NIWE WATER JOURNAL

Vol. 1, No. 1, December, 2018

PERIODICAL OF THE NIGERIAN INSTITUTION OF WATER ENGINEERS

www.niwe.org.ng

NIWE WATER JOURNAL

VOLUME 1, NUMBER 1, DECEMBER 2018.

ISSN: 2672 – 4960

Published by

NIGERIAN INSTITUTION OF WATER ENGINEERS

(A DIVISION OF THE NIGERIAN SOCIETY OF ENGINEERS)

Email: journal@niwe.org.ng
www.niwe.org.ng

NIWE WATER JOURNAL is a scholarly publication of the Nigerian Institution of Water Engineers (The Water Division of the Nigerian Society of Engineers). The journal aims to disseminate high quality and original research findings, topical reviews, technical notes/short communications in the fields of Surface water Engineering, Groundwater Hydrology, Water governance and Policy, Hydrodynamics, Wastewater Engineering, Environmental Engineering, Climate Science, Integrated Water Resources Management, Hydraulic Engineering, Irrigation and Drainage Engineering, Water and wastewater structures, Hydropower engineering, Polution Engineering and Coastal Rehabilitation. All articles published are first reviewed by the editorial team for relevance and then peer-reviewed by selected subjectmatter specialists selected by the Editor-in-Chief.

NIWE NATIONAL HEADQUARTERS
C/o National Engineering Centre, Behind National Mosque,
Central Business District, Abuja, Nigeria.
Tel: +234 803 596 7633, +234 803 343 3664
Email: journal@niwe.org.ng
www.niwe.org.ng

CONTENTS

DISSOLVED OXYGEN MODELING: A CASE STUDY OF ASORO STREAM IN ILESA, NIGERIA

J.O. JEJE[1*] and K. T. OLADEPO[2]

[1]*Department of Civil Engineering, Obafemi Awolowo University, Ile-Ife.*
jemails2000@yahoo.co.uk
[2]*Department of Civil Engineering, Obafemi Awolowo University, Ile-Ife.*
koladepo@oauife.edu.ng

**Corresponding author: Jemails2000@yahoo.co.uk*

Received: 5 October 2018 *Accepted: 24 December 2018*

ABSTRACT: A study of self-purification capacity of Asoro stream was researched with a view to providing baseline information on quality of water in Asoro stream. Dissoved Oxygen (DO) is a measure of the ability of water to sustain aquatic life; therefore, it is important in water pollution control and waste water treatment process control. Samples were collected from fifteen sampling points along the Asoro stream at 500 m intervals over a 5 km stretch for twelve-months. The average width and depth of the stream were determined at each sampling point. The average flow velocity was determined using float displacement method. The DO, Biochemical Oxygen Demand(BOD) and some other physico-chemical parameters of water (turbidity, total dissolvd solids, and electrical conductivity) were determined using standard methods. The hydrographic characteristics of the stream are; width (0.1 to 5.8 m), depth (0.1 to 0.55 m), discharge (0.30 to 0.52ms^{-1}), flow rate 0.07 to 0.0.73 m^3/s and reaeration coefficient (6.38 to 137.22 k_2d^{-1}). Asoro stream model was developed using non-linear regression and performance was checked using statistical and graphical parameters. DO model was evaluated and validated by comparing its performance with the Agunwamba's model using Group Methods of Data Handling (GMDH) Combinatorial Algorithm. The model gave a good dissolved oxygen predictive capacity compared with other models. The study concluded that release of organic matter from industrial effluent affects the DO and BOD concentrations of Asoro stream. The developed model could be used to adequately predict the DO concentration of Asoro stream.

Key words: Dissolved oxygen, model, non-linear regression, Asoro stream, self- purification

INTRODUCTION

Rivers and streams are used for the disposal of municipal and industrial wastes, and Hull (1963) and Agunwamba (2011) attributed these factors contributing to the general health and welfare of the people in Nigeria.

Discharge of wastes into a stream, however, does not simply dilute the wastes. Each Stream and river has a natural capacity for oxidizing biodegradable wastes, thus purifying the waters (Runkel, 2013). This purification capacity is dependent upon many factors, including the water discharge, the depth of flow, the velocity of flow, and the various sinks of dissolved oxygen along the stream.

Dissolved oxygen (DO) concentration is a vital health indicator of stream ecosystems. Variation in DO may be caused by various physical, chemical, and biological processes (Agunwamba *et al*, 2007). General efforts have been made to understand the processes and factors responsible for DO fluctuations (Streeter and Phelps 1925; Churchill *et al.*, 1962; Chapra, 2014: and Gualtieri *et al.*, 2002).

Rivers play significant role in the transport of industrial, municipal effluents and organic loading caused by runoff from agricultural fields, roads, and streets. Leaching and direct effluent discharge are primary sources of water pollution (Jeje. *et al* ., 2009). This problem is exacerbated when the purifying capacity of river systems is low in relation to the received contaminants.

Water self-purification is a complex process involving physical, chemical and biological processes that occur simultaneously, allowing a river to recover its natural state over a certain distance (Vagnetti *et al*., 2003; Demars and Manson, 2013). Changes in the oxygen content of polluted waters over time can be studied by using the dissolved oxygen sag curve" (Von-Sperling et al., 2014).

Asoro stream serves as a major source of water supply for the community around Ilesa East Local Government Area. Preliminary studies reveal unsuitability of the water from this stream for usual domestic purposes because of offensive odour and blackish colour arising from pollution by brewery effluents. Data on hydrographic and physicochemical parameters will help provide information on the suitability or otherwise of the water for domestic purposes,

Description of the Study Area

The study was carried out around the premises of a brewery and along the receiving stream of the brewery effluent in Osun State, Nigeria. The brewery is located in the South western part of Ilesa, Osun state on Latitudes (007^{o} ' 37' and 07^{o} 48' N and longitudes 007^{o} 40' E and 007^{o} 47' E (Figure.1). through the centre of Ilesa East a Local Government Area in Osun State, Nigeria, and runs through Iloko Town in Osun State.. The brewery industry covers an area of about 4,582 m^{2} with and average discharge of about 500 m^{3} per day.

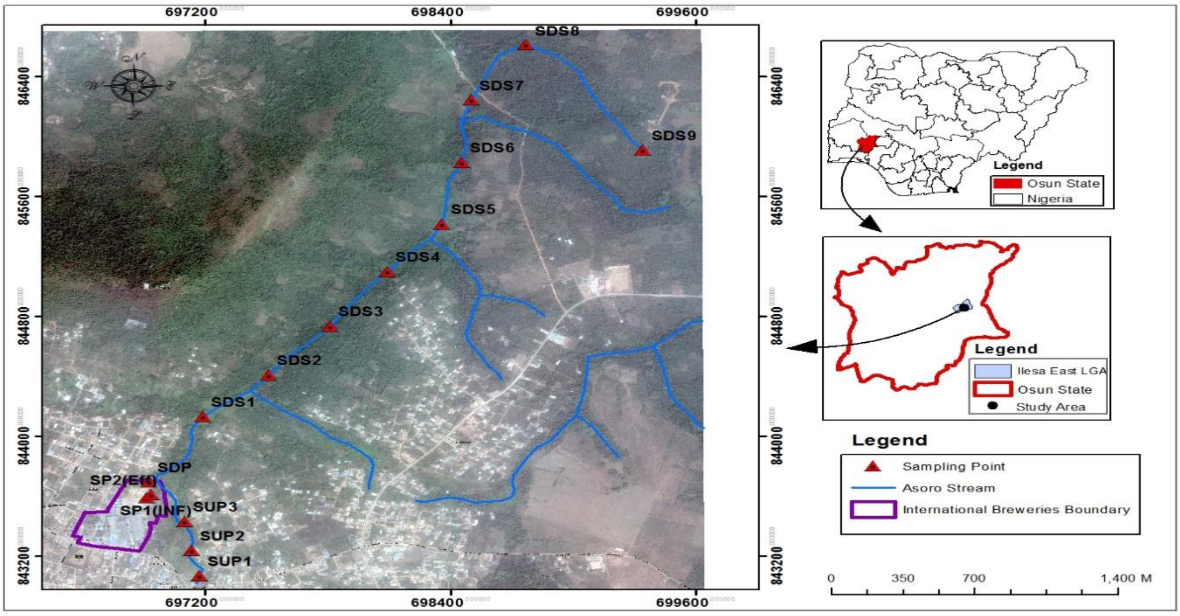


Figure 1: Map of the study area

MATERIALS AND METHODS

Fifteen sampling points were selected for this study, two points within the brewery and the remaining along the Asoro stream at 500 m intervals for 5 Km stretch. Within the brewery, one sample was taken at the influent to the treatment plant and another at the exit from the treatment plant (effluent). Along the stream, one sample was taken at the point of discharge from the brewery outfall, three samples was taken upstream of this point and nine samples downstream of the point every two weeks for twelve-months. The distance between the sampling points along the stream was established by measuring with a digital display measuring wheel. The average width and depth of the stream were determined at each sampling point. The average velocity was determined by using the float method. The temperature and pH was measured in-situ using a mercury thermometer and hand-held pH meter respectively. At each sampling point, water samples were collected in Dissolved Oxygen (DO) and Biochemical Oxygen Demand (BOD) bottles and a one-litre plastic keg. The DO, BOD and physico-chemical parameters (colour, turbidity, total solids, and electrical conductivity) were determined using standard methods.

All samplings were carried out between the hours of 7 am and 11.00 am.

Development and Validation of an Empirical Model

The data collected were used to develop an empirical model to relate DO concentration to the distance, depth, velocity, time and temperature along the stream. DO is the dependent variable, while BOD,k1, k2, Q and t are the independent variables. This study assumes that k1 and k2 formulae from existing literature are applicable to the study. The model was validated by using 20% of data (k1,k2,BOD,Q and t) which represented September and October data that were obtained from the stream (Raymond et al., 2012).

Statistical analysis using Group Method of data handling (GMDH) and combinatorial algorithm to examine the general associations of effluent discharge and flow and water quality with strong relationships with discharged effluents from the brewery industry.

Statistical and spatial analyses were employed to examine the statistical and spatial relationships of the flow and water quality in the receiving water. An empirical model was developed for the hydrologic response and validated for the water quality components. The dissolved oxygen (DO) profile was computed using the following equation (Churchill *et al*., 1962; Agunwamba *et al*, 2007):

$$k_2 = \frac{5.026\mathrm{u}^{0.969}(1.024)^{\mathrm{T}-20}}{H^{1.673}} \qquad (1.1)$$

Where v is the stream velocity (m/s) T is the temperature (^{o}C) and H is the mean hydraulic depth (m).

$$\mathrm{k}_1 = \frac{1}{t} ln\left(\frac{L_A}{L}\right) \qquad (1.2)$$

where t is the time and L_A and L is the BOD at time zero and time t respectively .These values were applied to all hydrographic parameters at each sampling point. k_1 and k_2 were determined for each sampling stations and the total mean value were computed.

This was carried out by supplying the mean values of all measured parameters into equations 1.1 (v, H and T) and 1.2 (L_A, L and t) respectively. Then, 80% of these data (November 2016 to August 2017) were supplied into to GMDH COMB to generate equation by making DO a function of k1,k2,BOD,Q and t, while accuracy of the model was carried out by validation using 20% of the remaining data (September and October).

RESULTS AND DISCUSSION

The Physico-chemical parameters of the sampled water from Asoro stream at every sampling station that showed the mean (+ standard deviations) and range values are sown in Tables 1 and 2 while hydrographic characteristics (widths, depths and velocities) of the stream, measured at each sampling point of Asoro stream are summarized in Table 3.

The model in in Eq. 1.3 was developed using the data obtained through the process described under methodology on Asoro stream. A non-linear regression analysis of the data was carried out using Group Method of Data Handling (GMDH) and combinatorial algorithm techniques (Godfrey, 2009). The first 80% of the data was used for modelling to obtain the Eq. 1.3. The remaining 20% was used to validate the accuracy of the model in predicting the DO of the Asoro stream.

$$DO = 334.651 + 21.841L^{\frac{1}{3}} - 15.847Lk_1^{\frac{1}{3}} + 0.247Lk_2^{\frac{1}{3}} - 0.04(LQ)^{\frac{1}{3}} - 3.638(Lt)^{\frac{1}{3}} - 934.071k_1^{\frac{1}{3}}$$
$$+130.946(k_1t)^{\frac{1}{3}} + 517.307k_1^{\frac{2}{3}} - 0.412(k_2t)^{\frac{1}{3}} + 0.078(Qt)^{\frac{1}{3}} - 86.5t^{\frac{1}{3}} + 5.7t^{\frac{2}{3}} \quad (1.3)$$

Where DO is dissolved oxygen, k_2 is coefficient of reaeration, k_1 is deoxygenation rate, t is the time, L is the BOD and Q is the stream flow rate. All these are independent variables which were the input used for the GMDH-combinatorial algorithm to generate Equation 1.3.

Table 1: Physico-chemical characteristics of Asoro stream, Ilesa

Year	Month	Mean/std dev /range	Temp (^oC) 20-33	pH 6.5-8.5	DO (mg/l) 4	BOD (mg/l) 30
2016	**Nov.**	Mean+sd	26.7±0.9	7.5±0.34	4.2±61.6	55.7±20.9
	n = 2	Range	24-29	6.5-8.4	0.8-6.8	18.3-78
	Dec.	mean+sd	26.5±0.99	7.59±0.16	4.28±2.40	29.0±14.05
	n= 2	Range	24-28	7.2-8.1	0.1-8.1	32.3-58
2017	**Jan.**	Mean+sd	26.23±1.09	7.60±0.5	3.53±3.2	73.50±21.7
	n= 2	Range	24-29	6.4-8.5	0.1-9	40-89
	Feb.	mean+sd	26.07±1.03	7.75±0.40	4.12±3.24	38.4±16.72
	n= 2	Range	24-27	7.2-8.3	0.1-9.7	57-67
	Mar.	mean+sd	26.5±0.99	7.68±0.57	3.71±2.8	35.7±14.7
	n= 2	Range	25-29	6.2-8.5	0.1-8.3	30-60
	Apr.	mean+sd	26.9±0.90	7.36±0.58	3.94±2.94	33.58±14.5
	n = 3	Range	26-29	6.2-8.2	0.1-10.3	46-68
	May	mean+sd	27.37±0.95	7.54±0.37	8.01±1.81	20.9±11.53
	n= 2	Range	25-29	6.6-8.2	4.5-12.2	40-50.6
	Jun	mean+sd	24.97±0.8	7.45±0.24	8.77±1.9	39.4±13.9
	n= 2	Range	24-26	6.9-8.1	6.0-13.1	39.2-62.1
	Jul	mean+sd	25.36±0.92	7.64±0.40	7.89±1.55	33.64±18.95
	n = 3	Range	24-27	7.2-8.2	4.2-12.6	50.3-88
	Aug.	mean+sd	25.8±0.88	7.7±0.39	3.41±0.39	29.12±34.4
	n =2	Range	24-28	6.8-8.1	0.1-6.3	16.4-48
	Sept.	mean+sd	25.77±1.33	7.67±0.40	3.36±1.49	24.71±67.50
	n= 3	Range	23.5-28	7.1-8.3	0.3-6.9	34.2-49.6
	Oct.	mean+sd	26.24±0.93	7.74±0.41	2.63±1.33	22.9±12.5
	n= 2	Range	24-27	7.2-8.5	0.1-4.8	42.3-54.3

n= no of sampling per month sd = standard deviation

Table 2: Physico-chemical characteristics of Asoro stream, Ilesa (continued).

Year	Month	Mean/std dev /range	Measured parameters/ FEPA STD Turbidity (NTU) 25	TDS (mg/l) 500	EC (µS/cm) 1000	Colour (pt-Co)
2016	**Nov.**	Mean+sd	144.8±97.9	265.1±93.8	284.2±213.9	320.1±180.5
	n = 2	Range	54.2-537.6	32-634	48-629	148-694
	Dec.	mean+sd	136.8±86.5	271.1±91.62	300.6±154.4	386.2±264.7
	n= 2	Range	49.87-436.2	34-569	46-612	129-1002
2017	**Jan.**	Mean+sd	135.5±81.9	553.2±114.2	429.23±157	810.27±636.1
	n= 2	Range	56.45-344.50	19-1403	31-1307	19-1974
	Feb.	mean+sd	147.9±98.7	641.1±372.69	694.07±362.34	287.4±238.16
	n= 2	Range	64.7-435.4	101-1501	52-1434	18.9-1032
	Mar.	mean+sd	146.8±90.5	685.8±215.98	666.9±431.43	472.99±469.8
	n= 2	Range	54.4-313.21	129-1811	109-1838	74-1953
	Apr.	mean+sd	152.44±89.6	664.9±251.8	670.8±411.62	786.6.7±632.3
	n = 3	Range	57.77-332.31	98-1665	90-1664	22.5-2614
	May	mean+sd	142.9±75.8	484.67±325.9	477.7±318.99	625±334.7
	n= 2	Range	54.32-318.11	97-1192	74-1193	145-1315
	Jun	mean+sd	161.3±100.8	435.6±310.18	432.17±307.35	518.5±269.7
	n= 2					
		Range	46.3-321.33	31-981	51-1120	177-1021
	Jul	mean+sd	160.4±99.3	343.1±264.7	415.07±245.31	624.16±343.65
	n = 3	Range	58.21-367.9	32-1105	40-988	124-1031
	Aug.	mean+sd	158.9±90.7	373.3±264.84	376.9±255.1	583.1±292.7
	n =2	Range	57.71-358.06	65-929	69-918	102-1211
	Sept.	mean+sd	162.9±88.5	419.56±269.18	424.2±247.70	700.4±325.9
	n= 3	Range	50.0-330.04	34-1120	46-885	114-1802
	Oct.	mean+sd	172.6±99.1	403.3±226.1	381.1±265.6	691.97±220.8
	n= 2	Range	45.46-339.05	31-980	30-1030	460-1223

Table 3: Hydrographic Characteristics of Asoro stream, Ilesa

Year	Months	Mean/std dev /range	Vel. (m/s)	Width (m)	Depth (m)	Q(m^3/s)	k_2 (day^{-1})
2016	**Nov.**	Mean+sd	0.34±0.03	3.27±0.03	0.26±0.10	0.25±0.13	19.61±5.49
	n = 2	Range	0.30-0.39	2.0-5.1	0.1-0.47	0.07-0.49	8.63-98.25
	Dec.	mean+sd	0.33±0.02	3.34±0.78	0.26±0.10	0.25±0.11	19.07±3.69
	n= 2	Range	0.30-0.37	2.2-5.2	0.1-0.46	0.08-0.43	6.38-93.21
2017	**Jan.**	mean+sd	0.37±0.05	3.46±0.91	0.26±0.11	0.28±0.14	20.15±7.49
	n= 2	Range	0.31-0,44	2.0-5.2	0.1-5.2	0.09-0.54	7.92-123.18
	Feb.	mean+sd	0.37±6.69	3.38±0.69	0.27±0.11	0.28±0.14	20.14±7.49
	n= 2	Range	0.31-0,46	0.1-0.46	0.09-0.55	0.09-0.55	9.38-114.99
	Mar.	mean+sd	0.34±0.04	3.18±0.0.7	0.26±0.10	0.25±0.12	19.59±5.98
	n= 2	Range	0.31-0.43	1.8-5.0	0.1-0.46	0.1-0.47	6.83-91.03
	Apr.	mean+sd	0.35±0.05	2.92±0.89	0.26±0.10	0.22±0.10	23.14±7.13
	n = 3	Range	0.30-0.44	1.8-3.9	0.1-0.46	0.08-0.47	7.43-98.76
	May	mean+sd	0.37±0.05	055±0.82	0.26±0.10	0.29±0.13	21.88±7.35
	n= 2	Range	0.32-0.48	2.0-5.4	0.1-0.46	0.15-0.52	7.7-137.22
	Jun	mean+sd	0.40±0.03	3.76±0.77	0.26±1.10	0.85±0.49	22.39±4.99
	n= 2	Range	0.36-0.46	2.6-5.6	0.1-0.46	0.13-0.62	8.34-120.46
	Jul	mean+sd	0.42±0.03	3.82±0.78	0.26±0.10	0.35±0.15	23.4±6.75
	n = 3	Range	0.38-0.48	2.6-5.6	0.1-0.46	0.14-0.67	8.7-120.5
	Aug.	mean+sd	0.43±0.02	4.05±0.83	0.26±0.12	0.37±0.16	22.56±4.87
	n =2	Range	0.40-0.47	2.6-5.8	0.1=0.4	0.15-0.07	8.08-74.75
	Sept.	mean+sd	0.44±0.04	4.13±10	0.26±0.10	0.38±0.17	23.32±6.45
	n= 3	Range	0.38-0.52	2.8-5.2	0.1-0.46	0.12-0.67	8.5-121.3
	Oct.	mean+sd	0.44±0.03	4.20±0.77	0.26±0.10	0.40±0.16	22.67±6.87
	n= 2	Range	0.39-0.51	3.0-5.0	0.1-0.46	0.14-0.73	8.56-124.1

Following the non-linear regression analysis, the statistics on the accuracy of the model (Eq. 1.3) are mean absolute error (MAE) = 0.5722, root mean square error (RMSE) = 0.8013 and coefficient of determination R^2 = 0.9498. The model was subsequently verified by comparing its performance with the model proposed by Agunwamba *et al.* (2007). The performance check was done by using Agunwamba's model to predict the present experimental data. It was clear that the model was unable to predict the DO for Asoro stream under the present study as shown in Figure 2. The statistics on the accuracy of the model and validation is presented in Table 4.

