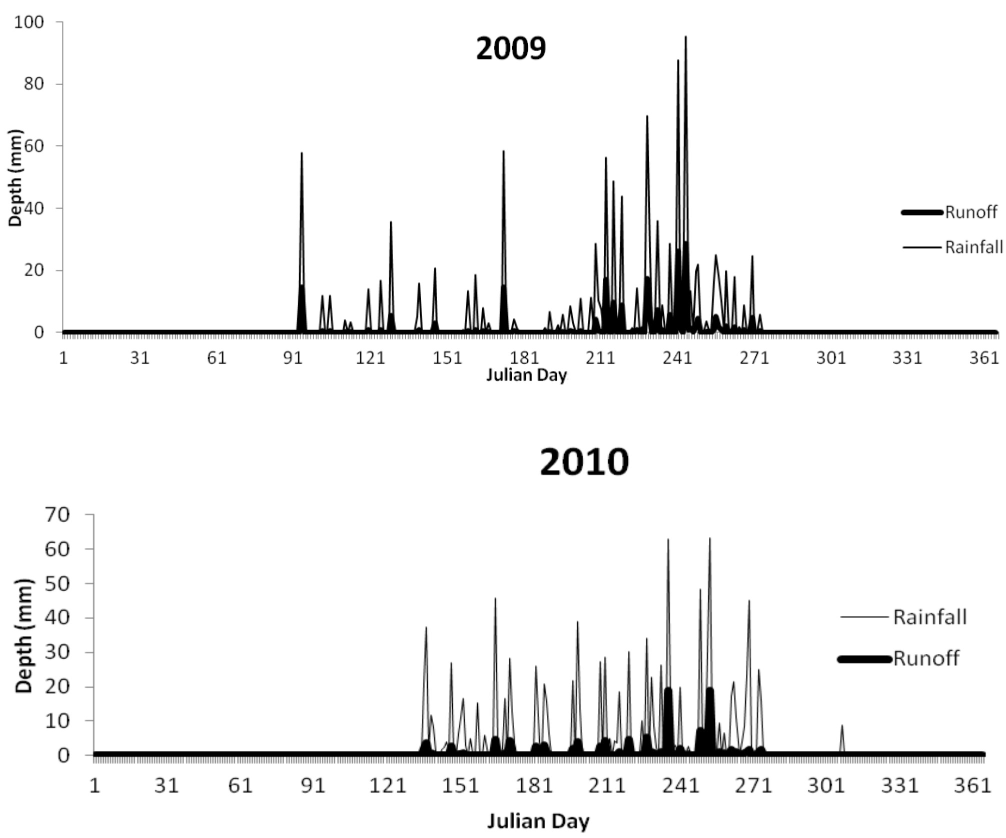


Fig. 7: Relationship between runoff depth and rainfall

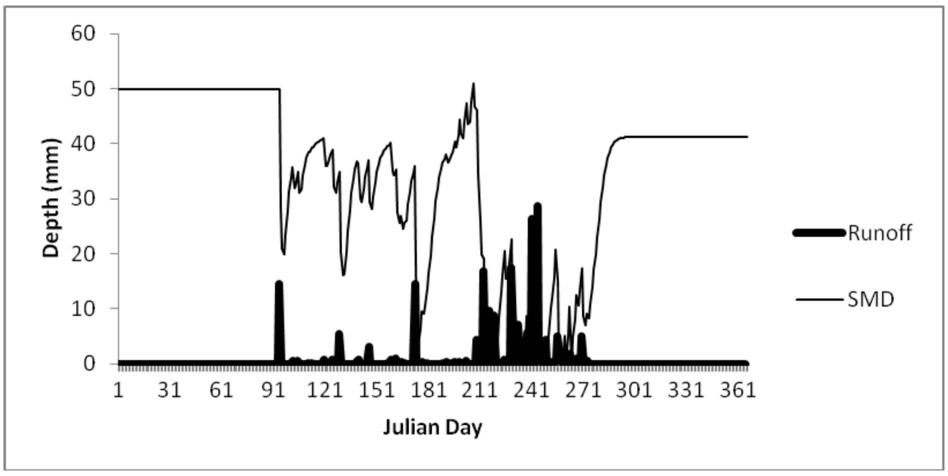


Fig. 8: Soil moisture deficit, SMD and runoff relationship for 2009

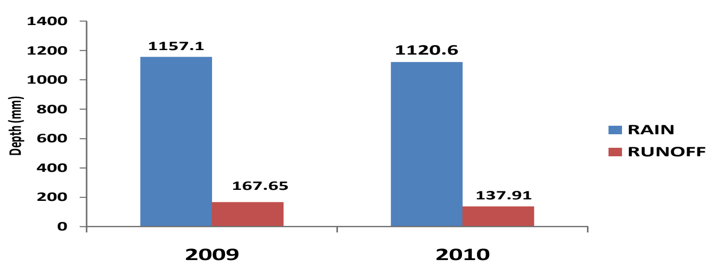


Fig. 9: Rainfall-runoff relationship for the study years

CONCLUSION

The results obtained from the field measurements and that of the model show that the model is highly applicable for the catchment used in this study. As it is observed that the output of the runoff in both cases compares favourably, this shows that the model, with all the hydrological parameters involved for a particular region, could be used especially for the catchment in this study. With the rainfall-runoff coefficients established with the aid of the field measurements and the subsequent runoff-SMD coefficients from the soil parameters in the catchment, it is possible to combine these coefficients and employ them in the SAMBA model just as used in this study for the purpose of daily runoff estimation.

The particles zero distribution of soil explains why the annual runoff in the model is just 11% of the annual rainfall. Low rainfall-runoff rate observed explains the nature of the soil in the catchment which allows for much water infiltrating into the soil mass there-by recharging the groundwater and reducing the soil moisture deficit, *SMD*. The annual recharge is 132.93 mm, 11% of annual rainfall.

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Modelling daily flows of River Benue using Artificial Neural Network approach

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Abstract

The importance of understanding the dynamics and forecasting of streamflow processes of a particular river finds relevance in the fact that the physical mechanisms governing flow dynamics act on a wide range. In view of this, this study presents a simple basis for and application of Artificial Neural Network (ANN) methodology as an alternative modelling tool for predicting flow. To this end, the main focus is the development of ANN model for short term streamflow forecasting of the Benue River using univariate time series; inter alia, evaluate its performance of extreme events. It is evident from the modelling framework that the application of the knowledge of evolution of a dynamical system in a multi-dimensional state space is a robust approach for determining the size of an ANN model input. The ANN model forecast performance showed that reliable short term forecasts, 5 day - ahead can be made for the daily streamflow series based on CE and R^2 *performance indexes. However, on the general question of the suitability of ANN model application for streamflow forecasting as applied in this study (i.e., daily streamflow), though the neural network could simulate the different attributes of the flow hydrograph, its relative forecast performance of high flows is robustly better than the case of low flows; it grossly under predicted and over predicted same depending on the particular network input data pre-processing schema. The forecast performance results also indicated that, for feed-forward MLP networks, with a tan-sigmoid transfer function, standardising the data by subtracting the mean and dividing by the standard deviation is better than rescaling the data to a small interval of particular range. Considering the findings, to appropriately capture the dynamics of the flow regime, it is necessary to include exogenous variables of the runoff generating process in the network input data base.*

Keywords: *System-theoretic*, *nonlinear dynamics, phase-space reconstruction, neural networks, modelling*

INTRODUCTION

The most important process in the hydrologic cycle is the section where rainfall occurs and results in flow; this flow is critical to many activities such as assessing how much water may be extracted from a river for water supply or irrigation (Delleur *et al*., 1976). Because the accuracy of flow estimation is very important, models that deal with meteorological, hydrologic, and geological variables should be improved so that controlling water and operating water structures effectively will be possible (Ozgur, 2004). There are many mathematical models to predict future flow such as those given by Hurst (1951), Matalas (1967), Box and Jenkins (1976), and Delleur *et al*. (1976). The mathematical models applied for real-time hydrological forecasting, broadly, are of two types: black-box or system theoretic and conceptual models (Singh, 1988). In a conceptual type model, the internal descriptions of the various sub-processes are modelled attempting to represent, in a simplified way, the known physical processes. Black-box or system-theoretic (data-driven) models are stochastically-based and empirical (Elena and Armando, 2002). They are based primarily on observations and seek to characterise system response from those data.

