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Climate Change on Discharge and Sedimentation of River Awara, Nigeria

The dynamics of variation in effect of climate change on discharges and sedimentation mechanism of River Awara is investigated using 14-year data of rainfall (mm), discharges (m^3/s), temperature (^0c) and sediment load (t). Surface runoff (mm) was computed using Water Balance Equation and some other empirical iteration based on the observed rainfall and temperature over a period of time. Analysis of Paired Sample reveals the relationship between tested hydrological variables: Rainfall-Runoff; Runoff-Sediment load; and Discharge-Sediment load are significant at 0.95 level of confidence interval. Logarithm calibration curve further illustrates that Rainfall-Runoff and Runoff-Sediment have coefficient values (R^2) of 0.996 and 0.822 respectively. Analytical iteration shows that the intensity and duration of precipitation determine the magnitude of river, generation of surface runoff and sedimentation rate. Increase in rainfall depth by 100 mm within the 14-year has resulted to serious erodobility and erositivity around River Awara. Cumulative average sediment load ratio of 0.46 has significantly reduced the reservoir capacity of the river by 10%. 78% of total annual surface runoff is lost to ocean; since reservoir capacity has been silted up which in turns reduces the volume of water that could be held for storage, treatment and distribution for its intended purposes. Comparative physics-based output indicates that temperature increase of 0.7^0c between 1997 and 2004, due to internal processes of the Earth and some human activities. It is however projected that temperature will rise by 0.9^0c by the end of 2015. Projected rise in temperature will adversely affect hydrological cycle and complicate already scarce-water resources due to intensive evapotranspiration, infiltration and reduction in stream flow. Holistic integration using bottom-up mechanism needs to be applied to address this constraint. Dredging of river Awara is very important to enhance its storage capacity and planting well covered crop across the tributaries to trap sediment flow and reduce river siltation. Comprehensive *adaptive measures are strongly encouraged to cope with multiple impacts of climate change in various human endeavors.*

***Keywords**: Rainfall, Runoff, sediment, temperature, climate change, calibration, discharges, iteration, period, reservoir capacity*

1. Introduction

Climate change is one of the most important phenomena in our contemporary world. IPCC (2007) defines climate change as a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and /or the variability of its properties, and that persists for an extended period typically decades or longer. In its most recent assessment, the Intergovernmental Panel on Climate Change (IPCC) reported that all of Africa is likely to warm during this century, with the drier subtropical regions warming more than the moist tropics. Annual rainfall is likely to decrease throughout most of the region, with the exception of eastern Africa, where annual rainfall is projected to increase. These changes in the physical environment are expected to have an adverse effect on agricultural production, including staple crops such as millet and maize. In addition, acute soil erosion and land degradation are also effect of land climate change to be considered. Climate change may have stronger or weaker, permanent or periodical, favorable or unfavorable, harmful (sometimes catastrophic), primary (direct) or secondary (indirect) impact on soil processes. Among these processes soil moisture regime plays a distinguished role. It determines the water supply of plants, influences the air and heat regimes, biological activity and plant nutrient status of soil (Montgomery, 2007).

The process of erosion, sediment delivery and sediment transport are key components and measures of the functioning of the earth system. Erosion and sediment redistribution processes are the primary drivers of landscape development and play an important role in soil development (Loveland, 1994). High sediment loads can, in particular, result in major problems for water resource development, through reservoir sedimentation and the siltation of water diversion and irrigation schemes, as well as increasing the cost of treating water abstracted from river. Furthermore, high sediment loads can result in pollution and habitat degradation in river system (Hekstra**,** 1985). Reservoir capacity of Awara dam has greatly reduced as a result of continuous sedimentation and siltation. Erodibility of the soil around the reservoir area is very high; the soil can easily be detached and transported by surface flow (Olotu etal., 2010). Agricultural sector uses the highest volume of water; and with the reduced reservoir capacity of Awara dam due to sedimentation, irrigation practices cannot be sustained. The most significant variables of climate change are temperature and rainfall. Potential future changes is rather difficult, due to the uncertainties in the forecast of global and long-term temperature and precipitation patterns (including their spatial and temporal variability) combined here with the changing hydrological cycle and the complex and integrated influences of natural vegetation and land use pattern. Many of the world's countries already struggle under existing water stress from pressures such as irrigation demands, industrial pollution and water borne sewerage. These pressures will be significantly exacerbated by climate change, which for many regions will result in reduced rainfall and increasing temperatures, further reducing the availability of water for drinking, household use, agriculture and industry. As these competing demands intensify under climate change, effective governance for balancing water demands will become essential, particularly in the face of strong pressures to priorities industrial uses over other uses such as drinking supplies. Higher temperatures changes will affect the amount of runoff that becomes groundwater - the main source of water supply in many parts of the country. Similarly, reduced rainfall, particularly in the northern part would further compound the inability of the zone to meet people�startup's demand for water. The northern part of the country of Nigeria may increase its dependence on underground water sources. But decreased rainfall would lead to lower water tables and this could increase the water stress and problems of environmental sustainability and water resources management futures (Heinrich Böll Stiftung (HBS), 2009). Many sectors of the Ikare community and its environs development will be affected by climate change induced by global warming. With nearly 70% of the community's population depending on agriculture for sustainable livelihoods, and agriculture still contributing nearly 40% of the region‛s GDP, the region is highly vulnerable to climate variability and long-term climate change, which could result in higher food prices, and lower domestic revenues. Agricultural sector uses the highest volume of water; and with the reduced reservoir capacity of Awara dam due to sedimentation, irrigation practices cannot be sustained. Having considered the challenges pose as a result of climate change on river discharge and sedimentation of Awara dam on numerous areas of human endeavour. Studies of this nature are highly significant to produce realistic outputs veritable to derive hydrological models for short and long resolutions.