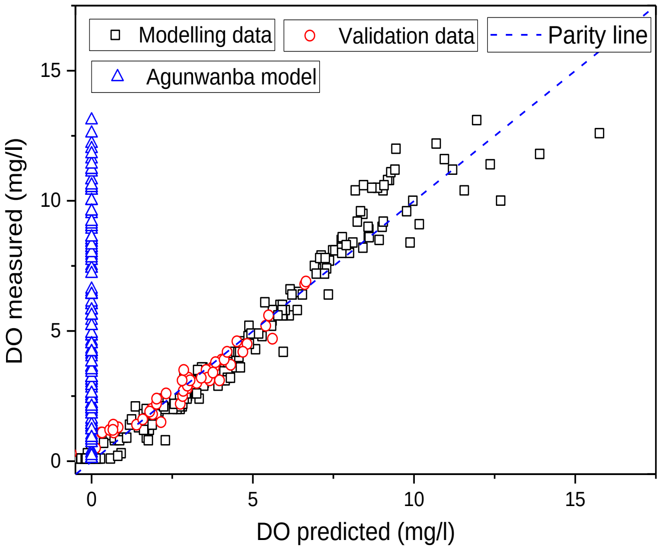


Figure 2: Comparison of Asoro Modelling data and its validation

The performance of equation 1.3, here after referred to as Asoro DO model after the name of the stream. It was tested and compared with other well-known selected models that were developed in the past from different parts of the world.

The importance of k_2 models in DO prediction is their use within the modified Streeter-Phelps equation which is defined by Eq. (1.4) (Longe and Omole, 2008; Omole, 2011).

$$D=\frac{L_a}{f-1}10^{-k_2 t}\left\{1-10^{[-(f-1)k_2 t]}\left[1-(f-1)\frac{D_a}{L_a}\right]\right\}$$

(Agunwamba *et al*, 2007) (1.4)

The independent parameters in Eq. 1.4 were supplied from the measured data from the Asoro stream. Therefore; this (Eq. 1.4) model was used to predict the DO along the Asoro stream based on the present experimental data. The result of the predictions from Eq. 1.4 (modified Streeter-Phelps) as shown in Figure 2 and 3 showed that the modified Streeter-Phelps equation under predicted the present experiment.

Figure 3 showed significant drops at 1000 metres and 2,500 metres away from the discharged point along the stream for both measured and predicted DO (2.35 mg/l to 1.5 mg/l and 2.6 to 2.31 mg/l respectively) which may be due to high concentration of organic pollution, while the value s in reduction at 2,500 metres away from the point of discharge were the same 3.5 mg/l. But such similar drops in dissolved oxygen concentration only occurred at 1500 metres away from the discharge point for both measured and predicted DO along the sampling stations for the month of october (Figure 3). The pattern of DO variations of both measured and the predicted DO followed normal self-purification trend of a stream (Von-Sperling and Verejken, (2014).

Table 4: Statistical goodness of fit

Parameter	Model fit	Validation
Number of observation	194	49
Mean Absolute Error (MAE)	0.572214	0.338788
Root mean square error (RMSE)	0.801262	0.426232
Coefficient of determination (R^2)	0.9498	0.9151

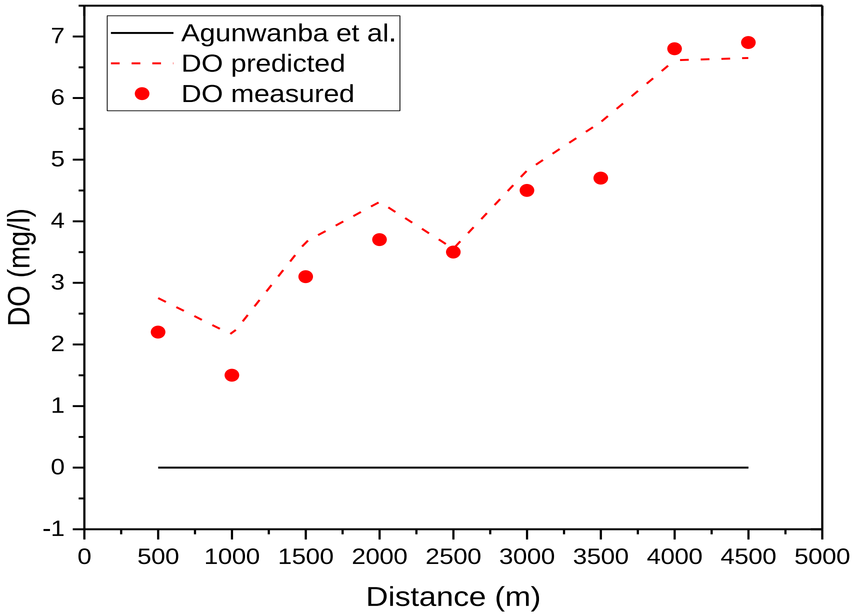


Figure 3: DO discrepancy plot against sampling stations using the present model (Eq.1.3) for September data.

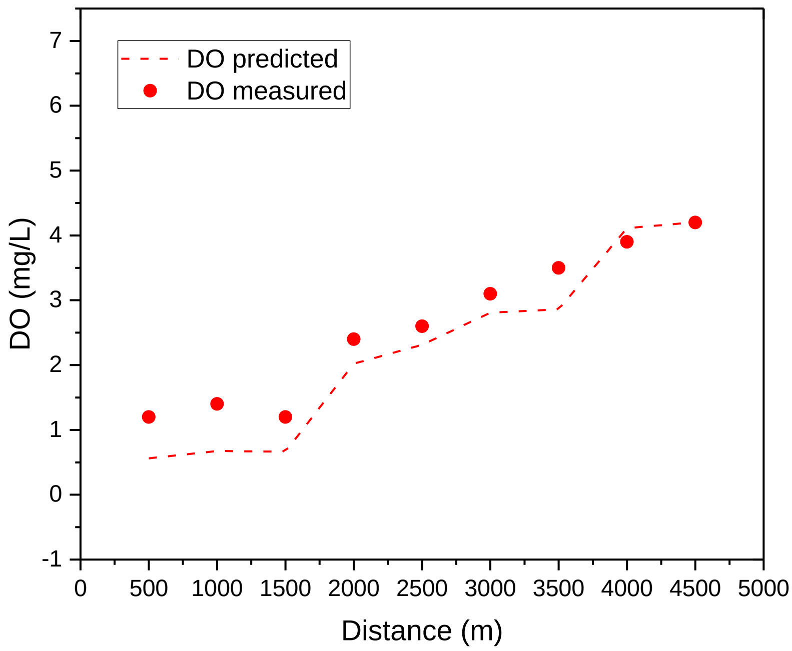


Figure 4: DO discrepancy plot against sampling stations using the present model (Eq.1.3) for October data.

CONCLUSION

A mathematical model for in predicting DO concentration was developed and the validation of model was carried out. Its relative predictive capacity was also established by comparing it with modified Streeter models. The results reveal an insignificant disparity between the statistical performance of the models and their predictive capacity. This study contributes towards an improved understanding of pollution undercurrents in the Asoro stream and draws attention to latent environmental problems that may occur.

Also, it warns about the problems caused by effluent discharges into the Asoro stream, since from this study it was possible to support reliable models and improve the management of water resources.

REFERENCES

Agunwamba J.C., C.N. Maduka and A.M. Ofosaren, (2007), Analysis of Pollution Status of Amadi Creek and its Management. *Journal of Water Supply: Research and Technology*-AQUA (55) 6. pp 427-435

Chapra, S.C. (2014). "Modeling impact of storage zones on stream dissolved oxygen." J. *Envir. Eng*., 125(5), 415-419.

Churchill, M.A., H.L. Elmore and R.A. Buckingham (1962**).** The prediction of stream re-aeration rates. *Journal of Sanitary Eng. Division,* ASCE 88(SA4),12 (4) pp 56 – 71.

Demars, S. and Manson, J.H. (2013), Water Quality and flow Simulation in River Kali, India, *Journal of the Institution of Engineers* (India), Part EN, Environmental Engineering Division. Vol. 85, no. 2, pp. 54-61.

Duan, Z., James, M., Tang, Y. (2010). "Modeling Oxygen Mass Transfer Rate through the Airwater Surface inStratified Flows. *World Environmental and Water Resources Congress,* ASCE, Providence, RI, pp 371-408.

Gualtieri, C., Gualtieri, P., and Doria, G.P. (2002). "Dimensional analysis of reaeration rate in streams." *Journal of Environmental Engineering*, 128(1), 12-18.

Godfrey, G.O. (2000). Hybrid Self –Organising Modelling Systems. Knowledge Management and Mining Inc. Richmond Hill, Ontario, Canada, pp123- 304.

Jeje. J.O., Ofoizie. I.E. and Achudume. A.C. (2009). Effects of Industrial Effluents from A BreweryIndustry on the Underground Water Quality of Ilesa in Osun State Nigeria, *Proceedings of the 2nd Annual Conference of the Institute of Ecology and Environmental Studies*. 2 pp 168-179.

Longe, E.O. and Omole, D.O. (2008). An assessment of the impact of abattoir effluents on River Illo, Ota, Nigeria. *Journal Environmental Science Technology*, 1(2) pp 56-54.

Omole, D.O. (2011) Re-aeration Coefficient Modeling: A Case Study of River Atuwara in Nigeria Research Journal of Applied Sciences, *Engineering and Technology* McGraw Hill Companies Inc., USA, 4(10) pp 1237-1243.

Streeter, H.W. and Phelps, E.B. (1925), A Study of the Pollution and Natural Purification of the Ohio River. *Public Health Bulletin* No 146, Public Health Service, Washington DC, 1925.

Raymond, P. A.; Zappa, C. J.; Butman, D.; Bott, T. L, and Potter, J. (2012) Scaling the gas transfer velocity and hydraulic geometry in streams and small rivers. Limnology and Oceanography. *Fluids and Environments*, 2 pp. 41-53.

Runkel R.Y. (2013), Evaluation of Relationships of Reaeration rate Coefficient for Modelling Dissolved Oxygen in a River with extreme flow Variations in Pakistan. Hydrological Processes, 27 pp 949-963.

Vagnetti, R. R.; Wool, T. A. and Martin, J. L. (2003). The water quality analysis simulation programme, WASP5: part A: model documentation. *United States Environmental Protection Agency*, Athens, Georgia. 202.91, No. 5, pp. 891–903

Von-Sperling, F.B. and Verejken, M. (2014) Reduction of COD in Wastewater from an organized tannery industrial region by Electro-Fenton process, *Journal of Hazardous Materials* Vol. 143, Issue 1 – 2, Pp 33 – 40.

MODELLING OF FLOOD PARAMETERS FOR ERITI WASTERSHED IN LOWER OGUN RIVER BASIN, SOUTH-WESTERN NIGERIA

ADEBAYO M. G.[1*], AWOKOLA O. S.[2], ADEKUNLE A. A[3].

Department of Civil Engineering, Federal University of Agriculture, Abeokuta

[1]gbolaadebayo@yahoo.com
[2]osawokola@yahoo.co.uk
[3]maykunle@yahoo.co.uk

*Corresponding Author: gbolaadebayo@yahoo.com

Received: 1 October 2018 *Accepted: 24 December 2018*

ABSTRACT: Flood is one of the natural disasters that had hit mankind severally irrespective of geographical locations and the disasters caused had been monumental. Despite the high risks of flooding, many settlements remain located near potential flood sources due to the socio-economic benefits offered by such locations. Therefore, this study modelled flood parameters for Eriti Watershed in Lower Ogun River Basin, South-Western Nigeria using physiographic [Basin Area, Watershed Average Slope, River Average Slope, Forest Cover, Runoff Curve Number and Stream Length] and climatic [Mean Average Rainfall for 10 years] characteristics of the study area. Geographical information system was used to collect the terrain data (longitudes, latitudes and elevations above mean sea level) while rainfall data were obtained from Ogun-Oshun River Basin Development Authority, Abeokuta. The terrain and climatic data were fed into ArcMap software which enabled production of boundary, topographical, drainage, land cover and soil maps as well as Digital Elevation Model of Eriti Watershed. The values of the various physiographic parameters were computed from the maps. These values and rainfall data were utilised to model Mean Annual Flood and Flood Quantiles using multiple regression analysis. The accuracy of the models was measured by their Multiple Determination Coefficients (MDC), Standard Error of Prediction (SEP) and Variance of Prediction (VP). The results obtained for MDC, SEP and VP were 98.9% accuracy, 2% error and 0.032 variance respectively. The two models developed for Eriti Watershed are therefore adoptable for designs of hydrologic engineering structures in lower Ogun river basin and other hydrologically-similar basins.

Keywords: flood, watershed, model, multiple regression.

INTRODUCTION

Flood is one of the natural disasters that had hit mankind severally irrespective of the geographical locations and the disasters caused had been monumental. The amount of losses and hardships that comes along with it is sometimes unbearable for individuals, communities as well as Governments to cope. Floods account for approximately one third of global natural hazards and more people are adversely affected by flooding than any other geophysical phenomenon. On the average, 20,000 people lose their lives due to flooding each year and it affects 75 million people globally, most of whom became homeless Smith, et al, (2004). It is interesting to note that, despite the high risks of flooding, many settlements still remain located near potential flood sources like rivers, seas and oceans due to the socio-economic benefits offered by such locations. Therefore, it seems mankind does not have much choice than to accept to live with floods since it cannot be totally eliminated.

Usually, design of any water resources project consists of the following three consequent steps: Hydrologic design, hydraulic design and structural design. Among these steps, hydrologic design has very important role because any mistake made at this stage will result in failure of the structure no matter how correct the other steps are carried out (Chanson, 2004). Therefore, hydrologic models are very reliable and regarded as standard tools for predicting fluvial inundation. In addition, the science of inundation modelling has transformed rapidly in the past few years from a 'data-poor' to a 'data-rich' discipline because flood models and data are being integrated or linked into states of the art technologies such as remote sensing and Geographic Information System (GIS) for time series analysis and visualisation (Barati, 2011).

In Nigeria, most of the rivers are ungauged while drainage basins have scanty streamflow data too. In fact, out of the eleven drainage basins in Nigeria, only six have streamflow data extending ten years and Eriti Watershed (the study area) in the Lower Ogun River Basin, South-Western Nigeria is no exception (Ogunnubi, 2011). This is why sizing of minor and major hydraulic structures such as culverts, bridges and dams at sites with little flood information is a common problem faced by Practicing Engineers in Nigeria. The main challenge of Eriti Watershed is seasonal inundation, that is, overflow of the banks of River Ogun and it's tributaries at the peak of raining season resulting in excessive flooding of a sizable part of the lands on both sides of the rivers. The flood had caused much havoc resulting in loss of live, property and agricultural produce. Therefore, this paper presents a method by which the flood regime in Eriti Watershed which is in Lower Ogun River Basin was modelled based on knowledge of the relationships between its flood statistics and the basin/climatic characteristics. Specifically, Eriti Watershed which is the study area lies within Obafemi-Owode and Ewekoro Local Government areas of Ogun State, South-Western Nigeria (Fig. 1). It is geographically located within Latitudes 6^o 50'N and 7^o 50'N and Longitudes 3^o 18'E and 3^o 32'E. The watershed covers an area of about 197.5 km^2.

The study area is generally low-lying with traces of undulating landscapes. There are also micro scale rugged areas with gentle slopes and gorges Sakirudeen and Raji (2014). Ogun River traverses the study area while there are also traces of connecting streams, wetlands, coastal marshes and hydrophytes. The drainage pattern is dendritic in morphology. Two seasons are distinguishable in the study area, dry season from November to March and wet season between April and October. Overall, mean annual rainfall ranges from 900 mm to 1,200 mm while the temperature ranges between 22^{o}C and 32^{o}C (Sakirudeen and Raji, 2014).

The two major vegetation zones that could be identified on the watershed are the high savannah vegetation in the hinterlands and central part as well as swamp/mangrove/riparian forest that cover the floodplains towards River Ogun. The land use of the study area revolves round its abundant water resources, rich alluvial soil and thick riparian forests. Therefore, the inhabitants of the area have taken to farming, fishing, logging and sand dredging (Adebayo, 2010).

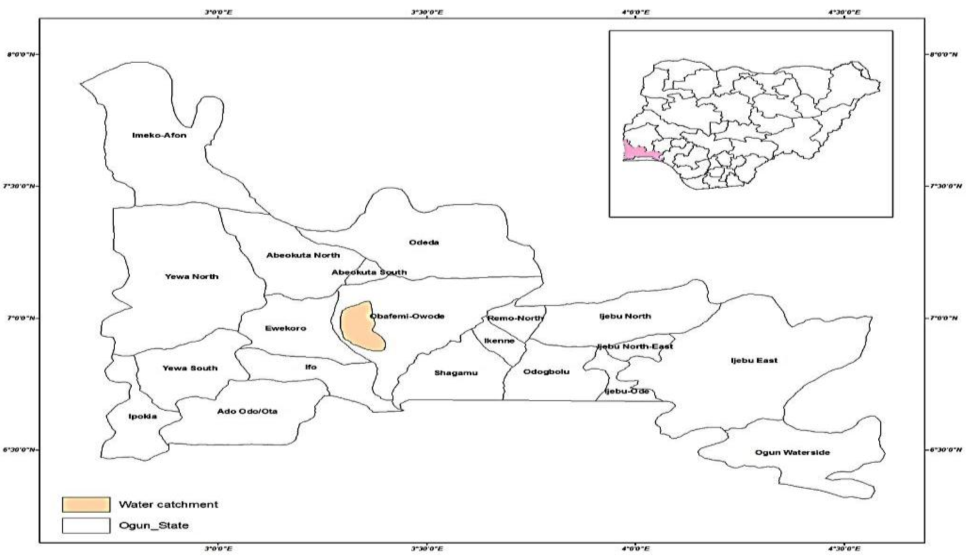


Figure1: Map of Ogun State showing the study area

The justification for this research work is hinged on finding lasting solutions to a common problem being encountered in many aspects of water resources engineering while estimating various critical parameters of extreme hydrological events such as design floods for a site. A reliable estimation of such extreme flood events is of great significance in minimizing damages by facilitating proper planning, accurate design and reliable economic appraisal of civil engineering structures such as dams, bridges, spillways, culverts, channels, barrages, embankments and other flood protection works.

Some research works related to flood modelling of Mean Annual Flood (MAF) of River Ogun Drainage Basin, South-Western, Nigeria was the subject of Awokola (2003) study. The study covered both the Upper-Central and the Lower Ogun River Basins. The study applied regression analysis to develop a predictive model for the Mean Annual Flood (MAF) using catchment characteristics of Ogun Drainage Basin. The result of the study shows that AREA gives a better correlation with a value of 94%. This means that, AREA contributed the larger proportion of the variance for the MAF in the derived regression model with a coefficient of determination of 94%. In this regard, AREA has been proved to be an important independent variable to be included in development of regression model to predict MAF. Eventually, a logarithmic equation was derived for Ogun Basin which is of the form:

$$MAF = cA^{m.} \quad (1)$$

The author derived c and m as 0.083 and 0.96 respectively.

Hence,

$$MAF = 0.038A^{0.96} \quad (2)$$

The equation was said to compare very well to those derived for Southern Africa. Also, the estimation of Mean Annual Flood (MAF) of Ogun Drainage Basin with geometric characteristic had been conducted by Awokola (2005) which gave rise to a linear equation presented as follows:

$$MAF = 0.0278A + 0.4206 \quad (3)$$

The author was of the opinion that both equations can be used to predict the Mean Annual Flood (MAF) for ungauged catchments in Ogun Drainage Basin. Incidentally, Eriti Watershed is within the Lower Ogun River Basins which means that, the derived equations are applicable. However, this study aimed at improving those equations by considering other terrain characteristics as well as climatic factors

Obot (2004) worked on simulation models for catchment yields using deterministic approach of Enyong Creek and Ikpa River Basin, South-Eastern Nigeria. The study did not only identified some multiple factors causing high flood levels but provided efficient and reliable models for planning and designing flood control, drainage and irrigation structures. One of the objectives of the study was to determine the high flood levels in the floodplains of Enyong creek and Ikpa River which constitute a constraint to productive agricultural development. Eventually, the multiple factors causing high flood level were identified as high rainfall amount, monthly runoff distribution, antecedent baseflow level and differential surface water gradients among others. Obot (2004) was able to conceptualize a model depicting the physical process of rainfall in Ikpa River and Enyong creek catchments which was calibrated, tested and simulated. This catchment is similar to Eriti Watershed in a number of ways.

MATERIALS AND METHODS

Types and Sources of Data

The types of data collected include rainfall as well as River Ogun water levels and discharges for a period of ten years (2005 - 2014). These data were collected from Ogun-Oshun River Basin Development Authority, Abeokuta. Also, the various physiographic parameters of Eriti watershed were collected which include the area and slope of the watershed, slope and length of the main river traversing the basin as well as the percentage of forest cover as defined in Table 1.

Table 1: Physiographic Parameters Collected for Regression Analysis

Parameters	Description/Effect
Area	Catchment area of the watershed which is the most significant
Slope 1	Watershed average slope which decides the velocity and volume of flood
Slope 2	Stream average slope which contributes to flood velocity and volume
Stream	The length of the longest stream/river
Forest	Percentage of forest covers which can reduce flood volume significantly
CN	Runoff curve Number which is a measure of land cover and soil characteristics. The higher the CN the higher the flood.
Rainfall	Annual average cumulative rainfall. This affects flood volume

Methods of Data Collection

The methods of data collection employed included the followings

Remote Sensing and Global Positioning System Techniques

The terrain data of the study area were collected using Geographical Information System (GIS) and remote sensing techniques while supplementary information were obtained from reconnaissance survey of the area carried out. These were processed by the aid of ArcView software to create a Triangulated Irregular Network (TIN). The TIN was then used to produce the Digital Elevation Model (DEM) and topographic map (with the spot heights embedded appropriately) of the study area. The DEM and the topographic map parameters were used as inputs into ArcInfo software which were used to calculate the output slope grid as a percentage slope or degree of slope (tagged Slope 1) and the channel slope (tagged Slope 2 in this study) using the "85-10" slope factor method respectively. The slope 2 is between the 10% and 85% points along the longest flow path from the basin outlet and the divide.