The modelling technique that adheres most closely to the black-box principle is the use of artificial neural networks (ANN). Inspired by the biological nervous system, neural network technology is being used to solve a wide variety of complex scientific, engineering, and business problems. When using artificial neural networks for forecasting, the modelling principle employed is similar to that used in traditional statistical approaches. In the hydrological context, as in many other fields, artificial neural networks are increasingly used as black-box, simplified models (Bishop, 1994). The advantage of Neural networks and the reasons why they fall firmly into black-box category are that, like their biological counterparts, a neural network can learn, and therefore can be trained to find solutions, recognise patterns, classify data, and forecast future events. Unlike analytical approaches commonly used such as the unit hydrograph method or time series analysis, neural networks require no explicit model or limiting assumptions of normality or linearity. Artificial neural networks are now widely accepted as a potential useful way of modelling complex non-linear and dynamic systems for which there are large amounts of sometimes noisy data. They are particularly useful in situations where the underlying physical process relationships are not fully understood or where the nature of the event being modelled may display chaotic properties.

Unlike mathematical models that require precise knowledge of all the contributing variables, a trained artificial neural network can estimate process behaviour even with incomplete information. It is a proven fact that neural networks have a strong generalisation ability, which means that once they have been properly trained, they are able to provide accurate results even for cases they have never seen before (Hecht-Nielsen, 1991; Haykin, 1994; Ozgur Kisi, 2004). The generalisation ability of the neural network really underscores the very basic need for its application to real world situation. Many of the available techniques for time series analysis assume linear relationships among variables; but in the real world, however, temporal variations in data do not exhibit simple regularities and are difficult to analyse and predict accurately. It seems necessary that nonlinear models such as artificial neural networks (ANNs), which are suited to complex nonlinear systems be used for the analysis of real-world temporal data; especially, the inherently nonlinear relationships between input and output variables complicates attempts to forecast streamflow events.

It must be pointed out that the use of neural networks does not preclude the need for knowledge or prior information about the systems of interest. However, they merely reduce the model's reliance on this prior information whilst totally removing the need for the model builder to be able to correctly specify the precise functional form of the relationship that the model seeks to represent. Against the backdrop of the fact that there is no reported work on modelling and forecasting done on this river in available literature , the exclusive objective here is to present a simple basis for and application of artificial neural network (ANN) methodology as an alternative modelling tool for predicting flow data. To this end, the main focuses are the development of Artificial Neural Network (ANN) model for short term streamflow forecasting, in this case, a univariate time series (daily flow series), and to determine which characteristics of the model have the greatest impact on model performance.

MATERIALS AND METHODS

Hydrology of the Study River

In this study, historical time series for gauging stations at the base of the Benue River (i.e., Lower Benue River Basin) at Makurdi (7°44′ N, 8°32′ E) was used. A total of 26 years (1974–2000) water stage and daily discharge data were collected. An existing rating curve was used to convert the respective stage data to their corresponding discharge values. The Benue River is the major tributary of the Niger River. It is approximately 1 400 km long and almost navigable during the rainy season (between July and October). Its headwaters rise in the Adamawa Plateau of the Northern Cameroon, flows into Nigeria south of the Mandara Mountains through the east-central part of Nigeria. There is only one high-water season because of its southerly location; this normally occurs from May to October, while on the other hand, the low-water period is from December to June. Figure 1 explains the hydrological flow regime of the Benue River in line with the general climatic pattern. There are definite wet and dry seasons which give rise to changes in river flow and salinity regimes. The flood of the Benue River (upper, middle, and downstream) lasts from July to October, and sometimes up to early November.

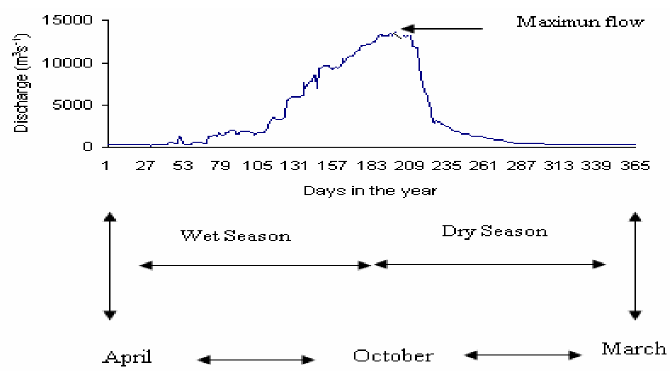

Fig. 1: General hydrological year flow regime

MODELLING FRAMEWORK

Network Design and Topology

When neural networks are used to build a function that estimates the process behaviour, the central issue is the determination of appropriate network structure. One of the ways to address this problem involve carrying out initial investigation of statistics like autocorrelation and cross-correlation which may explain the variance by multi-linear regression, and the Akaike criterion for ARMA model of corresponding order. However, cross-correlation approach can only be of useful application where there is a number of different input variables (i.e., multi-variate time series), and may not provide any meaningful relevance in the case of univariate time series. For a univariate time series, phase-space reconstruction using embedding dimension, which is based on dynamical systems theory is of better use.

This approach was adopted for the determination of the appropriate number of input neurons for this study.

To describe the temporal evolution of a dynamical system in a multi-dimensional state space with a scalar time series, the time delay coordinate method (Takens, 1981; Packard *et al*., 1980) can be used to reconstruct the state space. The method requires that the state vector X_i in a new space, the embedding space be formed from time delayed values of the scalar measurements $\{Y_i\}$ as $X_i = [Y_i, Y_{i-\tau}, \ldots, Y_{i-(m-1)\tau}]$, where Y_i is the observed value of the time series at time i, m is the embedding dimension, and τ is the delay time. To do this, It is expected that an optimum value of τ should give the best separation of neighbouring trajectories within the minimum embedding phase-space. Because of the strong annual seasonality, the autocorrelation function value of τ may become increasing large, and too, choosing τ value = 1 may result in the phase-space being redundant and consequently, lead to loss of valuable information (Wang, 2006). Besides, there could be intermittency problem in the data. Thus, to circumvent this problem, for the fear of the data being intermittent, τ was set to 78 based on the analysis of the autocorrelation function of the daily streamflow series (i.e., the point where the autocorrelation function plot first crosses the zero line) as shown in Fig. 2.

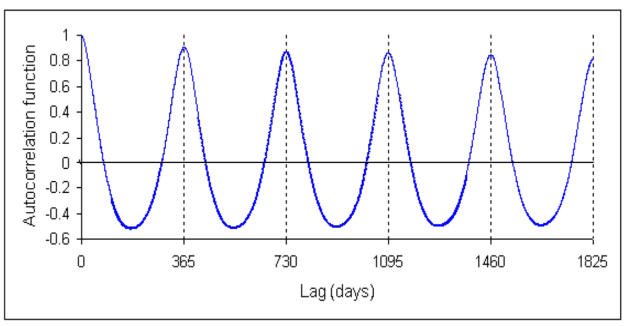

Fig. 2: Correlogram of the raw daily flow series

Because of the problems associated with the mutual information and autocorrelation methods, the method proposed by Kennel *et al*. (1992), called the ‘false nearest neighbour’ method to determine the minimal sufficient dimension m was used.

For this method, suppose the point

$X_i = [Y_{i-p+1},\ldots,Y_i]$ has a neighbour $X_j = [Y_{j-p+1},\ldots,Y_j]$ in a p-dimensional space, then the distance $\|X_i - X_j\|$ is calculated in order to compute

$$R_i = \frac{|Y_{i+1} - Y_{j+1}|}{\|X_i - X_j\|} \quad (1)$$

If R_i exceeds a given threshold R_τ (a suitable value is $10 \le R_\tau \le 50$), the point X_i is marked as having a false nearest neighbour. As a consequence, the embedding dimension p is high enough if the fraction of points that have false nearest neighbours is actually zero, or sufficiently small, say, smaller than a criterion R_f. For this study, the false neighbour threshold R_τ was set to 10. Based on this, the fraction of false nearest neighbours as a function of the embedding dimension, here, for daily streamflow series was calculated. Figure 3 shows the details of the computed fraction of false nearest neighbours. Thus, if the fraction criterion R_f is set equal to 0.01, the minimal embedding dimension will be 8; this implies that the state of the streamflow process can be determined by eight lagged observed values.

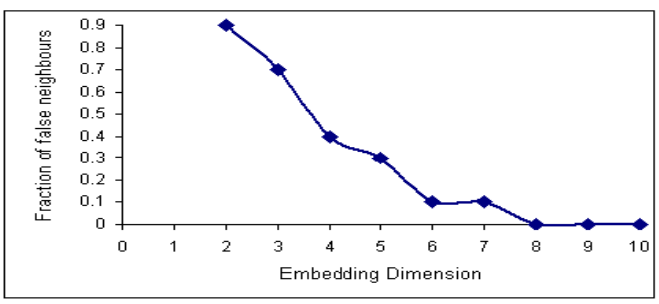

Fig. 3: Fraction of false nearest neighbours as a function of embedding dimension

Following from the analysis, eight lagged values of input variables can be used when fitting the ANN model to the series; specifically, this implies, based on the phase space reconstruction, the discharges are: Q_{t-7}, Q_{t-6}, …Q_t of day t-7, to day t. The eight lagged input values were used to forecast the discharge from time t+1, i.e., the next day, to t+5; that is, 5-ahead values, using a multiple-output approach rather than a single-output. Figure 4 shows the complete network configuration based on the results of the phase-space reconstruction and multiple-output strategy using feed forward multi-layer perceptron network (MLP); the number of hidden layer neurons was determined to be 7 based on the typical 'trial and error' approach.