1.2. Materials and methods

The study did consider the impacts of climate change on the river flow and sedimentation of Awara dam and its multiple effects on water supply for domestic and agricultural purposes. However, this report indicated that no specific methodology has been developed for this purpose. Hydrological data such as rainfall (mm), temperature (0^c), river discharge (m^3/s) and sediment load were obtained from the three gauging stations (Oyimo, Otaloke and Gbegbeda gauging stations respectively). Runoff data were computed from the obtained rainfall using the following expressions:

$$R = 0.91P - 34.6 \quad (1)$$

$$R = 0.88P - 46 \quad (2)$$

$$R = 0.87P - 44.9 \quad (3)$$

$$R = P - \frac{(T-32)}{3.74} \quad (4)$$

2.1. Results and discussion

The result in Table 1 shows the computed sediment load ratio in each of the measuring stations. Highest load ratio of 0.61 was recorded at $Awara_{a.}$ Erosivity and erodibility have caused high rate of soil detachability, transportability and deposition at the tributaries of river Awara. These hydrological mechanisms occurred proportionally to the duration and intensity of rainfall, runoff and river discharge.

Table 1. Measurement of changes in the sediment load

River	Stations	Catchment (km^2)	Sediment load ratio	Period of record
$Awara_a$	Oyimo	17,245	0.61	1997-2010
$Awara_b$	Gbegbeda	14,635	0.43	1997-2010
$Awara_c$	Otalooke	13,674	0.33	1997-2010

Source: Field study, 2011

As a result of climate change, some region starts receiving heavier and steadier rainfall and such areas would experience increased rainfall-runoff-discharge. Higher temperatures contribute to dry conditions which lower the soil moisture content, reduce water table and sea level through evaporation transpiration. Observed and simulated hydrological variables in Table 2 shows the highest annual rainfall depth of 1346.0mm was recorded in 2007 which corresponds to runoff depth and river discharges of 1231mm and 12310.9m^3/s respectively. The summary of the statistical analysis carried out on the hydrological data in Table 2 is showed is shown in Table 3, 4 and 5. The result of the analysis in Table 4 shows clearly that perfect relationship exists among the hydrological variables with the following Paired Sample Correlation index values of 1.000, 0.866, 0.866 and 0.866 respectively. This observation indicates that rainfall intensity, duration, distribution and pattern determine the magnitude and occurrence of other hydrological variable such as runoff depth, river discharge and sedimentation rate of river Awara.

Table 2. Observed and simulated hydrological data

Year	Rainfall (mm)	Runoff (mm)	Discharge (m3/day)
1997	1125	1023.8	10,231
1998	1036.7	939.2	9390.2
1999	1200	1093.4	10930
2000	1214.5	1106.6	11066
2001	1200	1093.6	10934.7
2002	1250	1140.4	11400
2003	1300	1187.4	11874
2004	1305	1192.1	11921.5
2005	1330	1215.6	12156
2006	1322	1208	12080
2007	1346	1231	12310.9

Source: Field study, 2011

Table 3. Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Rainfall (mm)	1269.5857	14	110.19624	29.45118
	Runoff (mm)	1158.8286	14	103.63080	27.69650
Pair 2	Runoff (mm)	1158.8286	14	103.63080	27.69650
	Sediment load (tons)	240.8714	14	124.63950	33.31131
Pair 3	Rainfall (mm)	1269.5857	14	110.19624	29.45118
	Sediment load (tons)	240.8714	14	124.63950	33.31131
Pair 4	Discharge (m3/s)	11587.0214	14	1037.77765	277.35774
	Sediment load (tons)	240.8714	14	124.63950	33.31131

Table 4. Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Rainfall (mm) & Runoff (mm)	14	1.000	.000
Pair 2	Runoff (mm) & Sediment load(tons)	14	.866	.000

		N	Correlation	Sig.
Pair 3	Rainfall (mm) & Sediment load(tons)	14	.866	.000
Pair 4	Discharge (m3/s) & Sediment load(tons)	14	.866	.000

Table 5.