Runoff Curve Numbers (RCN) for this study were obtained by using the Soil Conservation Service (SCS) Runoff Curve Number Method developed by the Soil Conservation Service of the United States which simply related land uses/covers grids and soil type grids of the study area imported into ArcInfo environment for processing. In other words, the SCS method uses a combination of soil conditions and land cover to assign runoff factors known as runoff curve numbers. The four types of soil within the study were also classified as Loam (SOIL A), Sandy-Loam (SOIL B), Clay-Loam (SOIL C) and Clay (SOIL D). The higher the CN, the higher the runoff potential.

Multiple Regression Analysis

Multiple regression analysis using Least Squares Technique of was employed to model Mean Annual Flood (MAF) and T-Year Return Period Flood otherwise known as Flood Quantiles (Q_T) for the study area in relation to physiographic and climatic parameters of the area. The models took linear forms as shown in equations 4, 5 and 6 below:

$$y = \boldsymbol{\beta}_o + \boldsymbol{\beta}_1 x_1 + \boldsymbol{\beta}_j x_j + \dots + \boldsymbol{\beta}_k x_k \tag{3}$$

Where ; the x's are the independent variables

The y is the dependent variable

The subscript j represents the observation (row) number

The $\boldsymbol{\beta}$'s are the unknown regression coefficients.

The equation 1 above can be rewritten for flood modelling purpose as below:

$$MAF = \boldsymbol{\beta}_o + \boldsymbol{\beta}_1 \text{ Area} + \boldsymbol{\beta}_2 \text{ Slope1} + \boldsymbol{\beta}_3 \text{ Slope2} + \boldsymbol{\beta}_4\text{Forest} + \boldsymbol{\beta}_5\text{CN} + \boldsymbol{\beta}_6\text{Stream} + \boldsymbol{\beta}_7\text{Rainfall} \quad (4)$$

$$Q_T = \boldsymbol{\beta}_o + \boldsymbol{\beta}_1 \text{ Area} + \boldsymbol{\beta}_2 \text{ Slope1} + \boldsymbol{\beta}_3 \text{ Slope2} + \boldsymbol{\beta}_4\text{Forest} + \boldsymbol{\beta}_5\text{CN} + \boldsymbol{\beta}_6\text{Stream} + \boldsymbol{\beta}_7\text{Rainfall}_T \quad (.5)$$

There are several computer packages that can be used for computation of regression analysis with a view to determining the unknown regression intercepts and coefficients in equation 2 which include Microsoft Excel and Minitab software among others. Considering the working load of computing the aforementioned variables, Minitab 17 Software was used in this study to perform the multiple regression analysis, so a detailed algorithm of deriving regression equations would not be a concern.

Methods of Evaluation of Accuracy of the Models

The suitability and applicability of the prediction equations are evaluated based upon statistical parameters given in the model output by Minitab software. Some of these parameters include:

Multiple Determination Coefficient (MDC) and Adjusted MDC

This is the most commonly used measure of the goodness-of-fit of a linear model. Typically the higher the MCD or adjusted MCD, the more confidence one can have in the equation. It has a range of values between 0 and 1.

Standard Error of Prediction (SEP)

The coefficient of determination alone is not a sufficient measure to judge the goodness-of-fit of a multiple linear regression model, since its value increases as more independent variables are added. For two models with the same R^2, the one having the smaller SEP is preferable.

Variance of Prediction (VP): The smaller the VP the better. It should be less than 0.5 for good predictive models.

Outliers: They are identified from the MINITAB screen output. These are where data items have a standardized residual value greater than 3.0.

RESULTS AND DISCUSSIONS

Maps and Physiographic Parameters for Eriti Watershed

There are four different maps of the study area produced and digitized with the aid of GIS techniques and ArcMap software namely: Drainage Map (Figure 2), Topographical Map (Figure 3), Land cover Map (Figure 4) and Digital Elevation Model (Figure 5). The various maps produced were used for estimation of the values of the various physiographic parameters for Eriti watersheds namely the Basin Area (BA), Watershed Average Slope (WAS), River Average Slope (RAS), Forest Cover (FC), Runoff Curve Number (RCN) and Stream Length (SL) for the 3 sub-watersheds as recorded in Table 3.1. The Mean Annual Rainfall (MAR_{10}) for 10 years was estimated from the rainfall data obtained from Ogun Oshun River Basin Development Authority.

Table 2: Physiographic Parameters obtained for the Sub-Watersheds

Watershed	BA (km^2)	WAS (%)	RAS (%)	FC (%)	RCN	SL (km)	MAR_{10} (mm)	MAR_{100} (mm)
Sub-watershed 1	73.9	4.43	2.50	33.9	69.0	7.2	129.0	143.7
Sub-watershed 2	56.5	2.56	1.98	45.2	57.3	8.6	138.0	156.4
Sub-watershed 3	67.1	3.87	2.78	71.1	88.2	6.4	117.0	159.5

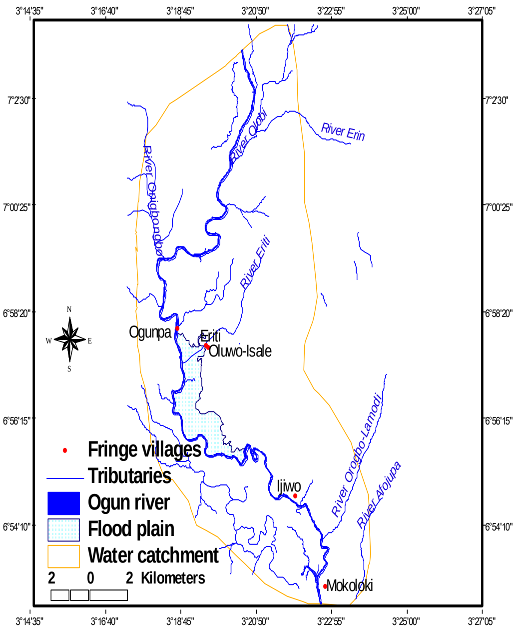


Figure 2: Drainage Map of Eriti Watershed

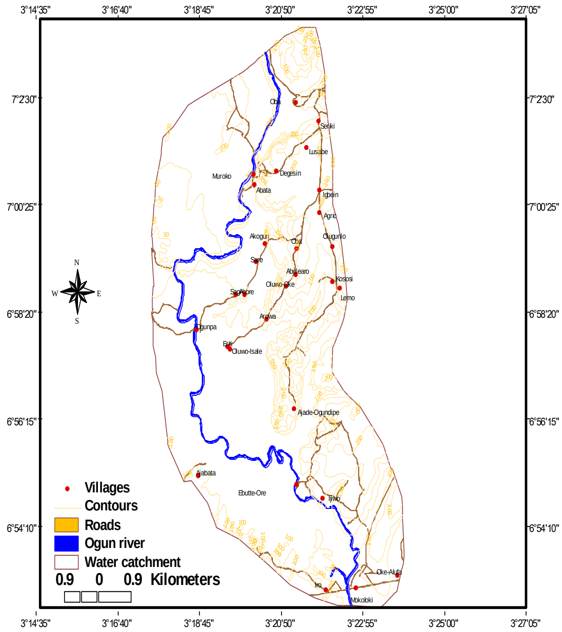


Figure 3: Topographical Map of Eriti Watershed

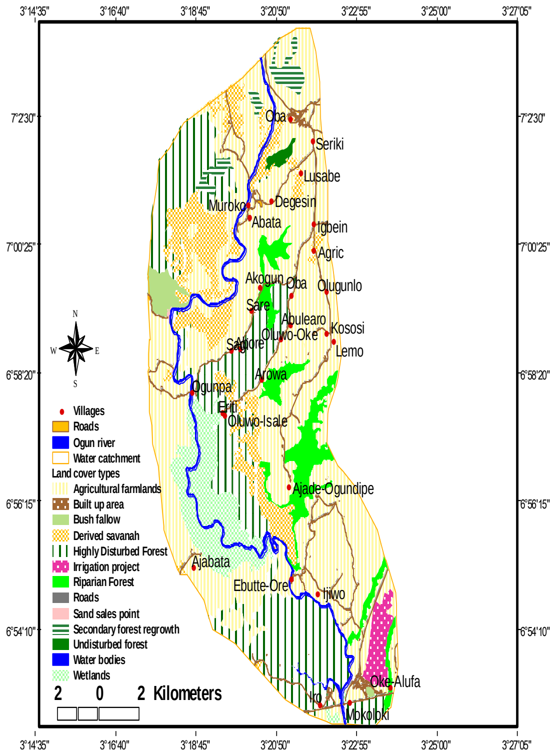


Figure 4: Land Cover Map of Eriti Watershed

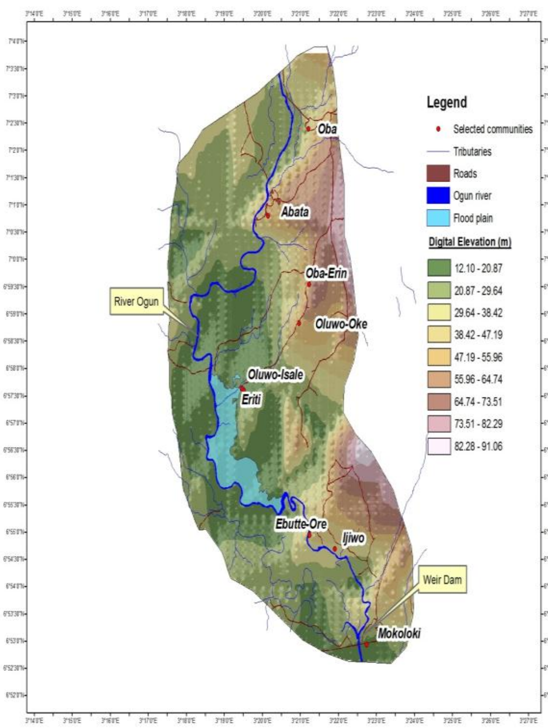


Figure 5: Digital Elevation Model of Eriti Watershed

Development of Predictive Models 1 and 2 for Eriti Watershed

The results obtained when the data in Table 2 were inputted into Minitab 17 software and linear regression equations 2 and 3 are shown in Tables 3 and 4 which were extracted from Minitab printout worksheets. Thus

Mean Annual Flood (MAF) was modelled and tagged model 1 while that of Flood Quantile (Q_T) is tagged model 2 as shown below:

$$MAF = -78.40 +0.03BA -5.61WAS + 1.75RAS -1.04 FC - 1.95RCN + 1.65SL + 0.65MAR_{10}$$
Model 1

$$Q_{100} = 171.12 + +0.74BA + 0.89WAS + 4.12RAS + 3.64 FC + 5.12RCN + 1.34SL - 4.52MAR_{100} .$$
Model 2

Table 3: Minitab Printout for Model 1 Extracted from Minitab Printout

Predictor	Coef	St. Dev	t	P
Constant	-78.44	24.76	-3.72	0.253
BA	0.03071	0.01544	-1.76	0.215
WAS	-6.6060	0.6537	-13.67	0.056
RAS	1.7455	0.5130	2.06	0.281
FC	-1.0377	0.1670	-10.25	0.071
RCN	-1.9456	0.3572	-4.12	0.143
SL	1.6444	0.2543	5.11	0.153
MAR	0.6544	0.0655	11.17	0.072

S = 1.106 MDC = 98.9% MDC (Adjusted) = 98.6% SEP = 5% VP = 0.032

Table 4: Minitab Printout for Model 2 Extracted from Minitab Printout

Predictor	Coef	St. Dev	t	P
Constant	171.12	26.16	-3.62	0.243
BA	0.7641	0.01734	-1.66	0.315
WAS	0.8770	0.7537	-12.67	0.046
RAS	4.1166	0.6130	2.05	0.261
FC	3.6493	0.1670	-11.25	0.051
RCN	5.1186	0.3842	-4.43	0.123
SL	1.3466	0.2663	4.89	0.143
MAR	- 4.5167	0.0565	10.87	0.083

S = 1.107 MDC = 98.8% MDC (Adjusted) = 97.9% SEP = 3% VP = 0.067

The accuracy of the 2 models was measured by their Multiple Determination Coefficients (MDC), Standard Error of Prediction (SEP) and Variance of Prediction (VP). The results obtained for MDC, SEP and VP were 98.9% accuracy, 2% error and 0.032 variance respectively. Since the results were within the acceptable limits, the two models developed for Eriti Watershed are therefore accurate, strong and reliable. Most importantly, the predictive models can be used to estimate the annual mean flood and flood quartiles of an ungauged watershed once the physiographic and climatic parameters of the basin in question had been obtained. Therefore, the two models are adoptable for designs of hydrologic engineering structures in lower Ogun river basin and other hydrologically-similar basins. Also, the models shall therefore be useful in developing countries where most of the rivers and basins have scanty or nil hydrological data. A useful recommendation for future research is that some other acute hydrologic parameters such as flood depth, volume and mean annual peak flood could be modelled.

CONCLUSION

In conclusion, the two predictive models are useful for estimation of Annual Mean Flood (MAF) and flood quartiles (QT) of an ungauged watershed once the physiographic and climatic parameters of the basin in question had been obtained. Also, values of MAF and QT are adoptable for designs of hydrologic engineering structures in lower Ogun river basin and other hydrologically-similar basins. Therefore, the models shall be useful in developing countries where most of the rivers and basins have scanty or nil hydrological data.

REFERENCES

Adebayo, M. G. (2010), ‘‘Technical Report on Intervention Projects on Eriti Watershed presented to the World Bank Country Office, Abuja’’, No 4, pp. 4 - 25.

Awokola, O. S. (2003), Prediction of Mean Annual Flood (MAF) for Ogun Drainage Basin, South-Western Nigeria. *Global journal of applied sciences* (9): 13 - 18.

Awokola, O. S. (2005), Estimation of Mean Annual Flood of Ogun Drainage Basin with Geometric characteristics. *Nigeria Journal of Science* (39): 153 -161.

Barati, R. (2011), ‘‘Parameter estimation of nonlinear Muskingum models using Nelder-Mead’’ *Journal of Hydrology (*89): 79 -100.

Chanson, H. (2004), ‘‘The Hydraulics of open channel flow - An Introduction’’, Second Ed. Elsevier publications, pp. 53-65

Obot, E. O. (2004), Simulation models for catchment yields using deterministic approach of Enyong Creek and Ikpa River Basin, South-Eastern Nigeria, A PhD thesis submitted to the Department of Agricultural Engineering, University of Ibadan. pp 23 – 44.

Ogunnubi, A. A. (2011), ‘‘Progress report on Ogunpa channelization project submitted to Ogun-Oshun River Basin Development Authority’’, pp. 3-8.

Sakirudeen Odunnuga, Saheed A. Raji, (2014), ‘‘Flood frequency analysis and inundation mapping of Lower Ogun River Basin’’, *Journal of water resources and hydraulic Engineering. (3): 48 - 59.*

Smith, Michael B., Dong-Jun Seo, Victor I. Koren, Seann M. Reed, Ziya Zhang, Qingyun, (2004), *‘‘Character of Drainage-Basins.” Transactions of the American Geophysical Union, (13): 332 - 339.*

AN INTEGRATION OF STOCHASTIC MODELS AND GIS AS DECISION SUPPORT TOOL FOR REGIONAL FLOOD MANAGEMENT IN SOUTHWEST NIGERIA

AIYELOKUN O. O.[1]*, OYELAKIN J. F.[2], OJELABI S. A.[3], AGBEDE O. A[4].

Department of Civil Engineering, University of Ibadan, Ibadan, Nigeria
[1]aiyelokuntobi@gmail.com
[2]oyelakinjohn01@gmail.com
[3]ojelabiakin@gmail.com
[4]oluwoleagbede@yahoo.com

*Corresponding author: aiyelokuntobi@gmail.com

Received: 5 October 2018 *Accepted: 24 December 2018*

ABSTRACT: Models are efficient decision support tools in mitigating climate induced hazards such as flood. This study assessed the adequacy of four probability distributions for regional flood management. A 30-year daily rainfall was selected for Ikeja, Abeokuta, Ibadan, Oshogbo and Akure meteorological stations; and fitted into Extreme Value Type-1 (EV1), Extreme Value Type-2 (EV2), Gamma and Log-Normal distributions. The trend of the series was tested using Mann Kendall test, while Goodness of Fit (GoF) statistics were employed to justify models' adequacy. Diagnostic test, involving D-index was used to select the most suitable distribution for estimating design storms for different return periods across Southwest Nigeria. The spatial patterns of estimated extreme rainfall for various return periods were further mapped using Inverse Distance Weighted interpolation scheme in GIS environment. The study revealed that EV1 was found to better suit Abeokuta, Ibadan, and Oshogbo; EV2 was better suited for Akure while Log-Normal distribution was better suited for Ikeja. It was further revealed that areas in the south-eastern part of the region are more susceptible to flooding than the north-western region. These results would serve as decision support for tackling the effects of climate change in Southwest Nigeria.

Keywords: climate change, flooding, stochastic model, interpolation scheme

INTRODUCTION

A major problem faced in developing countries is the absence of information to tackle inherent climate change induced challenges (Aiyelokun, 2016). Flood is a body of water which rises to overflow land which is not normally submerged (Duru and Chibo, 2014). Flood results from a number of causes, the most important being climatological in nature (Okorie, 2010). Flooding has been observed globally as one of nature's damaging phenomena. It is one of the most serious environmental hazards (Duru and Chibo, 2014). The high volume of rain water during rainy season can result in severe damage to properties and force several people to evacuate an area thereby rendering some people homeless. Flood risk management aims to reduce damage to people and goods to acceptable levels (Loucks et al., 2008). Risk management strategies require both structural and non-structural measures and must be designed according to the type of flooding and the associated flood risk (Plate, 2002).

Engineers and hydrologists deal with instantaneous peak data when designing water management, irrigation and drainage systems for economic planning. Engineering designs for flood management involve the construction of minor and major hydraulic structures such as barrages, bridges, culverts, dams, spillways, road/railway bridges, urban drainage systems, flood plain zoning and flood protection projects. These constructions are designed and mechanically fit for managing and utilizing water resources to the best advantage using the records of past events (Agbede and Abiona, 2012). It is possible to estimate the frequency of a given magnitude of extreme event by using an empirical distribution function in principle, but in practice where too few data are available, the empirical distribution produced cannot be used to estimate the frequency of occurrence of events larger than the maximum records (Arnell, 2002). Therefore, an alternative is to fit the samples of data into a theoretical frequency distribution. Numerous works have been done using probability distributions such as normal (NOR), log-normal (LN2), exponential (EXP), Gamma (GAM), Pearson Type-3 (PR3), Log Pearson Type-3 (LP3), Extreme Value Type-1 (EV1) and Frechet (EV2) for flood frequency analysis (Aksoy, 2000; May, 2004; and Sharda and Das, 2005). Salami (2004) studied the NOR, LN2, square-root-normal and cube-root-normal frequency distributions of meteorological data for Texas. The results showed that the square-root-normal distribution is suitable for precipitation data. Lee (2005) expressed that the PR3 distribution is better suited for the rainfall distribution of Chia-Nan plain area. Bhakar et al. (2006) studied the frequency analysis of consecutive day’s maximum rainfall at Banswara, Rajasthan, India. Fang et al. (2007) proposed an approach based on the peak-over-threshold sampling method and a non-identical Poisson distribution to model the flood occurrence within each season. Chen et al. (2010) proposed the use of a copula function to jointly model the distributions of flood magnitude and date of occurrence. Allamano et al. (2011) analyzed the magnitude of under (or over-) estimation of design events in the presence of seasonality by using the peak-over-threshold approach. Bowers et al. (2012) presents a statistical procedure to partition river flow data and focuses on power transformation and log-normal distribution to describe the constructed seasonal river flows. Vivekanandan (2012) concluded that LN2 distribution was best for modeling flood data for Tapi at Burhanpur, Girna at Dapuri and Bori at Malkheda sites; and LP3 was the best for Purna at Lakhpuri. Vijayagopal et al. (2013) applied Gumbel and Frechet distributions for development of intensity-duration-frequency relationships for Mandla and Jabalpur regions. Vivekanandan (2014) asserted that EV1 distribution was better suited for estimation of Peak Flood Distribution (PFD) for Malakkara whereas LP3 for Neeleswaram.

Furthermore, Ahmed et al. (2015) compared five probability models for Johor River Basin by estimating the average recurrent interval (ARI) of flood event based on the distributions of annual peak flow. The study employed distribution models, namely Generalized Extreme Value (GEV), Lognormal, Pearson 5, Weibull and Gamma. The goodness fit test (GOF) of Kolmogorov-Smirnov (K-S) was used to evaluate and estimate the best-fitted distribution. The results reaffirm the current practice that GEV is still the best-fitted distribution model for fitting the annual peak flow data. On the other hand, gamma distribution showed the poorest result. Agbede and Aiyelokun (2016) established a stochastic model for reducing economic floods risk in Yewa sub-basin, by fitting maximum annual instantaneous discharge into four normal (NOR), log-normal (LN2), exponential (EXP), Gamma (GAM), Pearson Type-3 (PR3), Log Pearson Type-3 (LP3), Extreme Value Type-1 (EV1) and Frechet (EV2). Vivekanandan and Ramesh (2017) adopted series of annual maximum 1-day rainfall derived from daily rainfall data observed at Kasauli rain-gauge station for estimating of 1-day extreme rainfall fitted to Gumbel distribution and concluded that estimated PFD could be used for design of flood protection works for different tributaries of Sirsa river. Aiyelokun et al. (2017) evaluated the adequacy of various probability distribution models for efficient flood forecasting in Opeki River basin and revealed that Log Pearson Type III distribution is best fit for flood prediction. Vivekanandan (2018) conducted Extreme Value Analysis (EVA) of rainfall and temperature recorded at Mandla observatory by fitting them to Gumbel and Frechet distributions. The study concluded that Gumbel is better suited probability distribution for EVA of rainfall and temperature for the region under study. The afore analysis of review shows that different probability distributions were observed to fit adequately with rainfall and discharge data for different locations, implying that it is essential to test the adequacy of stochastic models based on locally recorded data at the inception of any flood management project.