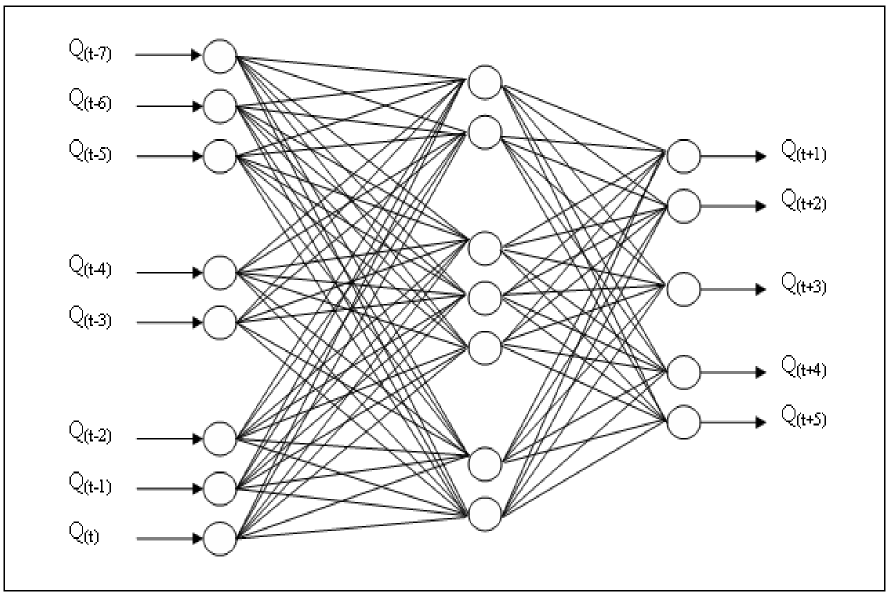

Fig. 4: Schematic of three-layer feed forward ANN architecture used for flow prediction

2.2.2 Network Training and Data base Management

Training a neural network to predict the properties of the input-target relationship consists essentially of teaching the network the relationship between the input ingredients and its performance. This learning process can take place in a supervised or unsupervised manner. For the purposes of this study, supervised learning was used. The entire time series of length of 9490 daily values was thus partitioned into two-sets of 8670 and 730 data points corresponding to training and validation, respectively. The success of the training procedure depends largely on the power of the optimisation method used to search for the best parameter estimates; training was implemented using the '*trainbr*' function in MATLAB Neural Network Toolbox. The Bayesian regularisation training algorithm (trainbr) was chosen because of its ability to overcome generalisation problems that do result from over-fitting. Also important in neural network training is the transfer function; generally, predictability of future behaviour is a direct consequence of the correct identification of the system transfer function. For the identified network structure in this study, the '*tansigmoid'* and '*purelin'* transfer functions were used in the hidden and output layers, respectively. The '*purelin'* transfer function was considered for the output layer because it allows the network outputs to take on any value, whereas the last layer of a multi-layer network with sigmoid neurons constrains the network outputs to a small range. Instead of making predictions based on an ensemble of neural networks trained for the same task, a single best ANN was used; this was determined after series of attempts using different network structures, based on the mean squared error (MSE) of the network performance during training.

Training of the network was done with some specific parameter considerations. To this end, a decreasing learning rate (0.2 to 0.05) was used to accelerate convergence toward a global minimum; and since without momentum, a network may get stuck in a shallow minimum as it allows the network to ignore small features in the error surface, its value was set to 0.9. A very important issue to consider in the training of an ANN is how to decide when to stop the training because ANNs are prone to either under-fitting or over-fitting if the training is not appropriately stopped. In this regard, when using '*trainbr'*, it is important to let the algorithm run until the effective number of parameters has converged; constant values of the sum squared error (SSE) and sum squared weights (SSW) over several iterations are indicative of convergence. So, training was stopped the moment these signals were experienced. The maximum number of iteration in this case was set to 2500 to avoid over-fitting of the network.

Before applying the ANN, both input and output data were pre-processed and normalized. In order to compare the influence of different pre-processing procedures on model performance, three different pre-processing procedures were applied, namely:

- ❖ Rescaled logarithmically transformed raw daily flow series
- ❖ Standardised raw daily flow series
- ❖ Rescaled raw daily flow series

Standardisation was accomplished by using the long term mean and standard deviation for both the training and validation data sets respectively. The '*trainbr*' algorithm generally works best if the network inputs and targets are scaled so that they fall approximately in the range [-1 1]. Thus, rescaling was done to ensure that the data series fall within this bound. Scaling of the original data, say to the network range was done by

$$x_t = \frac{(U_x - L_x)\hat{x}_t + (M_x}{M_x - m_x} \qquad (2)$$

where are the original input data, and the input data scaled to the network range, and are respectively the maximum and the minimum of the original input data, while and are the upper and the lower network ranges for the network input respectively. Similarly, the original output, say was scaled to the network range by

$$y_t = \frac{(U_y - L_y)\hat{y}_t + (M_y L_y -}{M_y - m_y} \qquad (3)$$

where the systems' output was scaled to the network range, and are respectively the maximum and minimum values of the original output data, whereas and are respectively the upper and the lower network ranges for the network output. After scaling the inputs and outputs, the resulting output, say is in the scaled domain. Hence, one needs to rescale the output back to its original domain; this was by inverting Equation (3) and using as

$$\hat{y}_t{}' = \frac{(M_y - m_y)\widehat{y_t} - (M_y L_y -}{U_y - L_y} \qquad (4)$$

In order to draw conclusions on the ANN model performance, parameters for statistical analyses (e.g. Root Mean Squared Error (RMSE), Mean Squared Relative Error (MSRE), Mean Absolute Error (MAE), Coefficient of Efficiency (CE), and Coefficient of Determination (R^2) were used to evaluate the ANN model predictions. Here, special attention is on the ANN model performance in terms of extreme events, that is, maximum and minimum flows. In this regard, the coefficient of correlation R as in Equation (5) was used.

$$R = \frac{\frac{1}{v}\sum_{t=1}^{v}[y_t-\mu_y][\tilde{y}_t-\tilde{\mu}_y]}{\left[\frac{1}{v}\sum_{t=1}^{v}[y_t-\mu_y]^2\right]^{1/2}\left[\frac{1}{v}\sum_{t=1}^{v}[\tilde{y}_t-\tilde{\mu}_y]^2\right]^{1/2}} \qquad (5)$$

where v = the number of output data points, y_t = the observed flow, $\tilde{y}_t$ = predicted flow, μ_y = mean of observed flow, and $\tilde{\mu}_y$ = mean of predicted flows. In terms of the measures of forecast accuracy with respect to extreme values, the ratio of the forecasted maximum to the observed maximum (peak) was determined as

$$R_{max} = \frac{\tilde{y}_t}{max\{y_t\}} \times 100 \qquad (6a)$$

where $max\{y_t\} = max\{y_1,\ldots, y_v\}$ and $\tilde{y}_t$ is the forecast corresponding to such maximum; and R_{max} = 100%, means that the observed peak is perfectly reproduced by the model. Forecasts with values of R_{max} about 100% are considered to be very accurate, while $R_{max} < 100\%$ indicates that the model underestimates the peak value; and $R_{max} > 100\%$ indicates overestimation. Similarly, the ratio of the forecasted to the observed minimum,

$$R_{min} = \frac{\tilde{y}_t}{min\{y_t\}} \times 100 \qquad (6b)$$

where $\tilde{y}_t$ now represents the forecast corresponding to the minimum observed value, was also used to judge the forecast capability of the model.

MODEL FORECAST PERFORMANCE AND DISCUSSION

Artificial neural networks (ANNs) are like conventional hydrological models in that different attributes of the hydrograph are simulated to varying degrees of success. Considering the issues involved in modelling within this context, as in any other forecasting procedure, forecasting based on ANNs has an associated uncertainty. The forecast uncertainty arises not only because of the model but could be due to limited sample size used for training. Within the premise of the focus of this study, the model uncertainty may be due to two factors; first, the streamflow generation which is directly intertwined with hydroclimatic forcing, and second, probably, the model order. Looking at this issue further, the type of forecast model selected herein has been pre-defined, i.e. a neural network type of model, is a mathematical artefact that has some practical appeal but no physical basis, and hence not without uncertainty. Based on the forecast results, the uncertainty associated with the model is minimal since its architecture was determined based on reconstruction of phase-space dynamics of the input data series.