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Rainfall (mm) - Runoff (mm)	110.75714	6.57556	1.75739	106.96053	114.55376	63.024	13	.000
Pair 2	Runoff (mm) - Sediment load(tons)	917.95714	62.53294	16.71263	881.85170	954.06259	54.926	13	.000
Pair 3	Rainfall (mm) - Sediment load(tons)	1028.714	62.36828	16.66863	992.70391	1064.725	61.716	13	.000
Pair 4	Discharge (m3/s) - Sediment load(tons)	11346.15	931.92678	249.06791	10808.07	11884.23	45.554	13	.000

Table 5 presents the result of Paired Sample Test. Pair 1(Rainfall-Runoff) has T_{lower}, T_{upper} values of 106.96053 and 114.55376 at 0.95 level of significant. These corresponded to computed t-value of 63.024 indicating that the tested-paired variables are highly significant at 95% confidence interval. The other paired variables are significant as it is shown in Table 5. Calibration iteration curves in Fig. 1-5 further illustrate the relationship between compared hydrological variables with strong coefficient of determination (R^2) using exponential, linear and power expressions. The result in Figure 2 shows that the difference between annual rainfall and runoff is not significant, infiltration and abstraction are very low. River Awara is located at the tropic region; which in most cases experiences ***Saturated Excess Runoff***. Rise in mean temperature affects the components of water-balance-equation such as Evapotranspiration(ET), Soil moisture storage (SW), Deep percolation (DP) and Capillary rise. Water balance equation can be written as follows:

$$ET = I + P - RO - DP + CR + SF + SW \quad (1)$$

Increase in ambient temperature would lead to reduction of surface runoff, soil moisture storage and increase in infiltration and evapotranspiration. The combined processes result to lowering of sea water level; and eventually partial-total drought, this development is very critical to determine comprehensive water budgeting and planning mechanism.