Geographic Information System (GIS) is recognized as a robust tool for solving problems and managing spatial data in holistic manner for discussion support (Oke et al., 2013). The GIS technology incorporates common database functionality such as query and statistical analyses providing capabilities to analyze and simulate quantitative data, as a result, decision makers and researchers integrate GIS in policy formulation and better presentation of findings. The spatial interpolation models are powerful analytical tools for converting points to grid data and have been found to be very useful for predicting unknown values based on known value of a spatial variable. The present study seeks to enhance flood management in Southwest Nigeria by developing most suitable stochastic models for flood prediction based on 1-day extreme rainfall across the region. This involves fitting historical data of extreme rainfall to various probability distributions, evaluation of the performance of models and spatial prediction of regional extreme rainfall based on most suitable model; by integrating the IDW interpolation method in GIS environment in order to aid the understanding of spatial pattern of extreme rainfall in the study area.

DESCRIPTION OF THE STUDY AREA

Southwest Nigeria is located approximately between longitude 2.51667^0 and 6.0000^0 East and Latitude 6.3500^0 and 8.61667^0 N and consists of Lagos, Ogun, Oyo, Osun, Ondo and Ekiti states (Fig 1). The study area consists of a land area of about 77,818 Square Kilometers; the area is bounded in the East by Edo and Delta states, in the North by Kwara and Kogi states, in the West by the Republic of Benin and in the south by the Gulf of Guinea. The climate of Southwest Nigeria based on the tropics and characterized by wet and dry seasons. Temperature generally ranges between 21 ^oC and 34 ^oC, while the annual rainfall ranges between 1500 mm and 3000 mm (Faleyimu et al., 2010). The wet season is characterized by Tropical Maritime (TM) air mass from the Atlantic Ocean, while the dry season is characterized with the Tropical Continent (TC) air mass from the Sahara Desert. The vegetation is made up of fresh water swamp and mangrove forest at the belt, the low land in forest stretches inland to Ogun and part of Ondo state while secondary forest is towards the northern boundary where derived and southern Savannah exist (Agboola, 1979).

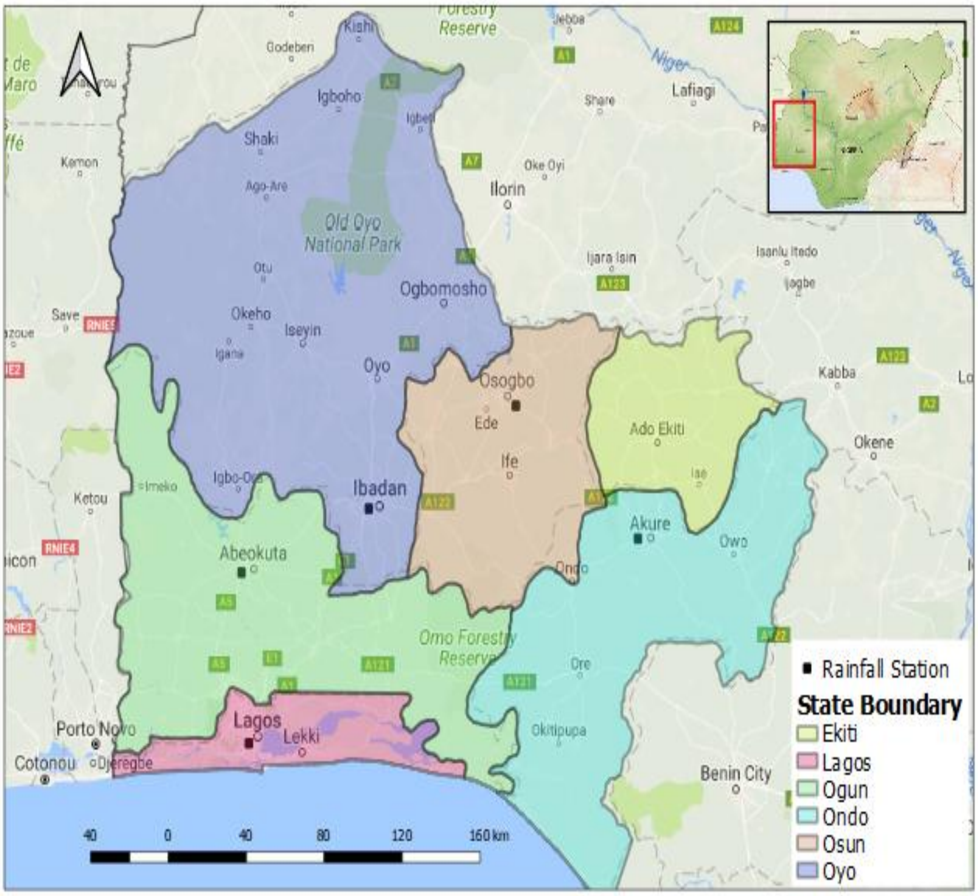


Figure 1: Map of the Study Area

MATERIALS AND METHODS

Materials

A 30-year (1981-2010) rainfall data from meteorological stations located at Ikeja, Abeokuta, Ibadan, Oshogbo and Akure (Fig 1) were obtained from the Nigerian Meteorological Agency (NIMET) to generate 1-day extreme rainfall for the study area.

Descriptive Statistics and Trend Analysis

Descriptive statistics that include mean, standard deviation, skewness and kurtosis were adopted to provide concise information on the 1-day extreme rainfall. Trends analysis based on nonparametric Mann-Kendall Statistics (S) which was developed by Mann (1945) and Kendall (1976) was further used to ascertain significant trend in instantaneous peak rainfall.

Probability Distribution Models

The generated 1-day extremes were arranged in descending order of magnitude to form an annual maximum series, after which the probabilities that the ranked annual maximum will be equaled or exceeded in any year were determined by the Hazen's plotting position:

$$\mathrm{Tr} = \frac{2n}{2m-1} \qquad 1$$

Where m is the order or rank while n is number of years of study.

Four probability distributions were selected to model and predict floods based on their simplicity, superiority, and popularity in literatures. As recommended by UNESCO (2005), the maximum-likelihood parameter estimation method was adopted for the study. The stochastic models selected for the study include Log Normal Distribution (LN2), Gamma (GAM), Extreme Value Type-1 (EV1)/ Gumbel and Frechet (EV2)/ Weibull represented probability density function (PDF) presented below in equation 2,3,4,5 respectively:

$$f(\mathrm{x}, \mu\mathrm{y}, \sigma\mathrm{y}) = \frac{1}{\sigma_y x\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{\ln(x)-\mu_y}{\sigma_y}\right)^2}, \ \mathrm{x, sy} > 0 \qquad 2$$

$$f(\mathrm{x}, \alpha, \beta) = \frac{1}{\alpha^{\beta}\Gamma\beta} x^{\beta-1} e^{-\left(\frac{x}{\alpha}\right)}, \ \mathrm{x}, \alpha, \beta > 0 \qquad 3$$

$$f(\mathrm{x}; \alpha, \beta) = \frac{e^{-(x-\beta)/\alpha} e^{-e^{-(x-\beta)/\alpha}}}{\alpha}, \ -\infty < \mathrm{x} < \infty, \alpha > 0 \qquad 4$$

$$f(\mathrm{x}; \alpha, \beta) = \frac{\beta}{\alpha}\left(\frac{\alpha}{x}\right)^{\beta+1} e^{-(\alpha/x)^{\beta}}, \ -\infty < \mathrm{x} < \infty, \alpha > 0 \qquad 5$$

Here, μx and σx are the mean and standard deviation of the series of the annual extreme storm; μy and σy are the mean and standard deviation of the log-transformed series of annual extreme rainfall, α and β are the scale and location parameters respectively (Rao and Hamed, 2000).

Performance Evaluation

The performance of the developed models was evaluated by statistical procedures such as correlation and Root Mean Square Error (RMSE) (O'Donnell, 1995); criteria of Akaike Information (AIC) and Bayesian Information (BIC). Models with high correlation coefficient, and lowest RMSE, AIC and BIC were considered to fit well to the recorded extreme events.

Goodness of Fit (GoF) and DiagnosticTest

The adequacy of fitting of the probability distributions to the recorded annual peak rainfall was ascertained by Anderson-Darling (A2) and Kolmogorov-Smirnov (KS) (Millington et al., 2011). Models were considered to adequately fit the observed data if estimated A2 and KS are lesser than 2.5 and 0.242 respectively at 5% significant level. The D-index (Diagnostic Test) was further used to establish the best probability distribution, where the model with least D-index was chosen as being the most adequate for predicting design flood (USWRC, 1981).

Spatial Interpolation - Inverse Distance Weighted (IDW)
The study adopted the IDW method for the study area due to its wide range of usage in geospatial statistical modeling. IDW predict cell values using linear weighted combination set of sample points and the weight assigned using distance of input points (Naoum et al., 2004).

RESULTS AND DISCUSSION

The result of the descriptive statistics and trend analysis is presented in table 1. It could be observed in the table that Ikeja received the highest average peak instantaneous rainfall and varies widely from its mean value, while Oshogbo with lowest peak instantaneous rainfall had least variability, being characterized with the lowest deviation from mean. It could be further seen that the peak rainfall distribution for all station is not symmetric since the skewness is not equal to zero, however, Ibadan and Akure were found to skew most to the right with long tails. Since the kurtosis value of all stations apart from Oshogbo was found to be greater than 3; the peak rainfall distribution of the stations have higher peak than normal distribution, which is as a result of high climate variability experienced in the areas. In addition, it was observed that extreme rainfall had positive trend in all stations, while, Ibadan station had a significant trend in contrast to other stations. This shows that variability of 1-day extreme rainfall is high in southern part of the study area. The performance evaluation tests of the models for all the rainfall stations are presented in table 2 to table 6. It could observed that Extreme Value Type-1 distribution was well suited for extreme rainfall prediction in Abeokuta (Table 2), Ibadan (Table 3) and Oshogbo (Table 6), Log Normal distribution was found to fit Ikeja extreme event (Table 4), while Extreme Value Type-2 distribution fitted well for flood prediction in Akure (Table 5). The distribution models were further used to predict design storms for different frequencies for the study area.

Table 1: Descriptive Statistics and Trend of 1-dayExtreme Rainfall in Southwest Nigeria

	Station	Mean (mm)	Std. (mm)	Skewness	Kurtosis	Kendall	Pvalue
1	Abeokuta	71.84	23.24	0.91	3.16	0.198	0.13
2	Ibadan	83.76	30.88	2.38	8.89	0.255	0.05
3	Ikeja	107.67	40.69	1.17	5.04	0.08	0.56
4	Akure	90.84	36.56	2.85	13.92	0.101	0.44
5	Oshogbo	71.76	17.75	0.71	2.97	0.186	0.15

Table 2: Performance Evaluation of Abeokuta Distribution

Test	Gumbel	Gamma	Log Normal	Weibull
KS	0.105	0.139	0.12	0.166
A2	0.29	0.44	0.31	0.79
AIC	270.68	272.32	271.04	276.91
BIC	273.48	275.12	273.84	279.72
COR	0.9985	0.9917	0.9973	0.9732
RMSE	29.99	40.07	32.25	46.79
D-index	1.35	1.78	1.44	2.05

Table 3: Performance Evaluation of Ibadan Distribution

	Gumbel	Gamma	Log Normal	Weibull
KS	0.139	0.207	0.181	0.239
A2	0.914	1.777	1.311	2.789
AIC	273.22	281.89	277.07	293.16
BIC	276.03	284.69	279.87	295.96
COR	0.9779	0.9917	0.9969	0.9985
RMSE	50.03	55.88	52.93	59.21
D-index	1.76	2.05	1.96	2.22

Table 4: Performance Evaluation of Ikeja Distribution

	Gumbel	Gamma	Log Normal	Weibull
KS	0.121	0.131	0.118	0.12
A2	0.215	0.242	0.191	0.504
AIC	303.97	304.88	303.74	309.32
BIC	306.77	307.68	306.54	312.13
COR	0.9985	0.9929	0.9985	0.9772
RMSE	50.87	66.98	48.61	77.14
D-index	1.41	1.83	1.34	2.07

Table 5: Performance Evaluation of Akure Distribution

	Gumbel	Gamma	Log Normal	Weibull
KS	0.125	0.141	0.118	0.186
A2	0.472	0.967	0.624	0.322
AIC	284.37	290.79	286.13	301.99
BIC	287.17	293.59	288.93	304.79
COR	0.9985	0.9923	0.9975	0.971
RMSE	64.27	64.94	60.06	58.16
D-index	2.12	2.1	1.97	1.78

Table 6: Performance Evaluation of Oshogbo Distribution

	Gumbel	Gamma	Log Normal	Weibull
KS	0.105	0.1148	0.099	0.154
A2	0.287	0.3885	0.323	0.713
AIC	257.07	258.06	257.39	262.41
BIC	259.87	260.87	260.19	265.21
COR	0.9985	0.9955	0.9949	0.9676
RMSE	18.59	26.37	28.36	38.9
D-index	0.948	1.338	1.338	1.849

The summary of extreme rainfall and their frequencies predicted from most appropriate probability distribution models are presented in table 6. The table shows that for all station, design storms leading to flood increased with return periods.

Table 6: Frequency Analysis of Extreme Rainfall (mm) in Southwest Nigeria

Station	Recurrence Interval (Years)								
	2	5	10	20	50	100	200	500	1000
Abeokuta	67.7	87.1	99.96	116.17	128.2	140.14	152.03	167.72	179.58
Ibadan	82.02	111.82	127.57	144.3	155.04	164.63	173.34	183.82	191.12
Ikeja	101.02	136.08	159.01	187.73	208.98	230.15	251.4	279.79	301.61
Akure	88.09	123.45	142.49	162.97	176.21	188.11	198.98	212.11	212.29
Oshogbo	68.75	84.57	95.05	108.29	118.11	127.86	137.57	150.38	160.07

The estimated magnitude of extreme rainfall for different return periods were further predicted using GIS and presented in figure 2 to figure 4. The maps show that extreme rainfall in Southwest Nigeria increased in the east-southern direction, while extreme rainfall increased in north-west direction for all return periods

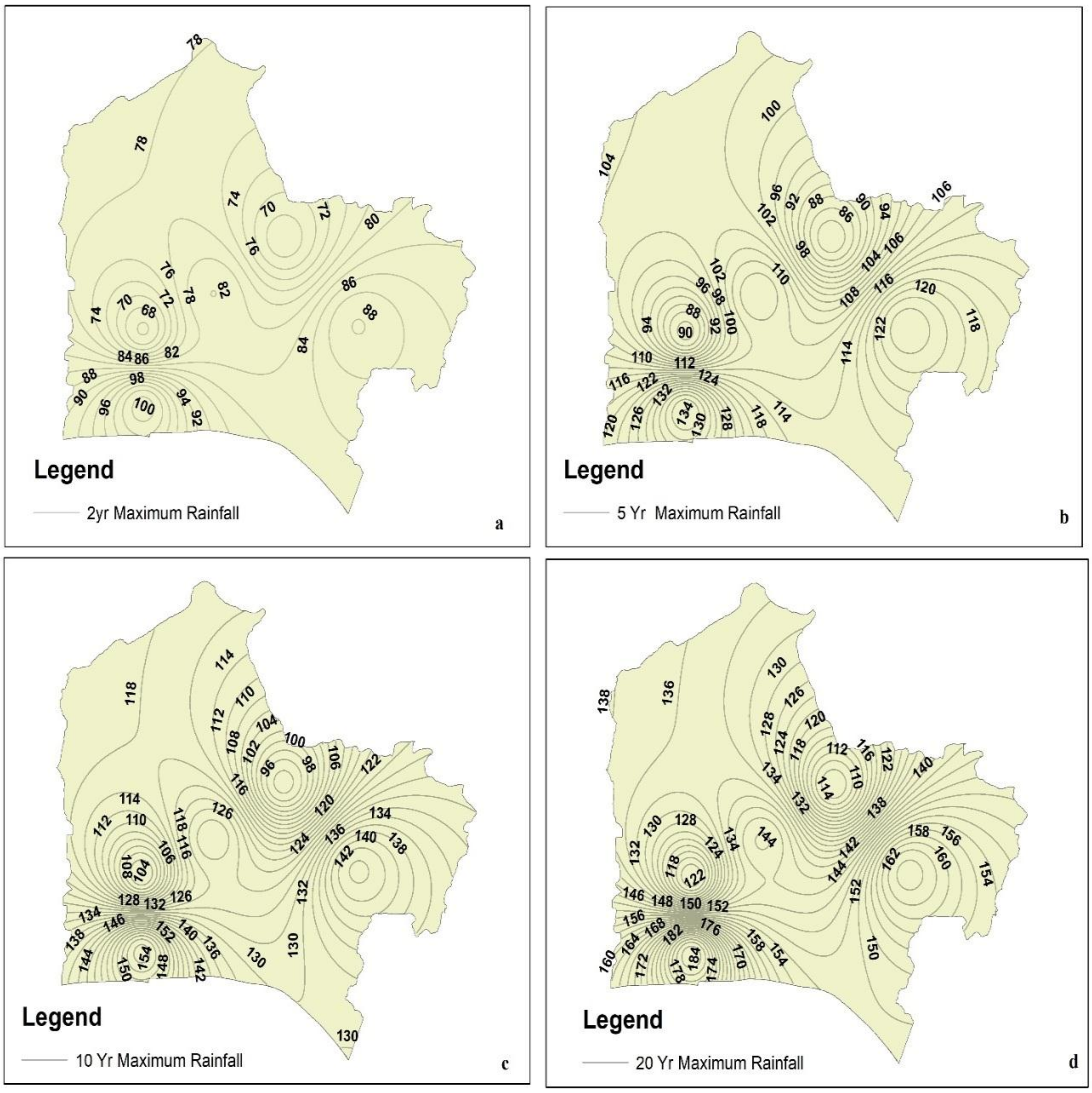


Figure 2: Spatial Distribution of Predicted Extreme Rainfall; 2a represents design storm for 2-years return period, 2b represents 5-years, 2c represents 10-years and 2d represents the 20-years return period.

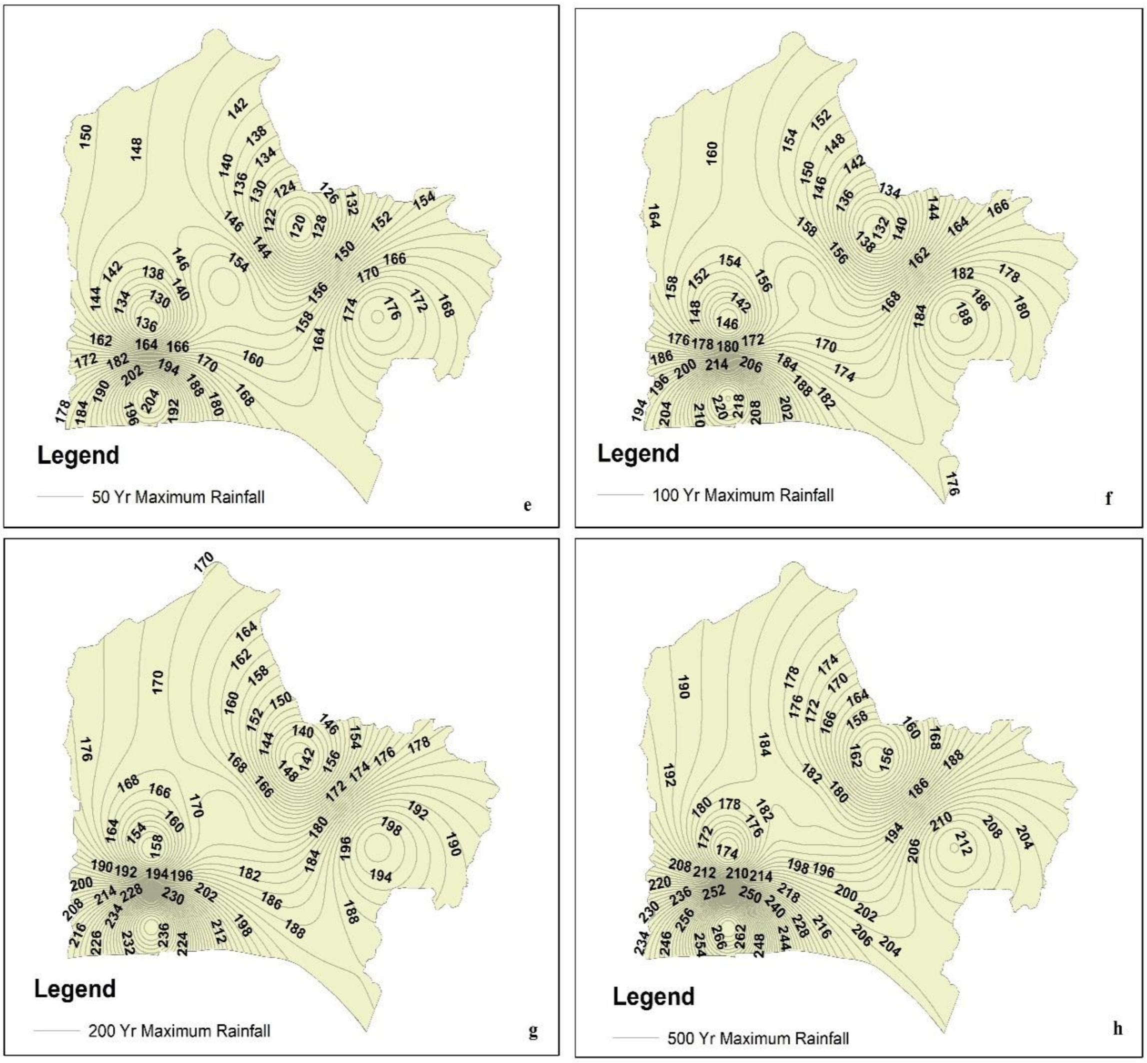


Figure 3: Spatial Distribution of Predicted Extreme Rainfall; 3e represents design storm for 50-years return period, 3f represents 100-years return period, 3g represents 200-years return period, while 3h represents 500-years return period.