The ANN model forecast performances are as reported in Tables 1 and 2, for both the training and validation periods, respectively; Table 3 shows the forecast performance of the ANN model (see Fig. 4: 8-7-5 feed-forward architecture with bias) in terms of extreme events. Based on the statistical details of the forecast performance as presented in Tables 1 and 2, the overall performance based on CE and R^2 indexes, the feed-forward MLP ANN (8-7-5) proposed here is robust enough and do indicate that probable short-term forecasts can be made if proper forecast function is developed accordingly.

Table 1: ANN forecast performance during Training period

Transform	Lead	MAE	MAPE	RMSE	MSRE	CE	R^2
Resc-log							
		60.5122	0.0423	65.2061	0.0127	0.9948	0.9949
		78.1075	0.0667	72.4789	0.0230	0.9900	0.9901
		97.9276	0.0894	118.4867	0.0337	0.9845	0.9845
		120.7359	0.1105	129.2995	0.0478	0.9781	0.9782
		128.1495	0.1309	140.4846	0.0633	0.9713	0.9714
Standardised							
		35.6221	0.0528	60.9822	0.0192	0.9952	0.9952
		48.1363	0.0820	69.9252	0.0335	0.9905	0.9905
		90.5212	0.1096	105.9536	0.0483	0.9852	0.9850
		103.1272	0.1370	118.1302	0.0687	0.9793	0.9792
		109.8650	0.1656	123.3604	0.0923	0.9730	0.9731
Resc-raw data							
		68.9218	0.0494	73.8954	0.0186	0.9951	0.9950
		80.8409	0.0752	85.5560	0.0337	0.9905	0.9910
		98.1809	0.1017	120.6724	0.0499	0.9853	0.9852
		134.0759	0.1296	152.581	0.0745	0.9794	0.9794
		137.7988	0.1569	159.4555	0.1006	0.9731	0.9732

Resc-log: Rescaled-logarithmic transformed flow series; raw data: Original flow data; Standardised: the demeaned original flow series divided by standard deviation; Resc: rescaled.

Table 2: ANN forecast performance during Validation

Transform	Lead	MAE	MAPE	RMSE	MSRE	CE	R^2
Resc-log							
		70.2001	0.1509	72.7876	0.0703	0.9561	0.9566
		79.3483	0.1642	80.4672	0.0872	0.9472	0.9476
		105.0832	0.1799	129.1394	0.1027	0.9395	0.9398
		122.5459	0.1935	131.8075	0.1134	0.9319	0.9324
		130.8713	0.2075	145.3140	0.1264	0.8187	0.9270
Standardised							
		45.4193	0.1666	68.5223	0.1063	0.9572	0.9573
		53.3808	0.1737	80.0700	0.1131	0.9493	0.9495
		98.2346	0.1830	117.8108	0.1182	0.8408	0.9410
		109.9609	0.1921	120.2051	0.1199	0.8405	0.9324
		115.2344	0.2015	125.5316	0.1186	0.8401	0.9239
Resc-raw data							
		75.0910	0.1665	80.8146	0.1044	0.9552	0.9557
		83.1199	0.1747	86.8868	0.1147	0.9481	0.9483
		107.5458	0.1878	130.0229	0.1236	0.8138	0.9383
		136.5948	0.1997	157.8905	0.1287	0.8115	0.9284
		140.0822	0.2117	168.1761	0.1357	0.8037	0.9199

Resc-log: Rescaled-logarithmic transformed flow series; raw data: Original flow data; Standardised: the demeaned original flow series divided by standard deviation; Resc: rescaled.

Table 3: ANN model performance in terms of extreme events (Max. and Min. flow)

		Training		Validation	
Transform	Lead	R_{max} (%)	R_{min} (%)	R_{max} (%)	R_{min} (%)
Resc-log					
		98.03	137.47	99.40	114.67
		98.78	148.64	98.87	118.47
		99.46	149.28	98.56	118.55
		100.02	145.45	98.29	119.96
		100.48	136.23	97.80	124.18
Standardised					
		98.27	94.87	100.95	105.91
		97.63	94.30	101.47	91.75
		97.80	67.16	101.61	82.02
		98.22	56.04	101.43	62.84
		98.10	32.59	101.25	45.05
Resc-raw data					
		98.45	87.68	98.22	82.05
		97.92	49.92	98.18	68.43
		98.23	22.93	98.00	45.92
		98.65	22.58	97.59	12.62
		98.96	20.60	97.18	95.83

Though the overall accuracy of the model in terms of the statistical parameters CE, R^2, and RMSE (Tables 1 and 2) are seemingly good, they do not really reveal the distribution of the forecast errors since there are global statistics. The values of MSRE and MAE in the validation period increase appreciably with the lead time (in days) indicating the distortion in the distribution of the forecast errors. This aspect in the forecast behaviour during the validation period is paramount since from a practical stand point they serve to assess and quantify the forecast errors of the ANN forecast model. Table 3 succinctly illustrates this distortion with regards to forecast of extreme events. It does provide an intuitive outlook on ANN model prediction when a univariate time series is used. In general, Table 3 also showed that in terms of R_{min} and R_{max}, it is obvious that ANN model forecasts high flows much better that low flows. This underscores the need for the inclusion of exogenous input (precipitation) in the network input variables. Peaks corresponding to larger values of discharge are always generated by rainfall that are heavy and of long duration and intermediate peaks, on the other hand, are caused by heavy rainfall of short duration; thus the non-inclusion of precipitation in the input data set which might mitigate this phenomenon probably explains the distortion. Comprehensively though, comparative hydrographs (Fig. 5) of the observed and forecasted streamflow for one-day-ahead depicts the goodness-of-fit for the network trained using the ANN structure as determined in this case.

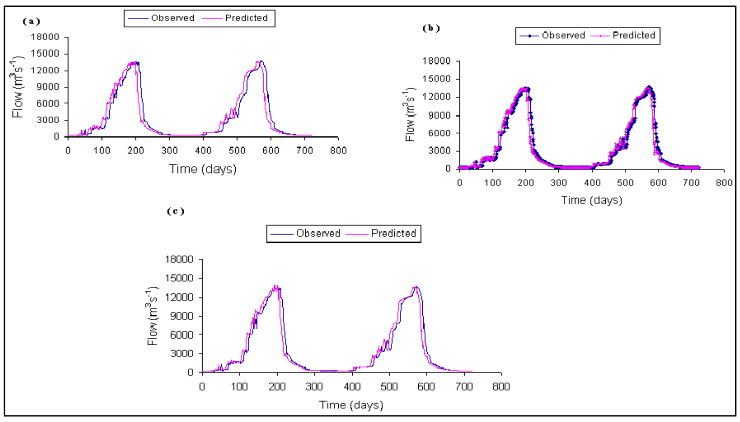

Fig. 5: ANN model 1-day-ahead forecasts: (a) Rescaled logarithmic-transformed flow series, (b) Rescaled raw flow series, (c) Standardised raw flow data

It is paramount not to only evaluate model forecast performance on the basis of statistical parameters, but to also consider the impact data pre-processing might have on ANN model forecasts (Wang, 2006). It is recognised that data pre-processing can have a significant effect on model performance (e.g. Maier and Dandy, 2000). It is commonly considered that, because the outputs of some transfer functions are bounded, the outputs of an MLP ANN will be in the interval [0, 1] or [-1, 1] depending on the transfer function used in the neurons. Reports in literature suggest using smaller intervals for streamflow modelling as [0.1, 0.85] (Shamseldin, 1997), and [0.1, 0.9] (Abrahart and See, 2000), so that extreme (low and high) flow events occurring outside the range of the calibration data may be accommodated. However, the advantage of rescaling the data into a small interval is not supported as illustrated in Table 3. In this case, the general performance of the MLP-ANN with standardisation pre-processing is much better in the overall; especially for low and high flows (i.e., extreme events in terms of minimum and maximum flows) during validation stage; this result is in agreement with similar findings by Wang (2006). This could be explained against the backdrop of the behaviour of the transfer function. For instance, to rescale the input data to [-1, 1] would limit the output range of the $\tan sig(x)$ function approximately to [-

0.7616, 0.7616] (Wang, 2006). Similarly, to rescale the input range to [-0.9, 0.9] would further shrink the output range approximately to [-0.7163, 0.7163] (Wang, 2006). Both 0.7616 and 0.7163 are still far away from the extreme limits of the $\tan sig(x)$ function; such a small output data range will make the output less sensitive to the change of the weights between the hidden layer and output layer, and will therefore possibly make the training process more difficult. In addition, in line with Wang (2006), since the neurons in an ANN structure are combined linearly with a lot of weights, any rescaling of the input vector can be offset the more, as corresponding weights and biases are changed.