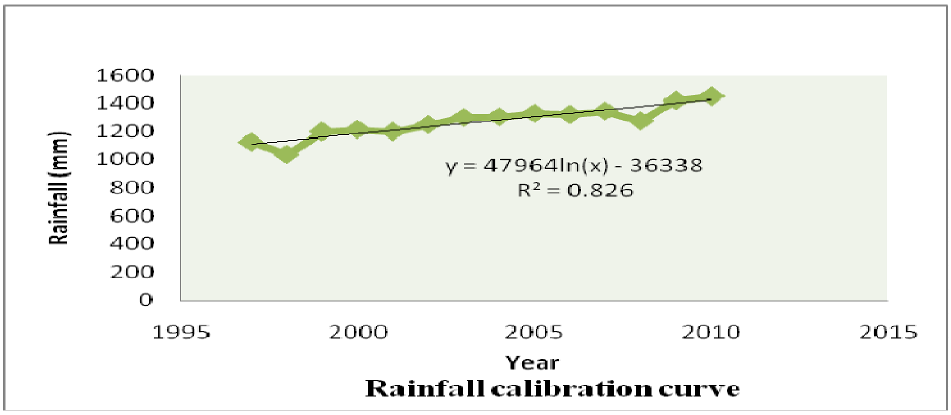

Figure 1. Rainfall calibration curve

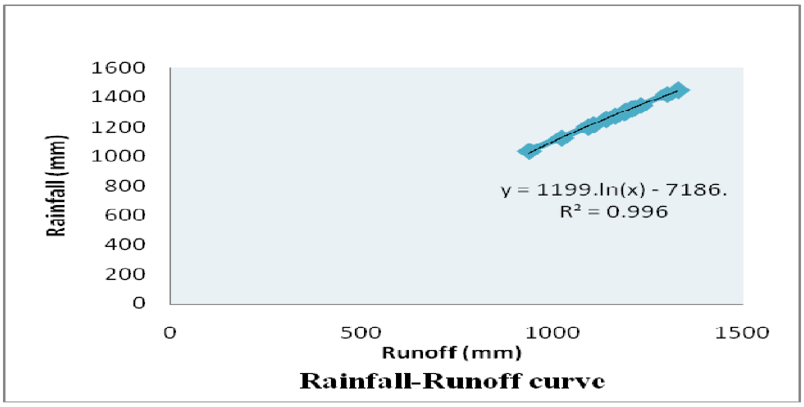

Figure 2. Rainfall-Runoff curve

Significant annual increase in rainfall, runoff and river discharge over the catchment for some years have resulted to high rate of reserviour sedimentation. Observation from River Awara in Nigeria (Figure 3, 4 and Table 6) indicates that the annual sediment load of the river, which drains a total catchment of 45,554 km^2, shows a significant increase in sediment load over the period of measurement. Sediment load increased from 78.3t in per year in 1995 to 445.4t per year in 2010. Apart from the hydrological factors such as surface flow, runoff, river discharge; catchment disturbance, which is associated to human activities such as deforestation, poor land clearance for agriculture, infrastructural construction results in increased sediment loads. Continuous sediment load has greatly reduced the reservoirs capacity of Awara dam; evaporation also reduces the small volume of the dammed water. Cumulative sedimentation rate has significant reduced the reservoir capacity of Awara dam by 1/10 th of its designed capacity.

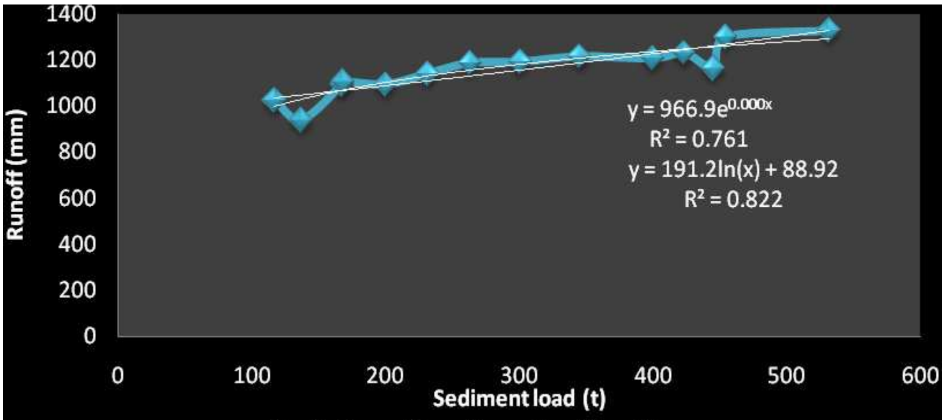

Fig.3:Runoff-sediment calibration curve

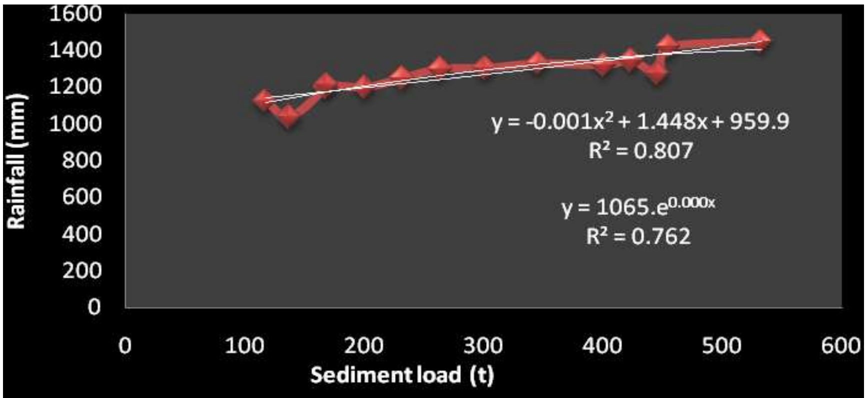

Fig. 4:Rainfall-sediment calibration curve

It is observed that there would increase in rainfall depth by 100 mm-150 mm between now and 2015, which in turn will lead to increase river discharge,surface flow and sediment deposit. The climate change at Awara and environ indicates an increase of surface temperature, precipitation evaporation and runoff. Precipitation stands tall with substantial increases of 43% and 46% respectively. It is projected that the ambient temperature will increase by 0.9^0C by the year 2015.