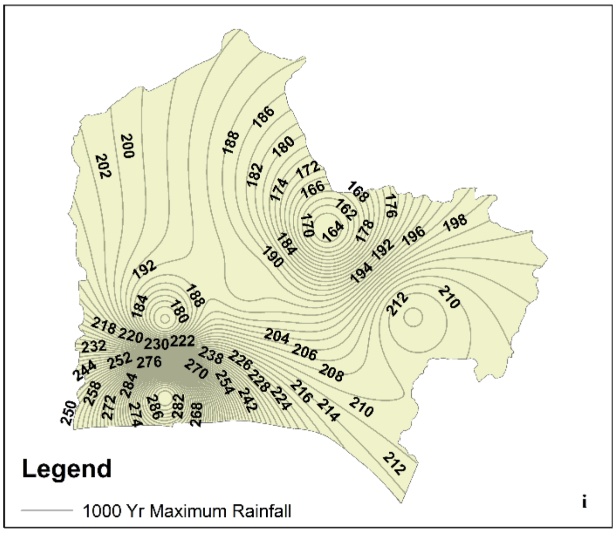


Figure 4: Spatial Predicted Extreme Rainfall for 1000-years Return Period

It could be observed that extreme rainfalls of highest magnitude for the different return periods were observed in the southern part of Southwest Nigeria, while the north-western had the lowest magnitude of extreme rainfall. This implies that areas in the south-eastern part of the region are more susceptible to flooding.

Extreme rainfall is known as a major cause of flooding in developing nations where drainages are either not properly designed or clogged by wastes, which hinders the draining of excess storms when they occur. Annual instantaneous maximum rainfall of five rainfall stations across Southwest Nigeria was assessed. The study revealed that extreme rainfall had highest magnitude with more variability in the southern part of the study area than the northern part. This corroborates the findings of Akinsanola and Ogunjobi (2014); that asserted that rainfall increases toward the coast in Nigeria at all seasons; this was also found to corroborate Nicholson (1993) who reported that rainfall in West Africa generally decreases with latitude. The study further unraveled that extreme rainfall had increasing trend throughout the study area which is in line with the study of Akinsanola and Ogunjobi (2014), which concludes that rainfall as well as temperature has been on the increase in Nigeria.

The modeling of extreme rainfall is important in making decision on flood risk reduction, since the models are used to predict flood magnitude in the construction of minor and major hydraulic structures such as barrages, bridges, culverts, dams, spillways, road/railway bridges and urban drainage systems; in order to ensure damage to people and goods is minimized to acceptable levels. Consequently, best extreme rainfall prediction models were established based on performance evaluation of fitted models. It was unraveled that Extreme Value Type-1 distribution was well suited for extreme rainfall prediction in Abeokuta, Ibadan and Oshogbo, Log Normal distribution was found to fit Ikeja extreme event, while Extreme Value Type-2 distribution fitted well for extreme rainfall in Akure. Generally, models with high correlation and lowest value of KS, A2, AIC, BIC, RMSE and D-index were acknowledged as most appropriate for predicting extreme rainfall for a station. Afterwards the magnitudes of 1-day annual maximum rainfall for 2 to 1000 years return period were estimated using the selected models.

Since extreme events from limited stations within the study area were employed, predicted extremes for the different return periods were interpolated for the whole region. It was revealed that settlements in the south-east region of the study area are more susceptible to floods resulting from extreme rainfall than the settlements located in north-west region. Furthermore, the results of the extreme rainfall magnitude and their frequencies for 24-hour annual maximum, integrated with spatial interpolation using GIS are adequate for engineering designs of drainage structures for regional flood management in Southwest Nigeria.

CONCLUSION

Models are efficient decision support tools in mitigating climate induced hazards such as flood. This study presents regional rainfall-frequency analyses of 24-hour annual maxima for Southwest Nigeria, where extreme rainfalls are expected to occur due to climate change and variability. GIS through spatial interpolation has further been used to map the magnitude of rainfall for 2 to 1000 years return period. These results would serve as decision support for tackling the effects of climate change in Southwest Nigeria.

REFERENCES

Agbede A.O and Abiona. O. (2012). Plotting Position Probability Fittings to Lagos Metropolitan Precipitation: Hydrological Tools for Hydraulic Structures Design in Flood Control. International Journal of Pure and Applied Sciences and Technology. 10: 37-43.

Agbede, O.A and Aiyelokun, O.O. (2016). Establishment of a Stochastic Model for Sustainable Economic Flood Management in Yewa Sub-Basin, Southwest Nigeria. Civil Engineering Journal. 2(12): 646-655.

Agboola S.A. (1979): An Agricultural Atlas of Nigeria, Oxford University Press, Nigeria Pp.248

Ahmad Z., Zulkifli, Y., and Zainab Y. 2015. Comparison of Flood Distribution Model For Johor River Basin. Jurnal Teknologi. 74(11): 123–128.

Aiyelokun, O. (2016). Evidence of persistent surge in atmospheric warming in Ijebu-Ode Metropolis. International Journal of Innovation, 6(2), 9–13.

Aiyelokun, O., Ojelabi, A., Malomo, S., and Agbede, O. (2017). Efficient Flood Forecasting for the Operation of Hydraulic Structures in a Typical River Basin. International Journal of Scientific and Engineering Research. 8(11): 463-481

Akinsanola, A.A and Ogunjobi, K.O (2014). Analysis of Rainfall and Temperature Variability Over Nigeria. Global Journal of HUMAN-SOCIAL SCIENCE: B Geography, Geo-Sciences, Environmental Disaster Management. 14(3): 1-18.

Aksoy, H. 2000. Use of Gamma Distribution in Hydrological Analysis. Turkey Journal of Engineering and Environmental Sciences, 24, 419-428.

Allamano, P., Laio, F. and Claps, P. 2011. Effects of Disregarding Seasonality on the Distribution of Hydrological Extremes. Journal of Hydrology and Earth System Sciences, 15, 3207-3215.

Bhakar, S.R., Bansal, A.K., Chhajed, N. and Purohit R.C. 2006. Frequency Analysis of Consecutive Days Maximum Rainfall at Banswara, Rajasthan, India. ARPN Journal of Engineering and Applied Sciences, 1, 64-67.

Chen, L., Guo, S., Yan, B., Liu, P. and Fang, B. 2010. A New Seasonal Design Flood Method Based on Bivariate Joint Distribution of Flood Magnitude and Date of Occurrence. Journal of Hydrological Sciences, 55, 1264-1280.

Duru, P. N. and Chibo, C. N. (2014). Flooding in Imo State Nigeria: The Socio-Economic Implication for Sustainable Development. Humanities and Social Sciences Letters, 2(3), 129-140.

Faleyimu, O. I. Akinyemi1, O. and Agbeja, B. O. (2010). Incentives for Forestry Development in the South-West Nigeria. African Journal of General Agriculture. 6(2): 67-76

Fang, B., Guo, S., Wang, S., Liu, P. and Xiao, Y. 2007. Non-Identical Models for Seasonal Flood Frequency Analysis. Journal of Hydrological Sciences, 52, 974-991.

Kendall M. (1976) Rank Correlation Methods. 4th Ed. Griffin.

Lee, C. 2005. Application of Rainfall Frequency Analysis on Studying Rainfall Distribution Characteristics of Chia- Nan Plain area in Southern Taiwan. Journal of Crop, Environment & Bioinformatics, 2, 31-38.

Loucks DP, Stedinger JR, DaArryl WD, Stakhiv EZ (2008) Private and public responses to flood risks. Int J. Water Resour D24(4):541–553.

Mann H. (1945). Nonparametric tests against trend. Econometrica, 13:245–259.

May, W. 2004. Variability and Extremes of Daily Rainfall during the Indian Summer Monsoon in the Period 1901-1989. Journal of Global & Planetary Change, 44, 83-105.

Naoum, S., & Tsanis, I. K. (2004). Ranking spatial interpolation techniques using a GIS-based DSS. Global Nest Journal, 6(1), pp. 1–20.

Nicholson, S. E., (1993). An overview of African rainfall fluctuations of the last decade. Journal of Climate, 6, 1463–1466.

O' Donnell, T. (1985). A Direct three-parameter Muskingum procedure incorporating lateral inflow, Journal of Hydrological Sciences, 30(4): 494-495.

Oke, A.O; Sangodoyin, A.Y.; Ogedengbe, K.; Omodele, T. (2013). Mapping Of River Water Quality Using Inverse Distance Weighted Interpolation In Ogun-Osun River Basin, Nigeria. Landscape and Environment 7 (2): 48-62.

Plate EJ (2002) Flood risk and flood managment. J Hydrol 267:2–11

Rao, A.R. and Hamed, K.H. 2000. Flood frequency analysis, CRC Publications, New York.

Salami, A.W. (2004). Prediction of the Annual Flow Regime along ASA River Using Probability Distribution Models. AMSE Periodicals. Modelling, Measurement and Control, 65, 41-56.

Sharda, V.N. and Das, P.K. 2005. Modelling Weekly Rainfall Data for Crop Planning in a Sub-Humid Climate of India. Journal of Agricultural and Water Management, 76, 120-138.

U.S. Water Resources Council (USWRC). (1981). Guidelines for Determining Flood Flow Frequency, Bulletin 17A, U.S Geological Survey, Washington, D.C.

UNESCO, (2005) "Concepts in Probability, Statistics and Stochastic Modelling", Water Resources Systems Planning and Management Report, 2005.

Vijayagopal, P., Vivekanandan, N. and Kannan, S. (2013) Assessing Adequacy of Probability Distribution for Development of IDF Relationships for Mandla and Jabalpur. Journal of Scientific Research and Reviews, 2, 99-114.

Vivekanandan, N. (2018). Assessing the Adequacy of Probability Distribution for Extreme Value Analysis of Rainfall and Temperature using Goodness-Of-Fit And Diagnostic Tests. i-manager's Journal on Future Engineering and Technology, 13(3), 1-8. https://doi.org/10.26634/jfet.13.3.14225

Vivekanandan, N. 2012. Assessing Adequacy of a Probability Distribution for Estimation of Design Flood. Bonfring International Journal of Industrial Engineering and Management Science. 2(3): 22-27.

Vivekanandan, N. 2014. Comparison of Probability Distributions for Estimation of Peak Flood Discharge. Open Access Library Journal, 1: e498.

Vivekanandan, N. and Ramesh, C. (2017). Statistical Analysis of Rainfall Data for Estimation of Peak Flood Discharge Using Rational Formula. International Journal of Emerging Engineering Research and Technology. 5(5): 1-6

Vivekanandan, N. and Ramesh, C. (2017). Statistical Analysis of Rainfall Data for Estimation of Peak Flood Discharge Using Rational Formula, International Journal of Emerging Engineering Research and Technology. 5(5): 1-6.

IMPACT OF CLIMATE VARIABILITY ON COWPEA YIELD IN IBADAN, SOUTHWEST NIGERIA

AKANGBE O. E.[1*], AKINYEMI J. O.[2], ADEOSUN O. J.[3], BADEJO A. A.[4], SOBOWALE A.[3], DAIRO O.U.[3]

[1*]*Department of Soil and Water Engineering,*
Oyo State College of Agriculture and Technology, Igboora
eoluseyiakangbe@yahoo.com
[2]*Department of Agricultural Engineering, Olabisi Onabanjo University, Ago Iwoye*
joakinyemi@gmail.com
[3]*Department of Agricultural and Bio-resources Engineering,*
Federal University of Agriculture, Abeokuta
adeosunoj@funaab.edu.ng
sobowalea@funaab.edu.ng
dairoou@funaab.edu.ng
[4]*Department of Civil Engineering,Federal University of Agriculture, Abeokuta*
badejoaa@funaab.edu.ng

**Corresponding author:* eoluseyiakangbe@yahoo.com

Received: 8 October 2018 *Accepted: 24 December 2018*

ABSTRACT: Variations in crop yield are associated with Climatic Variability (CV). In Nigeria, rain-fed agriculture is generally practiced and CV is becoming more unpredictable hence the need to assess its impact on crop yields. The study examined the relationship between cowpea yield and climatic variables – Rainfall, Temperature, Solar Radiation, Relative humidity, Sunshine hours and Wind speed. Data of climatic variables from 1990 to 2012 were collected from Nigerian Meteorological Agency (NIMET) Lagos State while historical data (1980-2005) and future data (2020-2100) were obtained from the archive of Intergovernmental Panel on Climate Change (IPCC) through General Circulation Models (GCMs) for Ibadan in Ona river basin. Cowpea yields from 1994 to 2012 were also collected for the study area from National Bureau of Statistics Abuja. Correlation and regression analyses were used to determine the relationships between climatic variables and crop yield, and predict future crop yield change due to CV impact. Regression model outcomes showed that 79% variations in cowpea yield was due to CV. Annual Solar radiation increased significantly at the rate of 0.05 MJ/m^2/day/yr ($p<0.05$) while monthly minimum and mean temperature significantly increased at the rate of 0.04 and 0.02 ^{o}C/mo/yr respectively in October. Annual cowpea yield decreased at the rate of 9.61 kg/ha/yr ($p>0.05$). Average projected change in cowpea yield from climate-yield model outputs for Ibadan showed a reduction of about 998 kg/ha (5%) and 5373 kg/ha (21%) for mid-century (2060) and late-century (2100) respectively. These findings are vital in planning appropriate adaptation and mitigation for cowpea production in Ibadan - Ona River basin.

Keywords: Climate Change, Climatic Variability, cowpea, models, Ibadan.

INTRODUCTION

Agriculture especially, crop growth, is heavily dependent on weather events in Nigeria and Sub-Shara Africa where 97% of agricultural land is rain fed (Rockström, 2004). However, rain-fed agriculture, including grains production, is highly sensitive to variation in climatic factors such as rainfall, temperature and sunshine hours etc. Amikuzuno and Donkon, (2012) reported the finding of Lobell *et al*. (2009) that changes in the agriculturally-relevant variables of climate such as increasing temperatures, declination and distribution of rainfall pattern are likely to reduce yields of maize, rice, wheat and other food crops in semi-arid regions of the world. Wassman *et al.,* 2009 further reported that some developing nations, Nigeria inclusive, are experiencing low crop yields as a result of fluctuation in weather pattern and climate change. This impact is already causing boundary shift in ecological zones, altering the composition of plant and animals, increasing soil erosion and flooding in many areas and draught (Odjugo and Ikhuoria 2003; Ayuba *et al.*, 2007). The frequent droughts and less rain have started shortening the growing season thereby causing crops failure and food shortage in Nigeria (Changnon, 2001; Ajetomobi and Abiodun, 2010).

Meanwhile, cowpea is a warm climate and drought crop grown throughout the tropics particularly in the semi-arid and low rainfall regions. It is an important staple crop in Nigeria, containing 25% protein and 64 percent carbohydrate. It provides food, fodder and enhances soil fertility and as a major source of plant protein and vitamins to man, it is therefore called the poor man's food (Ayanwuyi and Akintonde, 2012).

At present, Nigeria is one of the largest producers and consumer of cowpea worldwide with about 5 million ha and over 2 million tons production annually. Most Nigerians eat cowpea and the per capita consumption is about 25 to 30 kg per annum (Ajetomobi and Abiodun, 2010). Despite the importance of cowpea, its production is confronted with constraints such as drought, flooding, salt stress, extreme temperature and all these are expected to worsen with climate change (Ayanwuyi and Akintonde, 2012).

In order to ensure food security in Nigeria, through adequate productions of leguminous crop, information on the extent to which climate variability and change can contribute to a decline in agricultural productivity may assist in proffering adaptation strategies for a sustainable and improved crop yield. Since threats from undefined climate variability and change can hinder the national target for food security to some extent, it is of utmost significance to investigate the effects. Ibadan, representing Oyo state, has been identified as the major producer of cowpea in southwestern region of the country with a yield of 0.83 tonne per hectare (Ajetomobi and Abiodun, 2010) and located within Oyan river basin. The impact of the climatic variability within the basin would definitely affect the cowpea productivity in Ibadan. Hence the need to conduct research on climate variability impact on cowpea yields in Ibadan, southwestern Nigeria.

This, therefore, requires the need to develop an empirical model that can predict the impact of climate on the future yield of cowpea which is the focus of this work. This work aims at analysing trend and variability in climatic variables and cowpea yield, developing climate-yield model and evaluating the impact of future climate change on cowpea yield.

MATERIALS AND METHODS

The Study Area

Ibadan is situsted within Oyan river basin, in southwestern Nigeria. It is located about 110 km northeast of Lagos and falls within latitude 7° 22'N and longitude 3° 54'E. The city is reputed to be the largest native city in Black Africa (Sangodoyin, 1992, Oguntunde, 2011). Ibadan has grown rapidly in recent times and the population increased from about 1 million in 1963 to about 3.6 million in 2007. The climate is generally monsoon with bimodal rainfall pattern. Average annual rainfall is about 1300 mm and mean monthly temperature varied from 24.5°C in August to 28.8°C in February. The soil type is ferric luvisols and the vegetation is mild-hot farmland and settlements (Sangodoyin, 1992, Jagtap and Alabi, 1997, Oguntunde, 2011).

Datasets

Data on climatic variables, minimum temperature (Tmi), maximum temperature (Tmx), rainfall (Rf), solar radiation (Ra), sunshine hour (Sh) and wind speed (Wn) were obtained from the database of Nigerian Meteorological Agency (NIMET), Oshodi, Lagos State. Mean temperature and diurnal temperature range were estimated from minimum and maximum temperatures in addition to those collected. Monthly data collected for Ibadan were for 23years (1990-2012) before scaling up to annual average. Historical data (1980 and 2005) and future meteorological data (2020-2100) were downscaled, to the study location, from the archive of Intergovernmental Panel on Climate Change (www.ipcc.org) for projection of future cowpea yield. Similarly, data on annual yield of cowpea (Yc) were collected from the National Bureau of Statistics (NBS), Abuja between 1994 and 2012.

Data Analysis

Mann-Kendall test was used to test the presence of trends in the time series of both the climatic and yield variables on monthly and annual basis as applied by Oguntunde *et al.*, 2006 and Akinbile *et al.*, 2015; when the data values *xi* of a time series can be assumed to obey the model;

$$\chi = \mathrm{f(t)} + \sum \mathrm{t} \qquad (1)$$

Where *f(t)* is a continuous monotonic increasing or decreasing function of ti me and the Residual $\sum t$ can be assumed to be from the same distribution with zero mean. As a non-parametr ic test, no assumptions as to the underlying distribution of the data are necessary. The *Z*-statistic is then used to test the null hypothesis, H_o that the data is randomly ordered in time, against the alternative hypothesis, H_1, where there is an increasing or decreasing monotonic trend. To estimate the true slope of an existing trend the Sen's nonparametric method was used (Salmi et al., 2002).

Correlation matrixes were further estimated between cowpea yield and the climatic variables. Cross correlation analysis was firstly used to check whether there was any significant relationship between time series of cowpea yield and the climatic variables. Those climatic variables identified to have significant correlation with cowpea yield were regressed with cowpea yield using step-wise regression procedure with statistical software (Minitab version 16.0 developed by Minitab Inc, 2016). The significantly correlated climatic variables were selected to develop a new model of the form:

$$\gamma_c = \beta_o + \sum_{i=1}^{n} (\beta_n X_n) + e \qquad (2)$$

Where Y_c is the crop yield (kg/ha), X_n (n=1, 2....) are the significantly correlated parameters i.e (climatic variables), βo is model constant, β_n is the coefficient of respective variables and e_i is the error term.
For reliable prediction of the statistically developed models for the location in the basin, evaluation of their performance was carried out. Split sample validation was adopted which consists of splitting randomly available datasets into (halves) two samples. The first dataset sample was used for calibration of the models and the other one was used for validation. The validated model with better performance was fitted with future climatic variables taken from the archive of IPCC to predict the cowpea yield between years 2020 and 2100 in the future. Projection was based on the emission scenario (Representative concentration pathways-RCP 4.5) and four different outputs of General Circulation Models (ICHEC, MIROC 5, MPI_ECHAMS and NCC).

RESULTS AND DISCUSSION

Annual time series of rainfall and other climatic variables are shown in figure 1. The observed slopes for Rf, Rh and Ra show increased trends while Tmn, Tr, Sh and Wn showed decreased trends for the 23-year period. Ra showed significantly increased trend at the rate of 0.05 MJ/m^2/day/yr ($p<0.05$) in Ibadan however, both Rf and Rh showed non-significant ($p>0.05$) increase at the rate of 4.13 mm/yr^2 0.083 %/yr respectively. Mean temperature (Tmn) showed a non-significant ($p>0.05$) decrease at the rate of at 0.03 ^{o}C/yr. Cowpea yield (Yc) also showed non-significant ($p>0.05$) decrease at the rate of 9.61 kg/ha/yr. Analysis of each calendar month allows the identification of time characteristics peculiar to each month, which may be masked in annual analysis. Table 1 contains summary of monthly trend estimates for Ibadan. Rf showed increasing trends in almost eight months but slopes decreasingly in February, May, July and August, all the changes were not statistically significant. On average, highest monthly Rf was observed in September (198 mm). However, Ra showed significant increasing trends rated between 0.06 to 0.13 MJ/m^2/mo/yr. ($p<0.05$) in virtually all the months except in January and July. Despite Rh showed non-significant increasing trend in annual estimate, it showed a significant trend in March at the rate of 0.23 %/mo/yr. similarly, both Wn and Tmn significantly increased in May and October respectively which were not reflected in the annual trend estimate. However, Tr also showed significantly decrease in almost five months (March, April, June, October and November) which were masked in the annual estimate.