CONCLUSIONS

It is evident from the ANN model forecast performance that the application of the knowledge of evolution of a dynamical system in a multi-dimensional state space is a veritable way in determining the size of input in a neural network model, especially with a univariate time series as it does not involve the analysis of extensive model sensitivity to the input data. The ANN model forecast performance showed that reliable short term forecasts, 5 day - ahead can be made for the daily streamflow series, using multiple-output regime. However, on the general question of the suitability of ANN model application for streamflow forecasting as applied in this study (i.e., daily streamflow), though the neural network could simulate the different attributes of the flow hydrograph, its relative forecast performance of high flows is robustly better than the case of low flows; it grossly under predicts and over predicts low flows depending on the particular network input data pre-processing schema.

Analysis of the influence of different data pre-processing schema namely, rescaling, and standardisation on the ANN model forecast performance brought to the fore the associated encumbrances that the modeller might face; especially, in drawing up an objective conclusion if proper data processing was not done. Concisely, it is evident that, for MLP networks with a tan-sigmoid transfer function, standardising the data by subtracting the mean and dividing by the standard deviation is better than rescaling the data to a small interval of particular range.

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Water quality from hand dug wells in Oju town, Benue State, Nigeria

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Abstract

The physico-chemical and bacteriological properties of water from hand dug wells in Oju town is examined in this study. A total of fifteen hand dug wells were sampled across the three residential areas of the town in the month of August, 2010. Water samples were analysed according to standard methods of examination for water and reported based on Nigerian Standard for Drinking Water Quality (NSDWQ). This involves in-situ, field determination using meters and laboratory techniques such as titration and atomic absorption spectrophotometric methods of analysis. The result of analyses shows that iron, nitrates and bacteria concentrations exceed the NSDWQ standard in some hand dug wells. Other parameters like pH, temperature, turbidity, electrical conductivity, total dissolved solids, total hardness and chloride were within the NSDWQ standard. The high concentration of iron, nitrates and bacterial contamination is attributed to shallow well depth, distance to latrine/soak away, improper well construction as well as land use. This has rendered the water unsafe for drinking. It is therefore recommended that hand dug well water should be disinfected by the use of adequate volume of water guard as well as other water purifier to ensure its safety.

Key words: *Hand dug wells, physico-chemical, bacteriological, Water quality, Oju town*

INTRODUCTION

Water has always been an important and life-sustaining drink to humans and is essential to the survival of all organisms. The human body is 70% water. People begin to feel thirsty after a loss of only 1% of bodily fluids and risk death if fluid loss nears 10% (Alexander, 2008). Water is a basic human right. Without it societies wither and people die. Most of the ill-health which affects human, especially in developing countries can be traced to lack of safe water supply (UNICEF, 2003). Safe drinking water is water with microbial, chemical and physical characteristics that meet NSDWQ guidelines; that is, it can be consumed or used without risk of immediate or long term harm. There can be no state of well-being without safe water (USAID, 1990).

In Nigeria, the general inaccessibility or unavailability of public water supply in urban areas has caused untold hardship on the people. In the absence of potable water supply, alternative sources must be sought because water has no substitute (WHO, 2003). Hand dug wells are common source of alternative water supply in many cities and towns in Nigeria. However, water from this source can be prone to all kinds of pollution threats from both physical processes such as runoff, infiltration and dissolution of minerals from soil and rocks, geochemistry of the environment as well as anthropogenic activities such as urbanisation, and industrialisation (Akintola and Areola, 1980; Ezenwaji, 1990 and Edet, 2009). Concerns over the quality of water from hand dug wells have received attention from several researchers in different parts of Nigeria (Aseez, 1971; Nnodu and ILO, 2002; Egbulem, 2003; Mile, 2005). None of such study has been carried out on the quality of water from hand dug wells in Oju town.

In Oju town there is complete absence of public water supply. Inhabitants depend heavily on water from hand dug wells. Hand dug wells are well system whereby groundwater is abstracted at shallow depths. The quality of water from these hand dug wells is however in doubt as they are highly prone to pollution. This study is an attempt to assess the suitability of water abstracted from these wells for human consumption in line with Nigerian standard for drinking water quality (NSDWQ).

MATERIALS AND METHODS

The study area is Oju town the headquarters of Oju local government area (LGA) of Benue State in the North Central region of Nigeria. Oju town is located between latitude 6^{o} 53'N and 6^{o} 57'N and longitude 8^{o} 15' E and 8^{o} 33'E. It has a population of 38,135 people (NPC, 2006) and covering a landmass of about 4sq km. The town became prominent with the creation of Oju LGA in 1976 as it continues to witness increased in migration and socio-economic activities. These include markets, small scale food processing industries, and artisan works, hospital/clinics, a college of Education. There is virtual absence of public water supply as such the inhabitants of the town depends heavily on alternative sources of water supply from streams, hand dug wells, and water vendors with its health implications. The area is underlain by a thick sequence of Cretaceous age sedimentary rocks (Fig. 1). The sediments are mainly mudstones with occasional sandstones, siltstones and limestones (Davies and MacDonald, 1999).

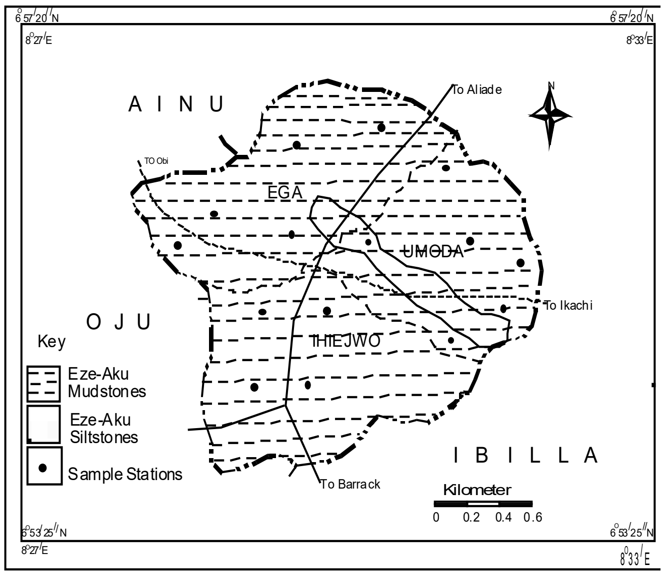

Fig 1: Geology of Oju Town.
Source: Modified of the British Geological Survey 2001

Data for this study were obtained from water samples collected from hand dug wells across the residential area of Oju town. A reconnaissance survey was carried out during which data on factors perceived to likely influence the quality of water from the hand dug well were collected. These include well characteristics such as location, orientation and spatial distribution, well protection, well depth, and mode of water fetching from the wells. Besides, geology and various land uses were analysed. Distance of hand dug wells to dump sites, toilets and soak ways and depth were taken using measuring tapes. Types of containers used in fetching water were also assessed.

The study covered three residential areas, namely; Umoda, Ihiejwo and Ega. Water samples were obtained from fifteen (15) hand dug wells across the three residential areas using random stratified methods. The selection was guided by the factors of geology and various land uses as they can release minerals and generate wastes which are capable of polluting groundwater sources. The collection, handling, preservation and analyses of water samples were carried as prescribed in the standard method of examination of water (APHA-AWWA-WPCF, 1995) and reported in accordance with NSDWQ (2007). Temperature of the water was determined using mercury thermometer dipped into the well in the field. pH ,electrical conductivity, turbidity were determined using Gallenkamp pH meter, Hach conductivity WPA 400digital model, and turbidity DREL spectrophotometer model 2100 respectively.

Total dissolved solids, total hardness, chlorides of water samples were determined through laboratory titrations methods. Iron was determined using atomic absorption spectrometric (AAS) methods. Bacteriological analyses were carried out through incubation and culture test. Through this method total coliforms and E.coli counts were detected in the water samples.

RESULTS AND DISCUSSION

Physico-Chemical Characteristics of Hand Dug Wells in Oju Town

The results of physico-chemical and bacteriological parameters are presented in Tables 1 and 2. Temperature of the water samples analysed falls within the NSDWQ acceptable limits of 34^{o} C-40^{o} C for drinking water as the temperature ranges between 23^{o}C-31^{o}C. The well, W8 has the lowest temperature values of 23^{0}c and the highest value 31^{0}c in W15. The temperature of groundwater is controlled by the ambient conditions under which the samples were collected.