Table 6. Sediment loading of Awara reservoir dam

N/S	Year	Sediment load(t)
1	1995	78.3
2	1996	94.4
3	1997	116.8
4	1998	137.1
5	1999	167.4
7	2000	168.2
8	2001	200.2
9	2002	231.6
10	2003	263.3
11	2004	300.7
13	2005	345.3
14	2006	400.1
15	2007	423.4
16	2008	445.4
17	2009	454.6
18	2010	531.9

Source: Field study, 2011

Temperature calibration curve in Figure5 indicates that maximum average temperature of 30.5^{o}c was observed in 2005, while least ambient temperature of 26.5^{o}c was obtained in 2003. Statistical measurement showed that there are no significant changes in average temperature between year (1997-2000) and (2001-2004). Average temperature range within eight years (1997-2004) is 28.7^{o}c. Temperature rise of 0.7^{0}c was recorded between 2005 and 2008. This observation could be related to the high rate of industrialization. Changes could also be caused by processes internal to the Earth, external forces such as variations in sunlight intensity or, more recently some human activities. Recession of 0.3^{o}c was obtained in 2009 and 2010 as a result of increase in precipitation and some technical measures that reduce cause ozone depletion.

Table 7. Temperature records between (1997-2010)

N/S	Year	Temperature 0^{c}
1	1997	28.1
2	1998	29.5
3	1999	27.5
4	2000	29.3
5	2001	30.1

6	2002	29.9
7	2003	26.5
8	2004	28.3
9	2005	30.5
10	2006	28.3
11	2007	29.9
12	2008	28.9
13	2009	27.9
14	2010	28.9

Source, Field study, 2011

The result of Rainfall-Temperature paired analysis in Table 8 indicates progressive increase in these metrological variables at 0.95 level of significance for lower and upper class.

Table 8. Paired Samples Test

		Paired Differences					T	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		Mean	Std. Deviation	Std. Error Mean
		Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
Pair 1	Rainfall(mm) - Temp (0c)	970.58571	63.37339	16.93725	933.99501	1007.17642	57.305	13	.000

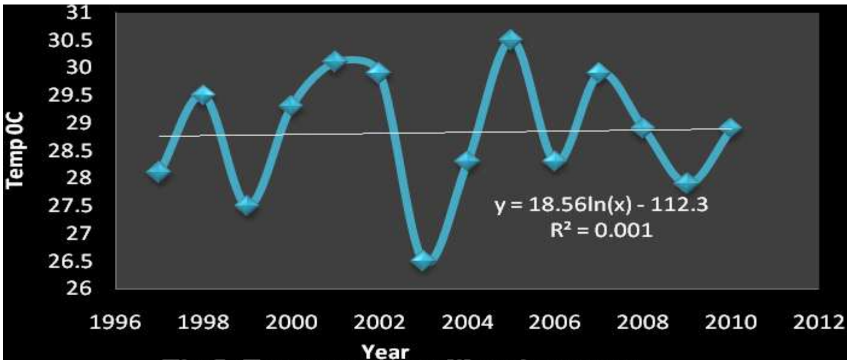

Fig.5: Temperature calibration curve

Logarithmic analysis of the temperature calibration curve shows that the coefficient of determination (R^2) is 0.001, indicating that no relationships exist in average ambient temperature and years of measurement. Rise and reduction in temperature is a very complex mechanism that requires long-range metrological data coupled with sensitive analytical models.

Where *R* is the computed runoff in (mm), *P* is precipitation (mm), *T* is the temperature (0^c). The outputs from each of the iterations were technically validated. Data range is between 1997 and 2010 for measured hydrological variable. Average monthly data were computed to give an average annual value. Simulated and observed data were subjected to statistical analysis using tools such regression analysis, One-Sample Statistics and Paired Statistics

3. Conclusion

The research study is imperative to the advancement in the field of environment engineering (Climate change) and water resources integration. Output of the study indicates increasing temperature, rainfall, surface runoff, river discharge and rate of sedimentation. Temperature increase of 0.7^0C was observed in 2005-2008; and reduced by 0.3^0C during 2009-2010. The recession is due to increase precipitation and some other technical measures to prevent ozone depletion. Maximum annual rainfall of 1346 mm was obtained; which generated 1231 mm; 12,310 m^3/s of surface runoff and river discharge respectively. This hydrological mechanism resulted to increased erodibility and erosivity index; and thus in turns led to high soil detachment and transportation. Analysis of sediment transport shows that sediment load increased from 78.3t per year in 1995 to 445.4t per year in 2010. Cumulative sedimentation over the years has significantly reduced the reservoir capacity of River Awara and dam; and has reduced the volume of water that could be stored for multipurpose applications. It is projected that the reservoir capacity of both River and dam Awara would be silted up by year 2045; if the rate of sedimentation is not checked. In addition, projected temperature increase of 0.9^0C by 2015 will further complicate already water-stressed system through intensive evaporation would lead to reduced stream flow and surface runoff. Constant researches will be useful in order to have better understanding of climate change; hydrological variables in relation to proffering realistic solution for acute water shortage and formulation of workable adaption measures.

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