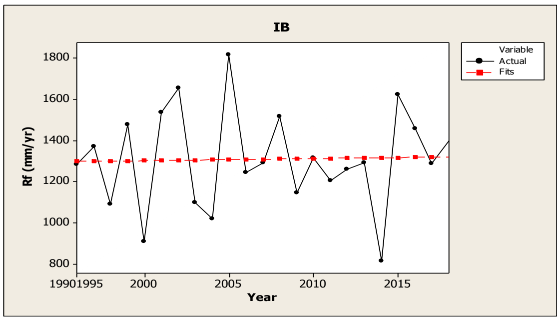
Both annual and monthly rainfall showed non-significant increased trends for Ibadan which agreed with previous studies that reported the absence of any significant trends in rainfall but the presence of large inter-annual variability (Liu *et al*., 2004; Roderick and Farquhar, 2004; Oguntunde *et al*., 2006). John and Olarenwaju (2014) also butress the increase in Rf trends recorded in this study by submitting an evidence of increasing trend for the same study area which was termed recovery of Sahelian rainfall - a recovery after devastating drought of 1970’s and early 80’s (Nicholson, 2005). The annual Z –statistic value of 0.475 obtained for rainfall is slightly less than 0.449 of Oguntunde *et al*. (2011) and a bit higher than 0.2 of Akinbile *et al.* (2015) for the same study area, following the same pattern both described and supported by other authors (Nicholson et al. 2000, L’Hote et al 2002, Kumar et al. 2012) that an apparently random succession of dry periods, ‘normal’ periods and wet periods characterized the rainfall series.

Annual and monthly solar radiation (Ra) significantly increased for the period examined. This agrees with Akinbile et al. (2015), but disagrees with global dimming due to decrease Ra reported by Oguntunde et al., (2011) for the study area. Wild et al. (2009) reported increasing Ra in Europe, USA and East Asian which is referred to as global brightening. Therefore, Ibadan is also experiencing global brightening due to decline in aerosol concentration achieved as a result of reductionn in airbone pollution (Wild et al., 2009).

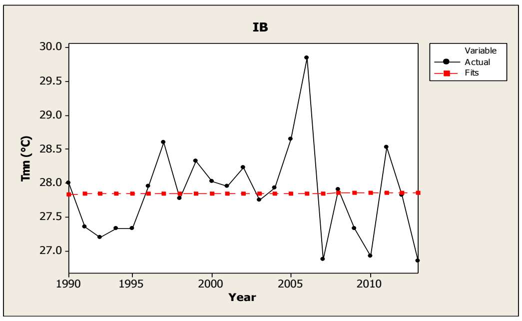
Table 1: Trend results for monthly climatic variables between 1990 and 2012.

Time	Rf		Tmn		Tr		Rh		Wn		Ra
Series	Test Z Q	Q	Test Z	Q	Test Z	Q	Test Z	Q	Test Z	Q	Test Z
Jan	0.253 0.047	0.000	-0.291	0.014	0.053	0.000	0.292	0.047	-1.273	-0.036	1.351
Feb	-0.555 0.059	-0.521	0.899	0.020	-1.216	-0.069	0.875	0.273	1.431	0.050	1.906^{+}
Mar	0.106 0.080	0.255	-0.053	0.000	-2.486*	-0.078	1.866^{+}	0.231	0.529	0.022	1.989*
Apr	0.158 0.067	0.369	0.265	0.005	-1.959^{+}	0.030	1.499	0.125	1.591	0.043	2.753**
May	-0.739 0.088	-1.775	1.061	0.014	-1.191	-0.033	0.724	0.000	2.040*	0.070	2.063*
Jun	0.581 0.108	1.929	0.000	0.000	-2.330*	-0.040	0.248	0.000	1.192	0.038	3.124**
Jul	-1.215 0.040	-3.078	0.662	0.010	-0.266	0.000	-0 .218	0.000	0.849	0.050	0.899
Aug	-0.475 0.059	-2.625	1.533	0.030	0.186	0.000	0.572	0.000	0.476	0.033	2.154*
Sep	1.637 0.073	3.724	0.026	0.000	-0.954	-0.029	-0.138	0.000	-0.848	-0.020	1.906^{+}
Oct	0.528 0.100	1.159	1.706*	0.015	-1.932^{+}	-0.033	-0.339	0.000	-0.160	0.000	2.302*
Nov	0.530 0.125	0.420	0.687	0.025	-1.800^{+}	-0.050	-0.027	0.000	-1.064	0.029	3.122**
Dec	0.281 0.057	0.000	0.185	0.003	-1.508	0.059	1.909	0.057	-0.585	-0.010	1.909^{+}

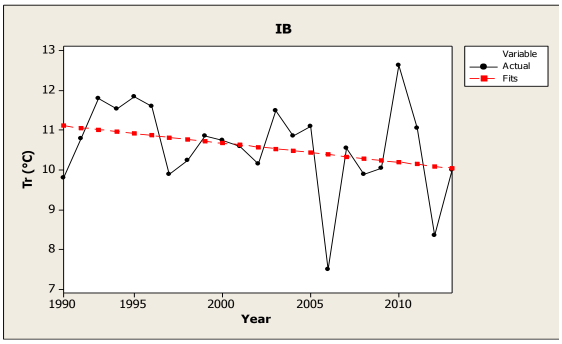
** Trend is significant at $\alpha = 0.01$; * Trend is significant at $\alpha = 0.05$ and $^{+}$ Trend is significant at $\alpha = 0.1$



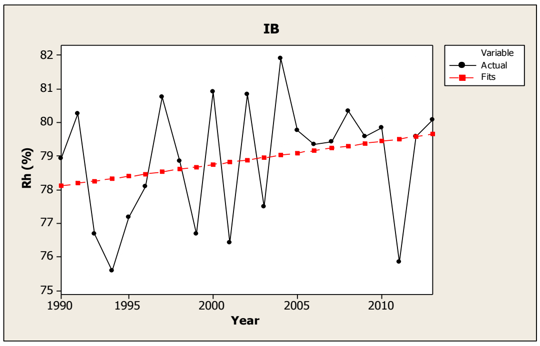
a



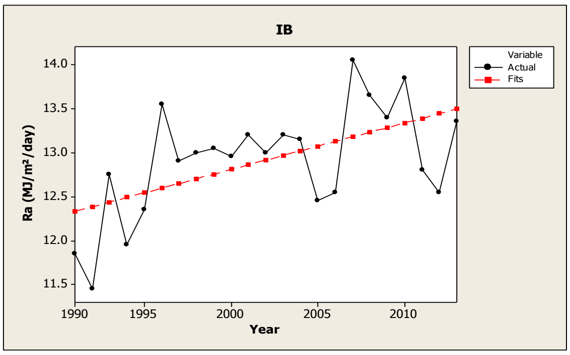
b



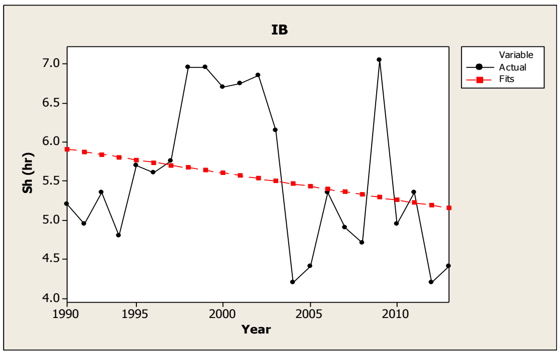
c



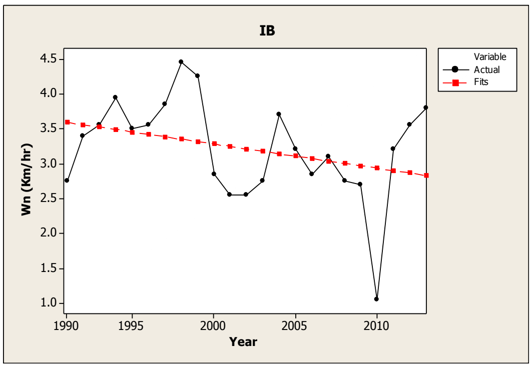
d



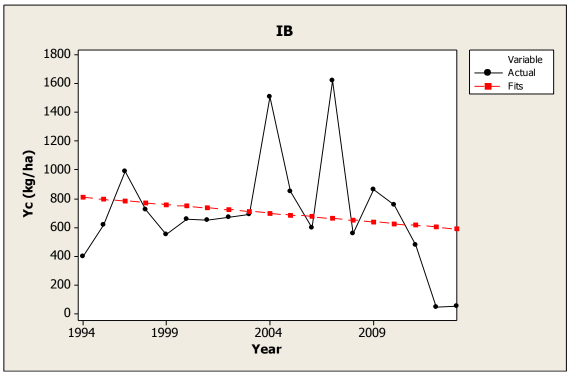
e



f



g



h

Figure 1. Times series plots and linear trends of (a) rainfall (Rf), (b) mean temperature (Tmn), (c) diurnal temperature change (Tr), (d) relative humidity (Rh), (e) solar radiation (Ra), (f) sunshine hour (Sh), (g) wind speed (Wn) and (h) cowpea yield (Yc).

Mean air temperature at the study area was found to decrease slightly at the rate of 0.01 $^oC/yr$ but not statistically significant. This is in agreement with the submission of Akinbile et al. (2015). Diurnal temperature range (Tr) decreased non-significantly at Ibadan which consists with the reports submitted for India and United State of America (Liu et al., 2004; Rimi et al., 2011). Maximum and minimum temperature were examined to elucidate more on Tr. A reduction in maximum temperature of 0.01 $^oC/yr$ and increase in minimum temperature of 0.03 $^oC/yr$ was observed, indicating that Ibadan has experienced warmer nights and colder afternoons in the last three decades which is in consistent with the submission of Akangbe et al. (2016).

Relative humidity (Rh) slightly increased for the study area which concurs with the findings of Dai (2006) that indicated large positive Rh trends over western China and most of East Asia in all seasons. Although Oguntunde *et al*. (2011) reported Rh to be fairly constant while akinbile et al. (2015) gave a decreased Rh trends for the same area. This contrast in the reports might be as a result of Dai (2006) submission that trends of surface Rh have been shown to vary with study period and data set, as well as differences between weather stations. Both wind speed (Wn) and sunshine hour (Sh) declined non-significantly for the same study period which is similar to the findings of Oguntunde *et al*. (2011) and Xu et al. (2006).

Cowpea showed insignificant decreasing trends at the rate of 9.61 kg/ha/yr in the study area which could be associated with the impact of climatic parameters variability. Highest cowpea yield was observed in 2006 while the lowest yield was recorded in 1994. This observation was similar to the reports of both Akinbile et al. (2015) and Akangbe et al. (2016) for rice and maize yields respectively for the study area. Both submitted that declines in rice and maize yields could not be separated from the impact of climate change in Ibadan. Monthly climatic variables showed more significant correlation with cowpea yields than annual variables for the study period which indicates that variation in cowpea yield for the study area is more of seasonal variability than annual variability. Monthly mean temperature and relative humidity were negatively correlated with cowpea which agrees with the submission of Ajetomobi and Abiodun (2010) that cowpea yield is negatively correlated with temperature in Oyo state. Cowpea yield further correlated negatively with both August and September minimum temperature which is corroborated by Ajetomobi and Abiodun (2010) that high night temperature can cause flower abscission in some cultivars during flowering and resulting in poor pod set which can also account partly for decline in cowpea yield for the study area. It was further observed that annual solar radiation also showed a moderate positive correlation but significant with cowpea at the same location.

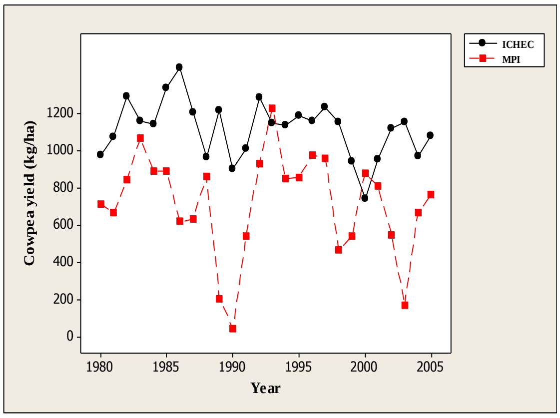
The step wise regression results between significantly related climatic variables and cowpea yield generated five models which were validated, and model type Y_{c5} with the highest value of coefficient of correlation (R) =0.84 and least value of mean absolute error (MAE) =123.05 and root mean square error (RMSE) =135.78 was selected for future projection of the impact of climate variability on cowpea yield. This finding agrees with the work of Tao et al. (2009) on modelling the impact of climate variability on crop productivity over two different provinces in North India with R and RMSE used for models evaluation found to be 0.53 and 1386 kg/ha for maize. Other studies on model validation in conformity with this work are Pohankova *et al.* (2015), Sayegh *et al.* (2014) and Chai and Draxler (2014).

The model equation is given below:

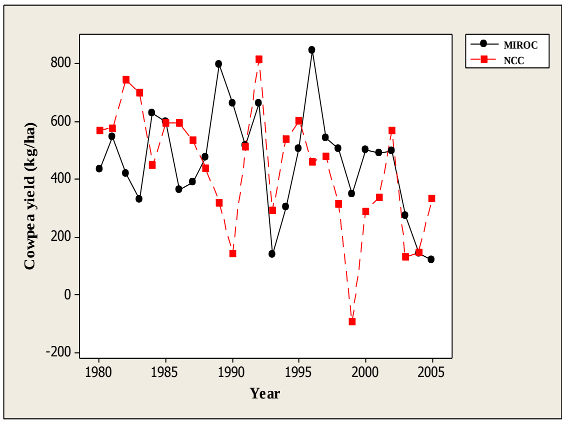
$$Y_c = -966.3 - 796Tmi_7 + 571Ra_{13} + 330Tmn_{13} + 381Tmi_8 - 227Tmn_7$$

This model has an explanatory power indicated by coefficient of determination (R^2) = 0.70. this shows that about 70% of variability in the cowpea yield in the study area could be accounted for by the climatic variables leaving the remaining 30% for some other factors such as soil, crop variety and other crop management practices.

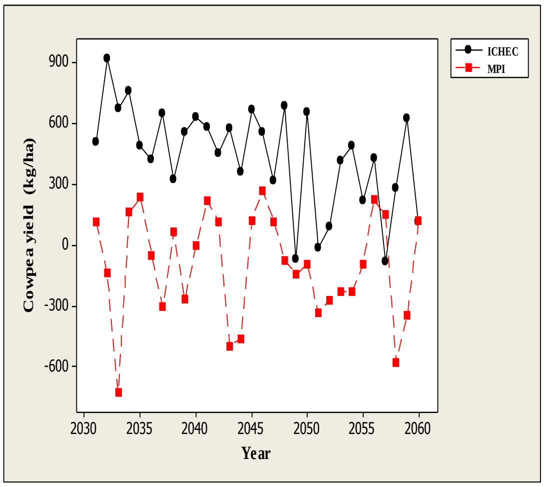
Both historical and future data generated from four general circulation models (ICHEC, MPI, MIROC and NCC) were fitted into cowpea climate-yield model developed for Ibadan, and the outputs of both historical and future projections are presented in figure 2 while change in yield projected for mid –term century (2031-2060) and late future century (2071-2100) is presented in Figure 3.



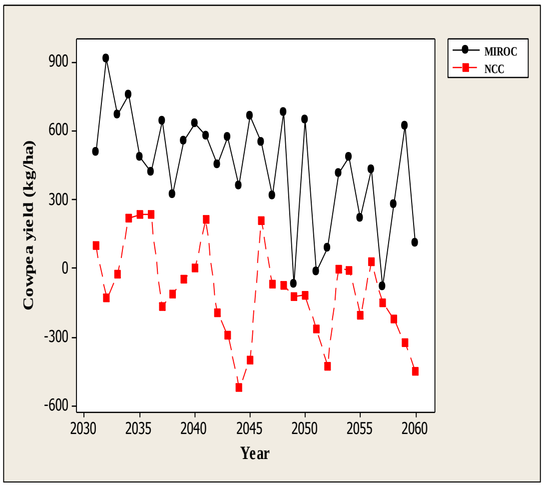
a



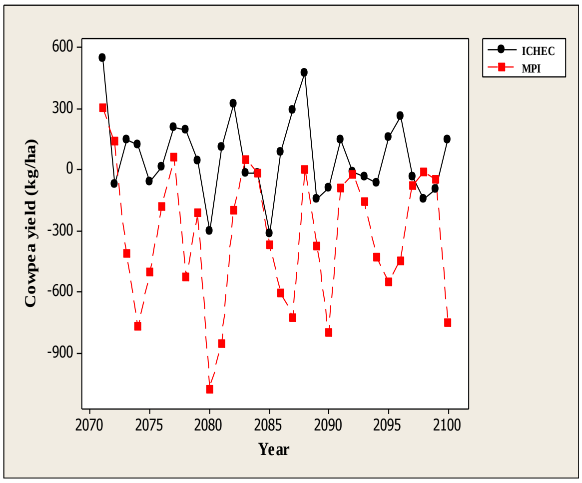
b



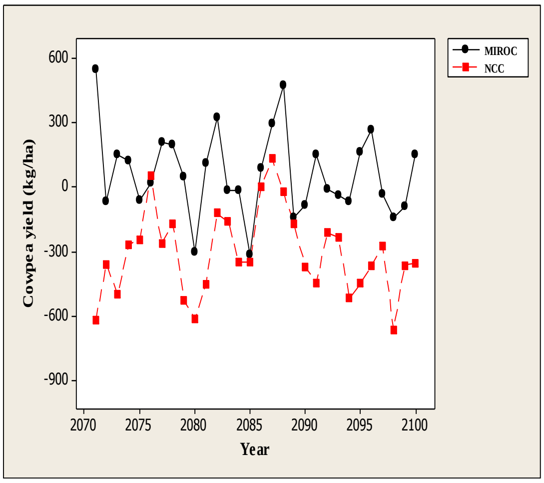
c



d



e



f

Figure 2. (a &b) : historical (1980-2005); (c & d): projected mid-term century (2031-2060) and (e & f) : projected late-future century (2071-2100) cowpea for four GCMs Outputs.

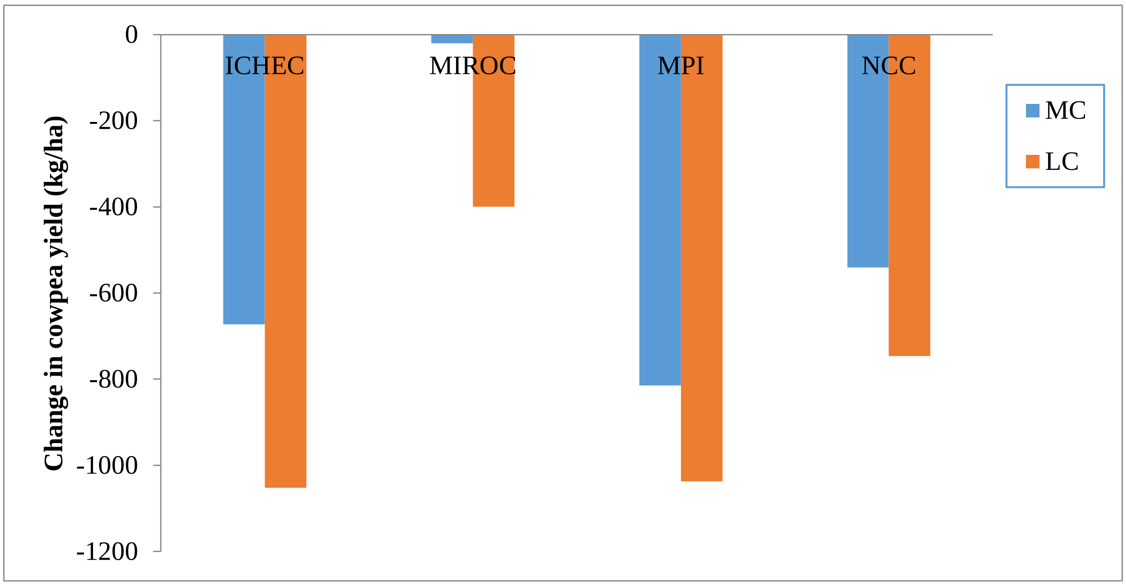


Figure 3. Change in cowpea yield projected for mid - century (MC; 2031-2060) and late -future (LF; 2071-2100)

The four GCMs (ICHEC, MPI, MIROC and NCC) gave the highest historical yields as 1336.45, 1230.07, 846.26 and 815.04 kg/ha in the years 1987, 1993, 1994 and 1992 respectively; while lowest yields were produced as 743.60, 46.06, 120.21 and -91.72 kg/ha in the years 2000, 1990, 2005 and 1999 respectively. ICHEC and MIROC projected equal highest yields for both mid-term century and late-future century as 919.39 kg/ha in the year 2032 and 547.80 kg/ha in 2071 and lowest yields for mid-term and late-future century as -68.98 kg/ha in 2049 and -315.01 kg/ha in 2085 respectively. MPI projected 292.68 kg/ha in 2046 and 305.84 kg/ha in 2071 as highest yields for both mid-term and late-future century while it projected -850.65 kg/ha in 2033 and -1076.53 kg/ha in 2080 for mid-term and late-future century respectively. Lastly, NCC projected its highest cowpea yields for mid and late century as 237.97 kg/ha in 2035 and 132.60 kg/ha in 2087 while the lowest yields were projected as -517.95 kg/ha in 2044 and -662.01 kg/ha in 2098.

The average future cowpea yields projected for mid-century (2031-2060) and late –century (2071-2100) in Ibadan from the outputs of the GCMs showed a decreasing yields of 998 kg/ha (5%) and 5373 kg/ha (21%) respectively. This finding agrees with some other empirical studies previously carried out in Nigeria on the effects of climate change on crop production, all indicating negative impacts on crop production (Ajetomobi and Abiodun, 2010; Oguntunde and Abiodun, 2013; Akinbile *et al.*, 2015; Remirez-Villegas and Thornton, 2015). This indicates that climate variability and change could have a serious negative impact on cowpea production in the future if necessary adaptation and mitigation measures are not put in place in Ibadan in Ona river basin to combat the threats.