The analysis shows that pH of all the samples ranged between 5.1 and 8.2. Out of the 15 hand dug wells studied, 12 (80%) have pH value between 4.70 and 6.20. This is outside the NSDWQ range of 6.5-8.5 for drinking water, implying that the water is predominantly acidic. Water from these wells is likely to have corrosive effect on materials. This is consistent with studies carried out in Benin City (Atuma and Ogbeide, 1984) and Lagos (FMHE, 1981).

Conductivity is a measure of the ability of water to conduct an electric current. It is used to estimate the amount of dissolved solids. It increases as the amount of dissolved mineral increases. The highest value (249 µm/cm) of electrical conductivity was observed in one of the samples from Ega (W8). The least value (67.5 µm/cm) was obtained in Ihiejwo (W1). These concentrations are within NSDWQ standard of 1000µm/cm.

Table 1: Results of analyses of the physic-chemical parameters of the water samples

Sample code	Location	Temp ^{O}C	pH	EC µ/CM	TDS mg/L	TBD FTC	Fe^{2+} mg/L	TH mg/L	Cl^{-} mg/L	NO_3 mg/L
W1	Ihiejwo	27.0	6.2	67.5	45.0	2.15	0.9	92.1	30.0	0.0
W2	Ihiejwo	24.0	6.1	79.4	52.9	1.15	0.5	71.9	30.0	0.0
W3	Ihiejwo	25.5	5.8	74.4	49.6	0.65	0.7	83.8	26.5	0.0
W4	Ihiejwo	26.5	8.0	92.3	61.5	7.75	1.6	100.7	26.1	63.0
W5	Ega	24.6	8.2	140.0	93.0	10.00	1.9	141.9	65.2	106.0
W6	Ega	24.8	8.0	119.0	79.3	0.75	0.9	79.3	37.9	96.3
W7	Ega	26.3	5.8	201.0	134.0	4.75	0.1	31.8	21.1	26.1
W8	Ega	23.0	4.7	249.0	166.0	3.45	0.0	25.4	10.1	17.9
W9	Ega	27.1	5.4	163.5	109.0	4.00	0.1	31.8	20.1	24.0
W10	Umoda	26.4	5.9	146.0	97.0	0.15	0.0	45.0	8.2	2.1
W11	Umoda	26.9	6.1	137.9	91.9	0.21	0.0	47.2	9.4	16.2
W12	Umoda	29.1	5.3	121.4	80.9	0.07	0.0	39.0	11.2	10.0
W13	Umoda	29.0	5.4	128.0	85.0	1.05	0.2	43.0	14.8	4.9
W14	Umoda	26.9	4.9	149.0	100.0	6.60	1.1	26.7	22.6	16.1
W15	Umoda	31.0	5.1	117.9	78.6	1.21	0.1	40.1	10.8	9.6
	NSDWQ limit	34.0-40.0	6.5-8.5	1000.0	500.0	5.00	0.3	150.0	250.0	50.0

key: well (W), Temperature (Temp), Electrical conductivity (EC), total dissolved solid (TDS), Turbidity (TBD), Iron (Fe), total hardness (TH),Chloride (CL), Nitrate (No3).

Table 2: Total and Faecal Coliform Concentration in Well Water Samples in Oju Town.

Sample code	Locations	T.coliform (mdl)	E.coli (mpn)
W1	Ihiejwo	B/D	B/D
W2	Ihiejwo	30	17
W3	Ihiejwo	20	23
W4	Ihiejwo	49	27
W5	Ega	30	20
W6	Ega	35	22
W7	Ega	60	21
W8	Ega	35	19
W9	Ega	40	30
W10	Umoda	B/D	B/D
W11	Umoda	30	39
W12	Umoda	40	10
W13	Umoda	46	27
W14	Umoda	45	25
W15	Umoda	28	18
NSDWQ Standard		10	0

Key: Below detection (B/D), Well (W)

Total Dissolved Solid generally reflects the amount of minerals content that is dissolved in the water, and this controls its suitability for use. Total dissolved solids test in water provides a quantitative measure of the amount of dissolved ions. It is used as indicator test to determine the general quality of water (Dezane, 1977). High concentration of total dissolved solids may adverse health effects if the ions in water are of heavy metals such as lead and arsenic. Studies however have not shown any health effect associated with ingestation of water with high concentration of total dissolved solids (Ocheri *et al.*, 2012). Highly mineralized water may also deteriorate domestic plumbing and appliances. In the study area, the concentration of total dissolved solids ranged between 45- 166 mg/l. The highest value is observed in (W8) in Ega. The total dissolved solids of the study area fall within the NSDWQ Standard.

Hardness or softness of water varies from place to place and reflects the nature of the geology of the area with which the water has been in contact. The concentration of water hardness in the study area is between 25 to 141.93 mg/l, this is within NSDWQ Standard. Water hardness is observed to be less than 50mg/l in wells W7, W8, W9, W10, W11, W12, W13, W14 and W15, while well W1, W2 and W3 have concentrations above 50-100 mg/l and well 5 with values above 100 mg/L. The water hardness noted in some of the hand dug wells may be attributed to the geology of the study area which is of mudstone rich in calcium. Calcium is generally responsible for water hardness. Water could be considered to be very hard if hardness exceeds the NSDWQ maximum permissible limit of 500mg/l. Excessive hard water is not good for drinking and is associated with rheumatic pains and gouty conditions. Hardness of water can cause disadvantages in domestic uses by producing poor lathering with soap, deterioration of cloths, scale forming, skin irritation, boiled meat and food becomes poor in quality (Pritchard *et al*., 2008).

Turbidity represents an important aspect of water quality. It is deemed as the cloudiness of a liquid as a result of particulate matter being suspended within it. Its importance is highlighted by the fact that suspended solids interfere with effective chlorination/disinfection and helps to shield bacteria (Asano, 2007). Additionally, suspended solids also serve as a place of attachment for bacteria (Hurst *et al*., 1996). The NSDWQ standard for drinking water is a turbidity of less than 5 (FTU). Turbidity concentration greater than 5 (FTU) is considered unhealthy. The turbidity concentration obtained in this study is between 0.07 and 10.

Iron concentration is between 0.00-1.93 mg/l in the well water samples. From the wells studied 3 (20%) have concentration above the NSDWQ standard. The source of this iron is probably due to the presence of ironstone in Eze-Aku Formation, which may have dissolved into the ground water. According to Ezeigbo (1988), iron is a characteristic of Nigerian groundwater. It is a very common element and is found in many rocks and soils in Nigeria.

Chloride is a major ion that may be associated with individual septic disposal system (Canter and Knox, 1985). Chloride is present in all natural waters, usually in relatively small amounts; however, chloride also can be derived from human sources. In the study area, the concentration of chloride is between 8.24 to 65.18 mg/l. These values are within NSDWQ standard. The highest concentration of chloride is in W10, while the lowest concentration is in W5.

From the result of analysis, nitrate level is between 0-106 mg/l. The concentration of nitrates in well water samples in Oju town is above NSDWQ standard of 50 mg/l. The elevated level of nitrates in samples W4, W5 and W6 has been related to shallow well depth and improper well construction materials. This facilitates runoff and seepage into the wells, giving rise to nitrates concentration. High concentration of nitrates has a lot of health implications, especially on growing infants and pregnant women (Adekunle *et al.,* 2007). This may give rise to potential health risk such as methmogloinemia or blue baby syndrome particularly in pregnant women and bottled-fed infants respectively. The symptoms of methmogloineamia are paleness, bluish mucous membrane, digestive and respiratory problems (McCasland *et al.,* 2007).

Water from a properly located and constructed well should be free of total coliform bacteria. While total coliform bacteria do not cause illness in healthy individuals, their presence in well water indicates the water system is at risk to more serious forms of contamination. The presence of another type of bacteria, Escherichia coli (E. coli), indicates fecal contamination of the water. E. coli bacteria inhabit the intestines of animals and are typically found in their fecal matter which causes illnesses. The analysis shows that the value of total coliform is between 20 and 60 cfu/100ml, while E.coli is between 10 and 39 cfu/100ml (Table 2). These values are above the NSDWQ limits for drinking water for both Total coliform and E.coli. The presence of significant levels of total coliform and E.coli in the hand dug wells may be attributed to the short distance from hand dug wells to dumpsites, pit latrine and soak way.

The mean distance of the well to the polluted sites is 3.62 m. The presence of E.coli bacteria of faeces in the wells confirms this. The mean depth of the hand dug wells is 11.6 m. As shallow wells contaminants originating from various land uses can easily get in pollute the water. Some of the wells have no protective covers and the sanitary environment of the well is stagnant waters all may aid transmission of bacteria. Beside the mode of water fetching using water bags and buckets may also contribute to the bacteriological pollution of the wells. These pathogens pose health risk in infants, young children and people with severely compromised immune systems (USEPA, 2002). NSDWQ has recommended a zero value for E.coli and 10cfu/ml for total coliform in drinking water. Oju LGA is generally noted for problems of water related diseases. The current intervention by government and non-government agencies has reduced the occurrence of waterborne diseases that use to claim several lives in the area.