CONCLUSION

The effect of climatic parameters on cowpea yield was considered for Ibadan for the last three decades and from the study, monthly climatic variables had more significant impact on the cowpea yield than annual variables. Climatic variables account for 70% variability in cowpea yield for the study area, and the projected 5% and 21% yields reduction in the mid and late century signify a serious threat to food security goals of the country. Therefore, there is a need for a proactive measure to be taken, using possible adaptation and mitigation strategies such as development of effective and affordable irrigation schemes, improved seed quality that can withstand the harsh effects of the climate change and positively influence the yield of the cowpea in Ibadan and Nigeria at large.

REFERENCES

Ajetomobi J.O. and Abiodun A. (2010). Climate Change Impacts on Cowpea Productivity in Nigeria. *African journal of Food Agriculture Nutrition and Development 10(3): 2258-2271.*

Akangbe O.E., Akinyemi J.O., Adeosun O.J., Badejo A. A. and Dairo O.U. (2016). Modelling the Climate Variability Impacts on Maize Yield in Rain Forest Ecological Zone of Nigeria. Proceedings of the 2016 International Conference on SET: A driving force for sustainable development tagged COLENG 2016, Adewunmi J.K., Adekunle A.A., Olayanju T.M.A., Ismaila S.O., Dairo O.U. (eds), Federal University of Agriculture, Abeokuta, March 7-11, 2016.

Akinbile O.C, Akinlade G.M. and Abolude A.T (2015). Trend Analysis in Climate Variables and impacts on Rice Yield in Nigeria. *Journal of Water and Climate Change. DOI: 10.2166/wwc. 2015.044:534-543.*

Amikuzuno J. and Donkoh S.A. (2012). Climate Variability and Yields of Major Staple Food in Northern Ghana. *African Crop Science Journal 20(2):349-360.*

Ayanwuyi E. and Akintonde J.O. (2012). Effect of Climate Change on Cowpea Production in Kuje Area Council, Abuja, Nigeria. *IJARMSS 1(2): 273-283*.

Ayuba H.K., Maryah U.M., Gwary D.M. (2007). Climate Change Impact on Plant Species Composition in Six Semi-Arid Rangelands of Northern Nigeria. *Nigerian Geographical Journal 5(1): 35-42*.

Chai T. and Draxler R.R. (2014). Root Mean Square Error (RMSE) or Mean Absolute Error (MAE)? - Arguments against Avoiding RMSE in the Literature. *Geosci. Model Dev. 7:1447-1250. DOI: 10.5194/gmd-7-1247-2014*.

Changnon S.A. (2001). Thunderstorms Across the nation. Mahomet, Illinois: Changnon. *Climatologist, pp59-76*.

Dai A. (2006). Recent climatology, variability, and trends in global surface humidity. *J. Clim. 19(15), 2197-2225.*

John K. and Olarenwaju A. V. (2014). Effect of Some Weather Parameters on Maize Yield in Ibadan, Southwest, Nigeria. *Int. J. Environ. Eng. Nat. Resour. 1(1): 53-60.*

Kumar M. N., Murthy C. S., Sesha Sai M. V. R. and Roy P. S. (2012) spatiotemporal analysis of meteorological drought variability in the Indian region using standardized precipitation index. *Meteorol. Appl. 19, 256–264.*

L'Hote Y., Mahe G., Some B. and Triboulet J. P. (2002) Analysis of a Sahelian Annual Rainfall index from 1896 to 2000; the Drought continues. *Hydrol. Sci. J. 47, 563–572.*

Liu B., Xu M., Henderson M. and Gong W. (2004) A spatial analysis of pan evaporation trends in China, 1955–2000. J. Geophys. Res. *109, D15102.*

Lobell D.B., Cassman K.G. and Field C.B. (2009). Crop Yield Gaps: their Importance, Magnitudes, and Causes. *Annual Review Environmental Resource 34: 179–204.*

Nicholson S. E., Some B. and Kone B. (2000) An Analysis of recent rainfall conditions in West Africa, including the rainy seasons of the 1997 El Nino and the 1998 La Nina years. *J. Clim. 13, 2628–2640.*

Odjugo P.A.O. and Ikhuoria A.I. (2003). The Impact of Climate Change and Anthropogenic Factors on Desertification in the Semi-Arid Region of Nigeria. *Global Journal of Environmental Science 2(2): 118-126.*

Oguntunde P.G., Abiodun B.J. and Lischeid G. (2011). Rainfall Trends in Nigeria, 1901-2000. *Journal of Hydrology 411:207-218.*

Oguntunde P.G., Friesen J., van de Giesen N. and Savenije H.H.G. (2006). Hydroclimatology of the Volta River Basin in West Africa: Trends and Variability from 1901 to 2002. *Phys. Chem. Earth 31: 1180–1188.*

Ramirez-Villegas J. and Thornton P.K. (2015). Climate change impacts on African crop production. CCAFS Working Paper no. 119. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Copenhagen, Denmark. http://www.ccafs.cgiar.org.

Rimi R. H., Rahman S. H., Karmakar S. and Hussain Sk. G. (2011) Trend analysis of climate change and investigation on its probable impacts on rice production at Satkhira, Bangladesh. *Pakistan J. Meteorol. 6, 37–50.*

Rockström J., Folke C., Gordon L., Hatibu N., Jewitt G., Penning De Vries F., Rwehumbiza F., Sally H., Savenije H. and Schulze R. (2004). A Watershed Approach to Upgrade Rain fed Agriculture in

Water Scarce Regions through Water System Innovations: An Integrated Research Initiative on Water for Food and Rural Livelihoods in Balance with Ecosystem Functions. *Physics and Chemistry of the Earth* 29: 1109-1118.

Roderick M. L. and Farquhar G. D. (2004) Changes in Australian pan evaporation from1970 to 2002. *Int. J. Climatol. 24, 1077–1090.*

Sayegh A.S., Munir S. and Habbebullah T.M. (2014). Comparing the Performance of Statistical Models for Predicting PM_{10} Concentration. *Aerosol and Air Quality Research 14: 653-665.*

Tao F., Zhang Z., Lui J. and Yokozawa M. (2009). Modelling the Impacts of Weather and Climate Variability on Crop Productivity over a Large Area: A New Super-Ensemble-Based Probabilistic Projection. *Agricultural and Forestry Metreology 149:1266-1278.*

Wassmann R., Jagadish S.V.K., Surneth K., Pathak H., Howell G., Ismail A., Serraj R., Redoña E., Singh R.K. and Heuer, S. (2009). Regional Vulnerability of Climate Change Impacts on Asian Rice Production and Scope for Adaptation. *Adv. Agron 102: 99 –133.*

Wild M., Konig-Langlo G and Zurich E. (2009). Global dimming and brightening: An update beyond 2000. *Journal of Geophysical Research Atmosphere 114 (16): 1-30.*

Xu C, Gong L, Jiang T, Chen D and Singh V. P. (2006). Analysis of spatial distribution and temporal trend of reference evapotranspiration and pan evaporation in Changjiang (Yangtze River) catchment. *Journal of Hydrology **327**: 81–93.*

TECHNICAL CAPACITY GAPS AND PERFORMANCE MODELLING IN STATE WATER AGENCIES IN SOUTHWEST NIGERIA

OGUNBOWALE Y.B.[1*], SOBOWALE A.A.[1], DADA P.O.O.[1], OJEKUNLE Z.O.[2]

[1*]*Department of Agricultural and Bioresources Engineering,*
Federal University of Agriculture, Abeokuta.
bolajiogunbowale@yahoo.com
sobowalea@funaab.edu.ng
dadafemo@yahoo.com
[2]*Department of Environmental Management and Toxicology,*
Federal University of Agriculture, Abeokuta, Ogun State, Nigeria.
oojekunle@yahoo.com.

**Corresponding Author*: bolajiogunbowale@yahoo.com

Received: 29 September 2018 *Accepted: 24 December 2018*

ABSTRACT: Access to adequate pipe-borne water is a major challenge in Nigeria. The study evaluated technical capacity gaps and staff performance modeling of Ogun, Osun and Oyo States water agencies (SWAs) in South West Nigeria. Primary data were collected from the agencies and their staffs to elucidate technical capacity, service delivery and job performance. Five Area Offices were selected in each state and pertinent data such as Design Capacity, Installed Capacity, Operating Capacity and current status of water treatment plants were collected alongside data on Staff Years of Experience, Academic/Professional qualification, Job Satisfaction, and other performance indices. Data were analyzed using descriptive and inferential statistics while modeling of variables was done using multiple regression techniques. Results showed that operating capacities were 59.1, 55 and 141 million liters per day (MLD) for Ogun, Osun and Oyo SWAs respectively; individual plants were operating at 0 – 59%, 0 – 83% and 38 – 100 % of installed capacities in Ogun, Osun and Oyo States respectively. The current population coverage was found to be 16.4%, 17.8% and 28.1% of the population in Ogun, Osun and Oyo States respectively, at a mean demand of 70 LCD. Administrative/technical staff mix in each SWAs were adequate; however, it didn't translate to effective service delivery. Senior staffs have better job satisfaction than their junior counterparts. The SWA in Ogun state lacked effective staff succession plan leading to staff replacement problems while that of Osun and Oyo states have training policy in place, but implementation was weak. Staff performance models shows weak correlations with R^2 between 0.29 – 0.51. A sustainable development framework for closing identified gaps was suggested.

Keywords: Water Supply, Performance, Capacity, Job Satisfaction.

INTRODUCTION

The importance of water to man cannot be over-emphasized, it holds the most important benefit to man's sustenance but unfortunately in Nigeria water crisis remain a major challenge. Ishaku et al., (2011) asserted that access to potable water is measured by the number of people who have reasonable means of getting an adequate amount of water (quality and quantity) that is safe for drinking, washing and essential household activities. However, it is unfortunate that Nigeria is one of the countries in sub-Saharan Africa whose records on general access to water supply by the citizens is unsatisfactory. Nigerian cities in particular are experiencing a rise of squatter settlements, overcrowded dwellings, inadequate water supply and human mortalities in such areas is caused by lack of safe drinking water supplies (WHO, 2010; Nwankwoala, 2011). Water demand in Nigeria is increasing, and water shortages in metropolitan areas remain a great concern, limits to water availability are imposed by a number of factors such as droughts, government policy, and cost of providing clean water. Although some states in Nigeria are making significant progress in addressing the

challenges of water supply, the general poor state of water supply in Nigeria, calls for a better understanding of the constraints and challenges.
According to Okeke *et al*. (2016), about 18 and 46 people out of 100 Nigerians had access to piped water and safe water respectively. These values were lower than the values obtained in other regions of the world which indicates that Nigeria needs to improve access to safe water. Adah and Abok (2013) opined that in Sub-Saharan Africa, water institutional capacity is one of the major problems and people are unaware that water is a finite resource and that there is a cost to using it. Ali (2012) attributes poor water supply to be as a result of poor infrastructure, inadequate technical capacity and absence of appropriate regulatory framework. To this effect, Nigeria got listed among the few countries which did not meet the millennium development goal which addressed the reduction by half the global population without access to improved water sources (UNICEF/WHO, 2012; Omole *et al.,* 2013). Presently, Nigeria is facing a lot of challenges relating to potable water supply, some of the problems includes low piped water coverage and unaccounted water losses. Berta *et al.,* (2015) reported that water coverage was 41% and 40% in year 2012 and 2013, also the number of people with accces to public standing tap was below average and unaccounted water losses was recorded to be 34% and 39% in 2012 and 2013 respectively and this was largely due to water pipe leakages and poor water metering.

Several agencies have been put in place for the management of water resources and provision of water services infrastructure in the country. At the Federal level, there is the Federal Ministry of Water Resources (FMWR) with the mandate for development of overall policy and regulatory mechanism for water development and utilization. Adoga, (2006) stated that in Nigeria, potable water supply is a state responsibility and towards this end, state governments have created State Water Agencies (SWAs) – Water Boards and water Corporations. They have the responsibility of providing urban, semi-urban and in some cases, rural water supply. Paradoxically, irrespective of proliferation of water works in the country coupled with a robust policy that spells out strategies and attainable targets, the water situation in Nigeria could be best described as precarious, over the years, improvement in domestic water supply has not been impressive. According to UNICEF (2012), improvement on access to safe water is a crucial to man's survival and Nigeria is not on course towards sustainable drinking water supply. Therefore, this paper examines the technical capacity gaps and staff performance in State Water Agencies in Southwest Nigeria and makes recommendations for sustainable water supply in Nigeria.

MATERIALS AND METHODS

Description of Study Area

Southwest region is one of the Geo-political zones in Nigeria.The region is dominated by the yoruba tribe.The three main religion are Christainity, Islam and Traditional religion. The region consists of six states comprising Oyo, Ogun, Osun, Lagos, Ekiti and Ondo States.

Ogun State was chosen because of its increasing population. The state has emerged as one of the fastest growing business destination in Nigeria, with several local and international businesses and factories located at some strategic areas. Ogun State is bordered by Lagos to the south, Oyo and Osun States to the north, Ondo State to the east and Republic of Benin to the west. The state is situated between Latitude 6.2°N and 7.8°N and Longitude 3.00 E and 5.00 E. The mean annual rainfall varies from 1280 mm in the southern parts of the State to 1050 mm in the northern areas. The average monthly temperature ranges from 23°C in July to 32°C in February and the geographical landscape of the state comprises extensive fertile soil suitable for agriculture, vast forest reserves, rivers, lagoons, rocks and mineral deposits (Odjegba *et al.,* 2015).

Osun State is an inland state in the southwest region of Nigeria.The State share the same geological and climatic characteristic with other southwest states of Nigeria. Its covers a total land area of approximately 8,602 km^2 and lies between 300 m and 600 m above the sea level with a largely gentle and undulating landscape. The average rainfall ranges from 1125mm in derived savannah to 1475 mm in the rain forest belt. The mean annual temperature ranges from 27.2°C in the month of June to 39.0°C in December. The soil types are varied but mostly contain a high proportion of clay and sand, and are mainly dominated by laterite (Adisa and Sofoluwe, 2013).

Oyo State was selected because of its historical background, population and the state equally share the same climatic characteristics with other States in Southwest Nigeria. Climate is equitorial, notably with dry and wet seasons with relatively high humidity. The dry season starts from November – March while wet season is from April – October and the average temperature ranges between 25 ^{0}C and 35 ^{0}C, almost through out the year.

Data Collection

In order to assess the capacity gaps in SWAs in the selected states two surveys were conducted to elicit both primary and secondary data useful for the study. These surveys were replicated in each state, and include: Institutional Assessment Survey and Water Agency Staff Survey. The survey instruments used were well structured questionnaires and personal interview schedules which were administered between 2016 and 2017.

Sampling Techniques and Sample Size

Owing to the enormity of the study, a multistage sampling technique was adopted as follows:

a) Stage one: A well-structured questionnaire was administered to each of the SWAs of the states considered. The questionnaires were completed on behalf of each SWA by their respective heads of Research and Planning Department.

b) Stage two: With the help of the Business Managers/Administrators of the five (5) selected Area offices of the SWAs, sixty (60) well-structured questionnaires were administered to staff as presented in tables 1.

Table 1: Distribution of Questionnaires for Staffs Survey in Ogun, Osun and Oyo State

Area Offices	No. of Questionaires Distributed	No. of Questionaires Retrieved	Recovery Rate (%)
Ogun State			
HQ	60	7	12
Ilaro	60	5	8
Ijebu-Ode	60	6	10
Ijebu- Igbo	60	11	18
Ota	60	5	8
Total	300	34	11
(Osun State)			
Osogbo	60	42	70
Iwo	60	40	67
Eko-Ende	60	40	67
Ilaorangun	60	41	69
New- Ede	60	45	75
Total	300	208	69
(Oyo State)			
Ogbomoso	60	41	68
Oke- Ado	60	40	67
Oyo	60	34	57
Eleyele	60	37	62
Saki	60	40	67
Total	300	192	64

Source: Field Survey 2017.

Generalized Model

The study proposes a model to evaluate the relationship between SWAs staff years of experience and job satisfaction on key performance indices using multiple regression analysis, the equation for the analysis has the form:

$$YE = \alpha + \beta_1 FS + \beta_2 QS + \beta_3 CS + \beta_4 WT + \beta_5 WP + \varepsilon \qquad .... \quad (i)$$

$$JS = \alpha + \beta_1 FS + \beta_2 QS + \beta_3 CS + \beta_4 WT + \beta_5 WP + \varepsilon \quad .... \quad (ii)$$

where:

YE - Years of Experience
JS - Job Satisfaction
FS - Frequency of Water Supply
QS - Quantity of Water Supplied
CS - Customers Satisfaction
WT - Water Tariff
WP - Willingness to Pay
ε - Root mean square error term

Data Analysis

Analysis of data involve the use of descriptive and inferential statistical tools such as mean, median, standard deviation, frequencies, ANOVA, Duncan Multiple Range Tests and Multiple Regression. The analysis was done using the SPSS® software.

RESULTS AND DISCUSSION

Technical Capacity of Ogun State Water Corporation (OGWSC)

Most of the water supply schemes in Ogun state were commissioned between 1960 and 1990, as at 2015, the total installed water production capacity was 212.76 MLD; while the agency was operating at 59.1 MLD, representing about 28% of installed production capacity. A total of 60 water supply schemes are currently in existence in the state, however, many of the schemes are non-functional indicating many years of neglect due to weak funding mechanism; When individual schemes were examined, the study revealed that all of them were operating at a range of 0 – 59 % of their installed production capacity. The big schemes at Abeokuta New (82 MLD), Abeokuta Old (15 MLD), Yemoji (17.2 MLD), Apoje-Igbo (18 MLD) and Ifo-Akinside (12 MLD) were operating at 46.3%, 24.3%, 25.3%, 13.4% and 9.8% of their installed capacities respectively. The result shows that potable water demand clearly surpassed available supply; thus creating a serious deficit and the people resorting to self-supply from unprotected sources. Moreover, Ufoegbune *et al.*, (2010), reported that the first water scheme in Abeokuta was commissioned in 1914, and was designed to supply water to a population of 40,000; in 1962, the water works was upgraded to 7MLD to serve a population of about 180,000. The new water scheme was redesigned to supply 163MLD; however, only 82 MLD was installed. Considering the current operating capacities across the state, and using a mean demand of 70 LCD, the present production capacity will only be able to supply 844,286 persons with potable water. This population is approximately 16.4% of the projected population of the state for 2018, indicating a serious water supply deficit.

Table 2: Water Demand Projection in Nigeria

Settlement (Water Supply) Category	Category on Water Demand Projection	Per Capita Consumption	
1	Urban	Urbanized water usage	120 lit/cap/day
2	Semi-Urban or Small Town	Semi-urbanized water usage	60 lit/cap/day
3	Rural	Ruralized water usage	30 lit/cap/day

Source: Federal Ministry of Water Resources (FMWR), 2014.

According to OGSWC (2010), Ijebu Ode in Ogun State suffers from limited water supply, and present water supply coverage is about 40%. Available water from existing water treatment plant is adequate to supply about 50% of the total estimated water demand of the inhabitants of the city (14,100 m^3/day out of the needed 28,200 m^3/day) of the existing plant after rehabilitation. However, the major problem is water loss due to leakages from poorly maintained water pipelines. However, most households still depend on hand - dug wells, water tankers and boreholes for water supply. Heavy reliance on water from alternative and unsafe sources has adverse effect on the population. Aderibigbe, *et al.*, (2008) stated that using unsafe sources has its consequences resulting in water related diseases. John-Dewole (2012) reported that water from unreliable sources are usually contaminated and often times unfit for human consumption. OGSWC should pay attention to the state of its infrastructure across the city. This was corroborated by the work by Pietrucha-Urbanik (2015) which stated that there should be constant monitoring of the pipe distribution network to check for leakages and for prompt repairs when discovered and also it is important for members of the public to report cases of pipe vandalism and destruction so that the quality of the water distribution network is preserved.

Figure 1 reveals that population increase in Ogun State has not been accompanied by significant increase in water demand therefore water supply demand-gap increase with population size. This was corroborated by Odjegba *et al.*, (2014) which noted that water supply in Abeokuta has been far from adequate due to the progressive decline in accessibility and reliability, this was due to the continuous population growth and expansion of the city. From this study, OGSWC production is not commensurate with water demand, the water supply infrastructure show extensive deterioration and poor utilization of existing capacities, due to under-maintenance and lack of funds for operation. For instance, OGSWC is presently operating in year 2018 at 59.1 MLD which is far less to 2018 projected water water demand of 359.2 MLD. Water demand deficit will continue if not checked, hence, necessary facilities should be to put in place through adequate finance and expansion of water works in order to improve production capacity of the SWA as the population of the State increases.

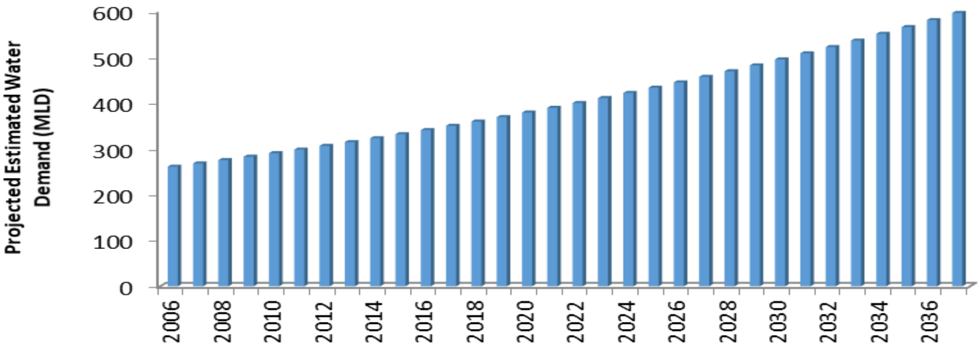


Figure 1: Projected Water Demand from 2006-2037 in Ogun State, Nigeria.