CONCLUSION

The study has shown that the bacteriological safety of water from the hand dug wells is in doubt due to presence of E.coli in the water. It is therefore recommended that hand dug well water should be disinfected by the use of adequate dosage of water guard, chlorination and boiling to reduce the risk of water related diseases. Beside, proper protection of the hand dug wells with good covers, neat sanitary environment and appropriate regulation of landuse activities capable of pollution the wells will help significantly. Government should step in to provide improved water supply system that will enhance the quality of the inhabitants.

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Lysimeter Study of Crop Evapotranspiration of African Spinach in Nsukka, Southeast Nigeria

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Abstract

A drainage lysimeter of 2m surface area with a depth of 1m was used to estimate the crop evapotranspiration of African spinach (Amaranthus Cruentus) in Nsukka southeastern Nigeria between mid February and mid March 2011. The crop was irrigated daily using a watering ca, and the lysimeter was instrumented to monitor rainfall, drainage, and soil moisture. The daily data generated were used to evaluate crop evapotranspiration (Etc) from the water balance equation. The crop evapotranspiration determined from the lysimeter for African spinach was 185.37mm, for the period with an average daily crop evapotranspiration of 5.98 mm/day. This compares favourably with the FAO Penman Monteith method which gave an average daily ETc of 6.08 mm/day for the same period.

Keywords: *Lysimeter, Crop evapotranspiration, African spinach, Drainage.*

INTRODUCTION

Water covers three-quarters of the earth's surface (Michael, 1978). However, inaccessibility, climate change and high water demand for domestic, industrial and agricultural needs have led to water shortages being experienced mostly in the developing countries. Most regions of the world engage in agriculture for production of food and raw materials for industries but, Asia and Africa are the worst hit of water shortage because most of their countries depend on agriculture for foreign exchange and food. Efficient use of water for crop production requires that crop water requirements are determined accurately. Since water use by crops, and its variations at various growth stages, is critical in reducing the risk of crop failure and avoiding water wastages, the lysimeter is an ideal device for determining and establishing crop water use at growth stages. The proper monitoring, use and management of limited water resources is a sure way to proffer solutions to water wastage, food shortage and poor crop yields.

Lysimeters are the most reliable research tool for direct evaluation of evapotranspiration (Burman and Pochop, 1994).

Lysimeter is a container which is set into the soil to separate a particular soil volume which is observed and analyzed. There are two major types of lysimeters; the weighing and the non-weighing or drainage lysimeters. Although, weighing lysimeters have been used extensively for evapotranspiration research in the United States and other countries, lysimeter designs have also varied widely. The design variability is due to area of study, differing objectives and improvement and refinement of the existing ones (Howell *et al*., 1985). Generally, drainage lysimeters are classified according to size, filling procedures and method of collecting drainage (Bergstrom, 1990). With respect to the way water is drained in the drainage lysimeter, two types of lysimeters can be distinguished; the free drainage system and the suction controlled drainage system. In a free drainage system, water is allowed to drain freely through the soil under gravity alone. The size and shape of lysimeters vary from cylindrical to rectangular shapes depending on the choice of crop in order to cover the root depth. A cylindrical to rectangular is often used for a "smaller" lysimeter (Cronan, 1978, McLay *et al*., 1992), whereas rectangular shapes generally are more practical for very large lysimeters (Hjelmar, 1990). Rectangular lysimeters are also recommended for studies involving crops due to the row crop geometry.

Apart from lysimeter types soil installation is grouped into two groups; disturbed soil and undisturbed soil monoliths. Researchers have processed steel cylinders over an exposed soil column to extract or isolate soil profile (Brown *et al.,* 1985 and Meshkat *et al*., 1999). The majority of undisturbed soil monoliths methods yield cores that are too small in either area or depth to fully encompass the root zone of several actively growing crops like maize. Disturbed lysimerters can be used, but they must represent the horizon distribution of the original soil, and must be conditioned for several months prior to the use.

Evaporation is governed by the availability of water in the topsoil and the fraction of solar radiations reaching soil surface. Evaporation (Ea) and transpiration (Tp) are the two most important processes governing removal of water from the land into the atmosphere. These processes occur simultaneously, and are hard to distinguish from each other (Allen *et al*., 1998). Evapotranspiration (ET) can be classified into: reference evapotranspiration (ETo) and crop evapotranspiration (ETc) (Allen *et al*., 1998). The evapotranspiration rate is normally expressed in millimeters (mm) per unit time. The rate expresses the amount of water lost from a cropped surface in units of water depth. The time unit can be an hour, day, decade, month or even an entire growing period or year. The amount of solar radiation reaching soil surface varies with the degree of crop shading. Transpiration on the other hand is a function of crop canopy and soil water status. The value of Ea has been found to dominate the ET by as much as 100% during early stages of crop growth while Tp contributes to nearly 90% of the ET for a fully matured crop (Allen *et al*., 1998). Liu *et al*. (2002) reported that soil Ea constitutes nearly 30% of the total ETc for winter wheat. A similar study by Kang *et al*. (2003) found that ET accounted for 67% and 74% of seasonal ETc for wheat and maize respectively, grown under semi humid conditions. The actual crop water use depends on climatic factors, crop type and crop growth stage.

African spinach (*Amaranthus Cruentu*s) belongs to the genus Amaranthus and there are approximately 60 species, and all are annuals with small seeds (approximately 0.07 grams per 100 seeds). The cultivated forms are useful for producing nutritious grain and foliage, and as colorful ornamentals (Brenner *et al*., 2000). Amaranth foliage is used as a vegetable and as an animal food especially in the tropics and subtropics.

MATERIALS AND METHODS

Description of the Study Area

The study area lies between longitude $7^0$22'E and latitude $5^0$50'N in the South Eastern part of Nigeria (Ezenne *et al*., 2010). It is in the humid tropical climatic region and is characterized by two distinct seasons (wet and dry season). The wet season occurs mainly between April and October while the dry season is experienced during the remaining months of the year (November to March). The area is known to be endowed with sandy loam type of soil and the major occupation of the local residents is (peasant) farming. Farmers in this area normally establish nurseries for African spinach in May each year. The clearing and tillage operations are done in the second week of June, while planting takes place immediately after seedbed preparation. But, this study was carried out during the dry season, between mid February and mid March, 2011.

Planting

The field was heavily applied with organic manure (poultry droppings) at the rate 25 tonnes per hectare (Uguru, 1996). Seedlings were transplanted onto the lysimeter, when the seedlings were three weeks old at a distance of 15cm between plants and 30cm between rows as shown in Plate 1 (Uguru, 1996). Weeding was done almost on daily basis during the course of this study. This is because weeds do not only compete with the crops for space and nutrients but also, transpire to affect negatively the result of the evapotranspiration studies intended for this study. Pests were controlled with Sevin at 5 litres per hectare mixed in 80 litres of water. Harvesting was done after 31 days of transplanting. During the study, the daily irrigation, drainage and change in soil moisture data were measured and recorded. The crop evapotranspiration was simply determined by water balance equation as shown in equation 1. Irrigation and drainage was calculated in millimeter by dividing the amount of water by the surface area of the lysimeter.

$$ET_C = I - D - \Delta S \qquad (1)$$

where ETc = Crop evapotranspiration, I = Irrigation, D = Drainage, Δ S = Change in soil water storage.

Harvesting

African Spinach is known to have matured when it starts flowering as shown in Plate 2 but, because it is vegetable crop, it can be harvested even before flowering. The reasons are that its greenish colour and freshness matters. Uguru (1996) describes the succulent shoot as due for harvest within three to six weeks of sowing depending on the variety and the environmental conditions.

Laboratory Analysis

The soil samples collected at different points within the lysimeter at the root depth were analyzed by gravimetric method to determine their daily soil moisture content. The gravimetric data were converted to volumetric data, determining the volume of soil samples by fluid displacement method. Irrigation and drainage were converted to millimeter by dividing the volume of water with the area of application (lysimeter).

Other methods, like Penman Montieth and evaporation pan methods were also used to estimate crop evapotranspiration at the same time. This is to compare the results obtained from the lysimeter with other methods.

Plate 1: Lysimeter planted with African spinach

Plate 2: Matured spinach

The Evaporation Pan Method

The reference evapotranspiration was determined by pan evaporation method using class A evaporation pan. The relationship between the evaporation and reference evapotranspiration is given in equation 2 as;

$$ETo = Kc \times Ep \qquad (2)$$

where ETo = Reference evapotranspiration, Kc= Pan coefficient, Ep = Pan evaporation

Allen *et al*., (1998) shows pan coefficient for different pan siting and environment, relative humidity and windspeed. The pan coefficient for class A evaporation pan placed in dry fallow at medium relative humidity of 40% to 70%, light windspeed of less than 2m/s and 1m windward side distance of green crop was given as 0.8. Having calculated the reference evapotranspiration (ETo), the crop evapotranspiration (ETc) was also calculated using the following equation 3.

$$ETc = ETo \times Kc \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where ETc = Crop evapotranspiration, ETo = Reference evapotranspiration, Kc= Crop coefficient.

The FAO Penman Monteith Method

From the CROPWAT output for the reference evapotranspiration (ETo) values were converted to crop evapotranspiration (ETc) by multiplying with the crop coefficient (Kc) using Equation 3. The crop coefficient for spinach depending on the crop stage is given as 1 or 0.95 except at the initial stage growth that it is 0.7 (Allen *et al*., 1998). The Penman Montieth results for evapotranspiration was used as comparison to the evapotranspiration results obtained from the lysimeter studies and Pan Evaporation methods.

Water balance Method

Irrigation, drainage and water storage data were collected from the lysimeter as shown in Table 1. The values were converted into millimeters per day, firstly by converting liters to millimeter then dividing with the total surface area of the lysimeters. The soil initial moisture was taken into account before transplanting and first irrigation on 15^{th} February, 2011. Gravimetric method was used to determine soil moisture values which were later converted to volumetric values. Average daily rainfall during the experiment was zero as it was conducted during the dry season. The runoff in and out of the lysimeter was also zero because, the design and installation was to restrict runoff in and out, by allowing a freeboard of 7 cm above the ground surface within the lysimeter. Two other methods, evaporation pan method and Penman Montieth methods were also used to estimate crop evapotranspiration of African spinach during the same period of study and same study area.

RESULTS AND DISCUSSIONS

Figure 1 shows that irrigation, drainage and moisture follow almost the same pattern except the lysimetric measurement of ETc. The result shows that drainage and moisture increase as soon as irrigation is increased while the crop evapotranspiration increases slightly over the period, but this can be said to be caused by gradual increase in the temperature.

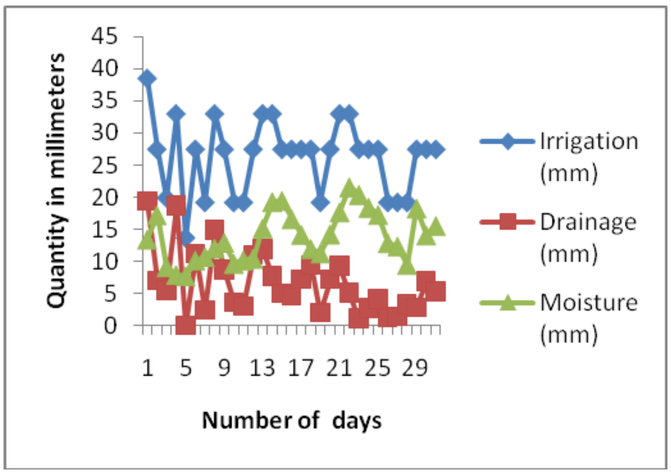

Fig. 1: Relationships of irrigation, drainage and moisture changes.

The results of the three methods for the period of study were shown in Fig. 2. The ETc lysimeter and ETc Penman Monteith values were close with total values of 185.37 mm and 188.56 mm, respectively, while ETc Evaporation Pan deviates from the trend with a total value of 143.12 mm. The results show that ETc Penman Monteith values are virtually the same with that of ETc lysimeter. Since ETc Penman Monteith is the most widely accepted indirect method, the lysimeter can be said to be tested and functional. The deviation encountered in the values of ETc Evaporation Pan can be said to have been caused by improper readings obtained from the evaporation pan, because the evaporation pan was not shielded with screen to keep animals like birds and rats away from the pan. Another reason was improper sitting of the evaporation pan to the recommended height of 15 cm in accordance with FAO, guidelines (Allen *et al*., 1998).

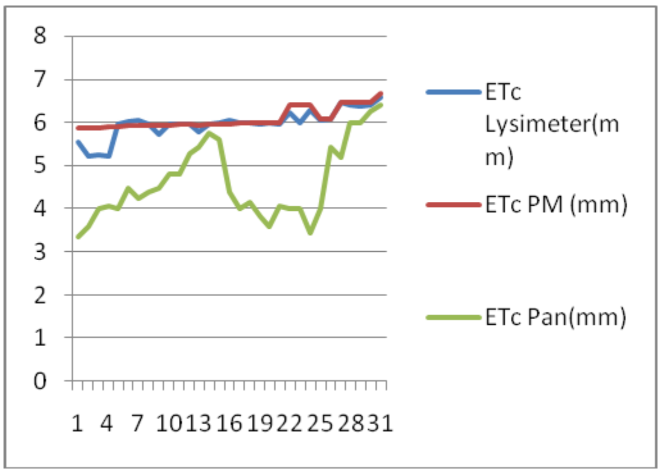

Fig. 2: The Crop Evapotranspiration for African Spinach

CONCLUSION

The study revealed that the crop evapotranspiration or crop water use of African spinach (Amaranthus Cruentus) in Nsukka southeast Nigeria between the month of February and March is 185.37 mm. This result shows that proper irrigation scheduling and planning can be made in the study area to reduce and avoid water wastages during irrigation, especially during the dry season, when water scarcity is sure to be high.

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Authors should prepare their manuscripts in English using Microsoft Word an send as email attachment and send to the Editor-in-Chief of the Nigerian Journal of Hydrological Sciences at njhseditor@gmail.com.

The following instructions should be adopted in preparing the manuscript.

1. *write in English*
2. *present the material simply and concisely; in particular cross-check details of references*
3. *use 12 pt Times New Roman font and use Equation Editor 3.0 to present equations*
4. *Set the paper size to 'A4' (210 mm* × 296 mm*)*
5. The title should be precise and informative. It should be followed by the names of the authors and their affiliations with e-mail contacts specified.
6. An abstract of not more than 250 words should precede the main text. It should state, among others, objectives, scope, methods and significant results. A list of about 5 key words should be provided below the abstract.
7. *include tables and figures at appropriate points in the text (or at the end of the text); plan their layout to use page space economically and ensure all figures and tables are cited in the text, in numerical order*
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11. *All symbols should be defined* ***either*** *in the body text, immediately after their first appearance,* ***or*** *in a separate section, immediately after the key words. Do not use both methods.*
12. *If a list of Notation is used, they should be put in alphabetical order (Roman letters first, then Greek letters).*
13. *Heading:*
    (a) HEADING 1 should be Upper case, bold, start at left margin
    (b) Heading 2 should be Lower case, bold, start at left margin

(c) Heading 3 Lower case, bold, indented; text run on

14. Units

(a) Use SI units or SI derived units.

(b) Do not abbreviate week, month or year, which are non SI units. Use s, min, h and d (rather than sec, mins, hr/hrs, day/days) for second, minute, hour and day, respectively.

(c) Use L (rather than l) for litre

(d) Multiplication of units should be indicated by a space, e.g. N m, and division either by negative exponents (e.g. m s^{-2}) or by use of the solidus (e.g. m/s^2); however repeated use of the solidus (e.g. m/s/s) is not permitted. The convention adopted must be used consistently throughout the paper.

(e) Prefixes of units such as M (mega = 10^6) and μ (micro = 10^{-6}) have no space between (e.g. μs, MW). Note that any power to a unit applies also to the prefix. Note also that the prefix kilo is lower case k (e.g. km, not Km – the upper case K is the symbol of kelvin).

(f) All units should be typeset using upright (Roman) fonts, not italic or bold.

15. Use initial capital in Names

(a) proper names, e.g. River Niger, Shiroro Dam, the Earth;

(b) adjectives derived from proper names, e.g. Markov series, Arctic ice, Bayesian estimation;

(c) geological eras and formations etc., e.g. Cambrian, Holocene, Upper Greensand;

(d) references to tables and figures, e.g. "it is seen from Fig. 2 and Table 4 that ...".

16. The Harvard system should be adopted. References cited in the text should follow the format of: (author, year) e.g. Kehinde (2003), Diop and Bulaye (1990), Mwanga et. al. (2002). References should be listed in alphabetical order at the end of the paper based on the author's surname. Surnames and initials for all the authors must be listed in the case of multiple authors, followed by the year in brackets, full title of the article, full name of the journal, volume, first and last pages of the article.