Technical Capacity of Osun State Water Corporation (OSWC)

OSWC is responsible for effective drinking water service provision in Osun state. It provides bulk water supply to many cities and towns, the agency was established by Osun State Government in 1991 when the state was created from the old Oyo State. All the existing fifteen (15) water shemes found in the state are government owned. Osun State Water Corporation is currently trying to produce as much water as it can in, a very constrained operating environment and with a production capacity insufficient to supply the existing water needs (the design capacity of water plants often cannot be attained because of the deteriorated state of facilities and erratic power supply). The current total water production capacity of OSWC is 54.83MLD conpared to 238.59MLD installed capacity. However, taking into account, 2018 projected population of 4,713,240, the average water coverage of piped water in Osun state is estimated at 16.6%, using the average mean demand of 70 LCD, indicating that only 783,286 water users can be supplied daily. It is important to emphasize that water schemes in Osun state are not operating at reasonable capacities and are constrained by power unreliability; this has major effect on the operations of all the water schemes in the state. Furthermore, there is high rate of unaccounted-for-water in most of the houses supplied as water is not metered and this has compounded the problem of inefficient operations.

Figure 2 shows that the projected water demand in Osun State range from 239.6 – 557.7 MLD for 2006 – 2037, the expected increase in water demand will be due to expected population growth. The present population of 4,713,240 (2018) has a projected water demand of 329.9MLD, which is a far cry from the existing production. Ameyaw and Chan (2015), stated that the potentials of existing urban water supply infrastructures were not fully utilized owing to mismatching of water supply and demand and the poor and declining operational efficiencies of the waterworks among other factors. According to Sojobi (2016), some other challenges include but not limited to increasing urbanization rate, inadequate technical dimension, inadequate management capacities and poor governance, inappropriate institutional frameworks, inadequate legal and regulatory framework.

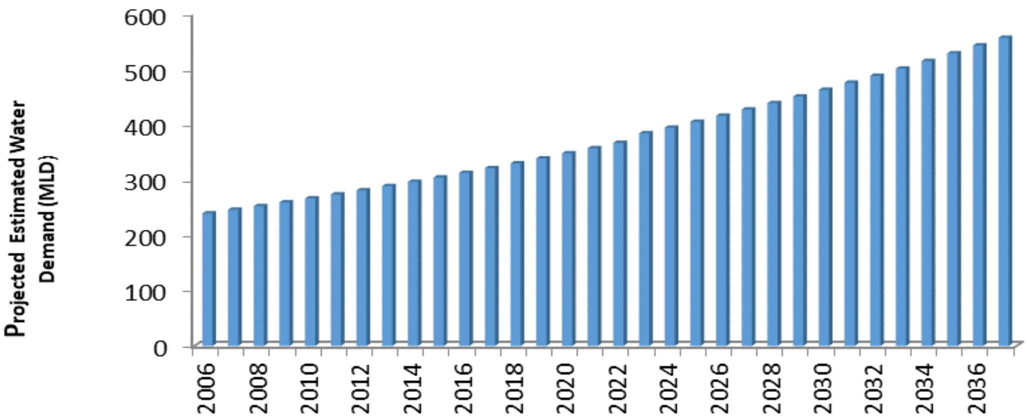


Figure 2: Projected Demand from 2006 -2037 in Osun State, Nigeria.

Technical Capacity of Water Corporation of Oyo State (WCOS)

WCOS is the major agency of Oyo State government charged with the mandate to deliver safe and adequate water to the people. The Water Corporation has been in operation for the past 40 years, as it was created on the 1st of July, 1976. The functions of the Corporation include effective drinking water supply to the general public; conduct researches relative to water supply; prepare master plans necessary for the development and maintenance of its undertakings; construct, operate and maintain waterworks; water stations; necessary for the discharge of its functions. Over the years, the conditon of water infrastructures in Oyo state had been worrisome and the situation on ground is worrisome inspite of numerous effort by government and development. Presently, the existing operating capacity of WCOS is 141 MLD as against 247 MLD installed capacity, the diminished water production of WCOS together with an increased population has made it difficult to satisfy the water demand of the current 7,698,039 (2018) inhabitants of the state. To further examine the water supply/demand situation of Oyo state, 2018 projected piped water coverage is estimated at 26.2% of the present population.

Figure 3 shows that, the projected water demand in Oyo State from 2006 – 2037, with many facilities not operational and thus Oyo SWA is currently unable to meet the existing water demand. Limited funds have led to under-investment in new and expanded capacity while preventing the periodic replacement of the aging components of existing facilities. However, Adekalu and Ojo (2002) reported that due to deficiencies in piped water availability, households invest in coping strategies in the form of alternative supplies and storage facilities to supplement piped water and more than half of the total respondents in Ibadan city indicated borehole/well as the source of water they used most frequently, while, in Ibadan rural communities, river/stream is the commonest and most available source of water they use.

Capacity Development in SWAs

Figure 4 present the staff response on availability of training policy and implementation in Ogun State. The study reveals that 43%, 64%, 50% and 60% of staffs in OGSWC Headquater, Ijebu – Igbo, Ijebu – Ode and Ilaro confirmed that there existed a training policy in the organization and some staffs are not sure of such policy. Moerover, there were mixed reactions on non-implementation of the training policy in Ijebu- Ode and Ijebu- Igbo as approximately 50% of the staff asserted that the training policy is not implemented, while 60% are not sure. Guest (1997) mentioned in his study that training and development programs as one of the vital human resource management practice, positively affects the quality of the workers knowledge, skills and capability and thus results in higher employee performance on the job. This relation ultimately contributes to organizational performance. However, the management of OGSWC need to improve on the implementation of the staff training policy, this is an important motivational tool that ensure enhanced service delivery. Training should cover all staff cadre and should be job specific and relevant to the achievement of the SWA's goals and strategy.

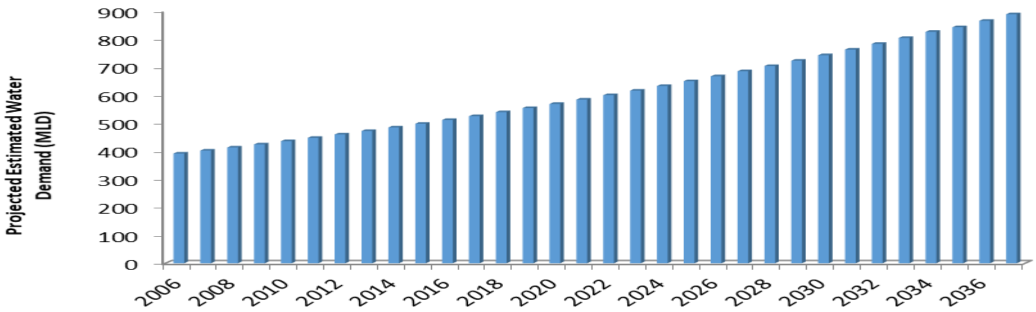
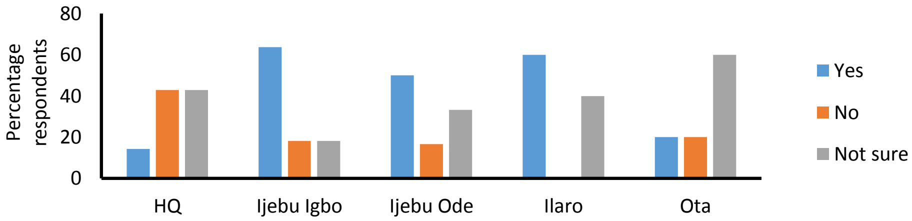
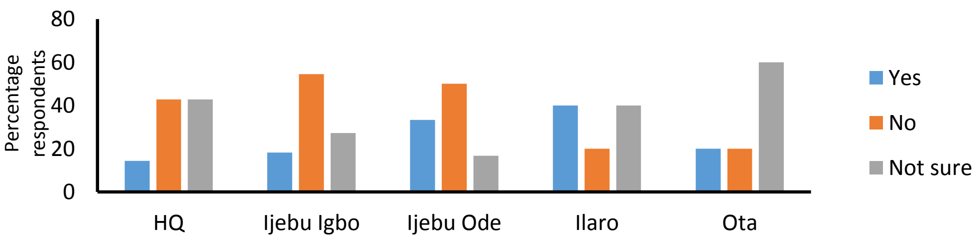


Figure 3: Projected Water Demand from 2006 – 2037 in Oyo State



a: Availability of Staff Training Policy

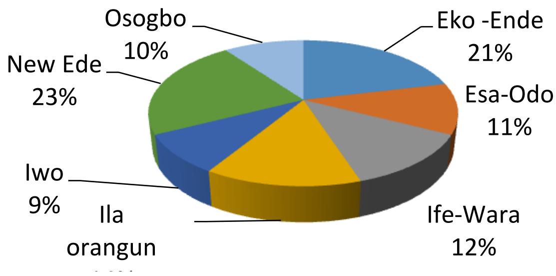


b: Implementation Staff Training Policy

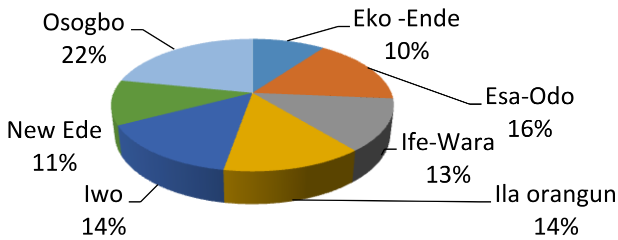
Figure 4: Staff Training and Professional Development in Ogun State

Figure 5 shows the perception of OSWC staff on training policy. This indicated that staffs New-Ede and Eko- Ende are most exposed to training. This study found that though there was trainning policy in OSWC, they are either inadequate or not being implemented equitably. According to Wright and Geroy (2001), staff competencies changes through effective training programs, it not only improves the overall performance of the staff to effectively perform the current job but also enhance the knowledge, skills and attitude of the workers necessary for the future job, thus contributing to organization efficiency. Through training the staff, competencies are developed.

Figure 6 shows the perception of WCOS staff on training policy, many of the respondents stated that there is existence of training policy in iseyin, Ogbomoso, Oke- Ado, Oyo and Saki Area offices, but, implementation is very weak. Previous studies provides the evidence that there is a strong positive relationship between staff capacity development and organizational performance without proper training, staff both new and current do not receive the information and develop the skill sets necessary for accomplishing their tasks at their maximum potential, staff who undergo proper training tend to keep their jobs longer than those who do not (Purcell *et al.*, 2003).



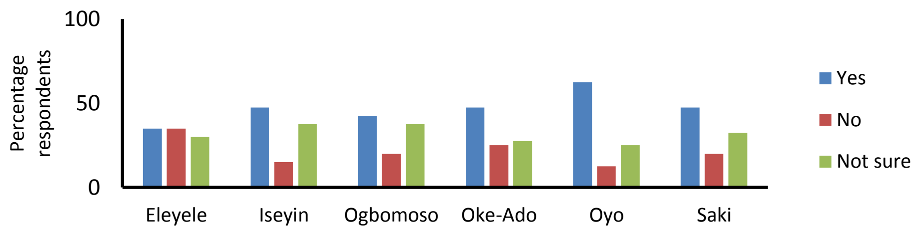
a: Availability of Staff Training Policy



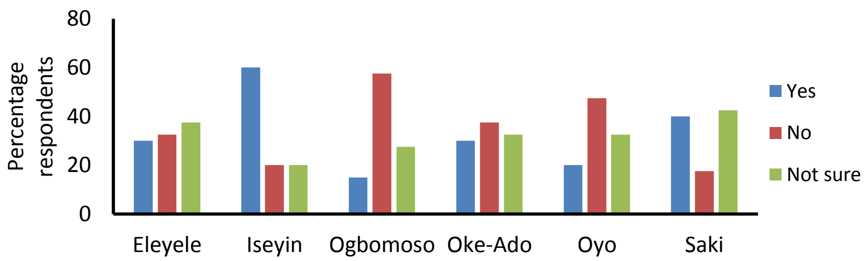
b: Implementation Staff Training Policy

Figure 5: Staff Training and Professional Development in Osun State

Chandrasekar (2011) opined that there is the need for increased investment in training and development of staffs in order to increase staff productivity. Effective training policy implementation will enchance better management of infrastructure, improved project coordination as well as proactive maintenance. This will help to large extent for sustainable water supply in Oyo state.



a: Availability of Staff Training Policy



b: Implementation Staff Training Policy

Figure 6: Staff Training and Professional Development in Ogun State

SWA Performance Model

Ogun State Water Corporation Performance Model

For several years, poor utility performance of SWA has been one of the main concerns in Ogun State. This study assessed the SWA capacity gaps and consequently the way it affects the sub-optimum operating capacity of the various water schemes in the State. The model for Ogun SWA is shown in equation iii:.

$$YE_g = 4.24 - 0.17FS_g - 0.99QS_g - 0.731CS_g - 0.45WT_g + 1.09WP_g \quad \text{(iii)}$$

At 95% confidential level and 0.51 coeficient of determination (R^2), the result indicated that the staffs despite their several years of working experience do not translate to increase in frequency and quantity of water supply, customer satisfaction and willingness to pay for water by water users due to lack of effective training policy in SWA. Stone, (2002), buttressed this by the fact that training has the distinct role in the achievement of an organizational goal by incorporating the interests of organization and the workforce. Training is important to enhance the capabilities of staff members. According to Rasheed *et al*.(2010), higher working experiece reflects better job performance. However, OGSWC staffs need necessary support and incentives such as grants to promote staff career development in their various discipline of study and this will commit them to be more proactive and productive and to a large extent, improve the efficiency of the State Water Corporation.

The model relating job satisfaction of SWA staff and performance indices in Ogun State is presented in equation (iv), at 95% confidence level, R^2 was 0.29 indicating weak correlations.

$$JS_g = 1.55 - 0.20FS_g + 0.12QS_g - 0.08CS_g + 0.11WT_g + 0.47WP_g \quad \text{(iv)}$$

The study further revealed that there seems to be misconception about job satisfaction in SWAs, as majority of the senior the staff members said they have job satisfaction while most of the junior staffs registered displeasure about job. The SWA performance depends on the Staffs job satifaction because it is important in the growth and the organizational performance. Baron, (1996) pointed out the importance of job satisfaction in an organization, especially, in terms of its efficiency, productivity and staff relations. Rad *et al.* (1995), posited that Job satisfaction suggest a workforce that is motivated and committed to high-quality performance. So to improve staffs performance, staffs capacity building such as trainning and retraining of staff on operational and utility of water supply should be put in place.

Osun State Water Corporation Performance Model

Modeling the relationship between staff years of experience and key performance indices in OSWC produced the model stated in equation (v), a poor correlation was observed at 95% confidence limits and R^2 of 0.02.

$$YE_s = 5.231 - 0.05FS_s - 0.24QS_s - 0.40CS_s - 0.02WT_s - 0.08WP_s \quad \text{(v)}$$

The model indicated that years of experience has no direct effect on service delivery. Although, the SWA in the State still have active staff members who have the strength to execute specific assigned duties but are unwilling due to lack of job satisfaction and non - implementation training policy. According to Workforce Special Report (2006), spending on training should increase because organizations will get more efficiency and effectiveness. Equation (vi) shows the model relating staff job satisfaction with key performance indicators.

$$JS_s = 1.898 - 0.003FS_s + 0.023QS_s - 0.090CS_s - 0.010WT_s + 0.146WP_s \quad \text{(vi)}$$

The was no visible correlation between the parameters, however, when staff are well motivated, it has a way of fostering effective service delivery. Motivation of staffs goes a long way in determining the success of an organization and also for the growth of individual employees (Meyer *et al.*, 2006).

Water Corporation of Oyo State Performance Model

Modelling of staff years of experience with key performance indicators in WCOS indicated very poor correlation showing that staff years of experience has little to do with service delivery. Highly motivated staffs with short duration years of experience are capable working his best to meet organizational goals. The model is presented in equation (vii).

$$YE_y = 3.78 - 0.03FS_y - 0.10QS_y - 0.12CS_y + 0.01WT_y + 0.11WP_y \qquad \text{(vii)}$$

It is advised that WCOS evolve a staff sucession plan which will involve mentoring of the younger workforce. The staff mix need to be approximately balanced to achieve the needed service delivery. It is recommended that WCOS should create a balanced age structure and establish a combination of both younger and older professional staff that are able to provide the needed capacity, knowledge and expertise to implement the variety of maintenance and project works for effective, adequate and sustainable water supply in the State. According to Abolagba *et al,* (2003), workforce, in their prime age are expected to be highly productive.

$$JS_y = 2.34 - 0.08FS_y + 0.04QS_y + 0.06CS_y + 0.05WT_y - 0.07WP_y \qquad \text{(ix)}$$

There was a very weak correlation between job satisfaction and service delivery indicators. The findings was similar to that by Iliyas (2006) in Kano, he observed that the challenges faced by public water supply institution led to among others poor attitude to work, poor motivation and irregular remuneration. The challenges have also resulted to low productivity; hence SWA cannot meet the supply of water to the populace.

Sustainable Development Framework for SWAs in South West Nigeria

Figure 7 describes the suggested framework for SWAs development in Southwest Nigeria. Adequate water infrastructural development is a veritable tool for achieving sustainable water supply; water should be availabe at affordable cost, and staff exposure to on – field experience coupled with an effective staff succession plan and staffs motivation will go a long way to enhance SWAs staff efficiency and effectiveness. Presently, SWAs in Southwest Nigeria are facing under-investment in water infrastructural development; in order to overcome this, all the SWAs should be unbundled. SWAs unbundling will ensure optimum performance of the various states water corporation, it will also curb corruption and mismanagement of resources. However, during the unbundling process, government should be more objective and setup well-defined and sustainable institutional and legal frameworks that will ensure a win – win utopia.

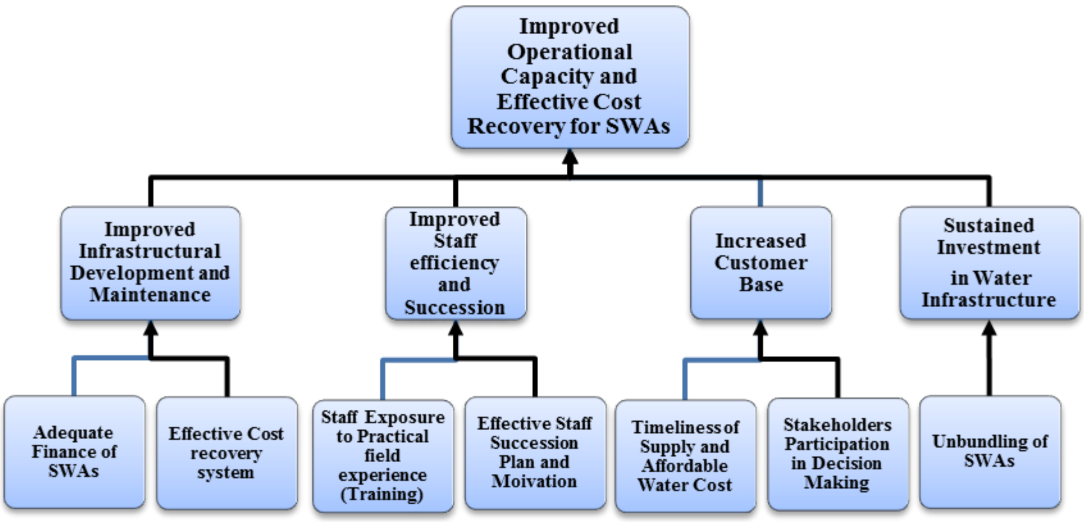


Figure 7: Suggested Sustainable Development Framework in SWAs

CONCLUSIONS

The study revealed that all SWAs evaluated are operating below their installed capacity, vast number of equipment and facilities were found to be obsolete and require replacement. Presently, water demand in all States surveyed is not commensurate with potable water supply and population increase has led to growing need for further investment in the water supply sector. Limited funds have led to under-investment in SWAs while preventing the periodic replacement of the aging components of existing facilities. However, SWAs should be concerned about the impending knowledge loss and expertise on how to run water facilities as old staffs in the field retire. For sustainable water supply, an effective framework should be put in place such as staff capacity building through training and retraining of technical staff in order to handle new task, also SWAs should be unbundled in a manner that will exhibit seriousness from all the partners concerned as recommended by the World Bank, because government alone cannot efficiently finance SWAs.

REFERENCES

Adah, P.D. and Abok G. (2013). "Challenges of Urban Water Management in Nigeria": *The Way Forward, J. of Environmental Sciences and Resource Management, Vol.5* (1): 111-121.

Ali, K. A. (2012) "Development of Water Supply Infrastructure in Nigeria: Challenges and Prospects.". Delivered at the 2012 Nigerian Society of Engineers October Lecture. October 04, 2012 Accessed on 12/10/14 and Available at www.nse.org.ng. Vol. 39 (3) : 20- 61

Adekalu, K.O and Ojo, O.E . 2002. Water Sources and Demand In SouthWestern Nigeria: *Implication for Water development planners and Scientist*. ScienceDirect. Vol 22, issue 12, December 2002: 299-80

Aderibigbe, S. A., Awoyemi, A. O., and Osagbemi, A. O. "Availability, Adequacy and Quality of Water Supply in Ilorin Metropolis, Nigeria." *European Journal of Scientific Research.* 23, no.4 (2008): 528 – 536

Adisa O. D. and Sofoluwe N. A (2013). "Economic analysis of selected food crops in Ile-Ife of Osun State, Nigeria" *Global Journal of Agricultural Economics and Econometrics*, Vol. 39: 2.

Adoga, O. (2006). Nigerian Water Policy and Law: A Need for Global Compliance., *Water Supply and the Urban Poor*. In: The Poor Die Young, J.E. Hardoy, *et al*., (Ed.), 1st Edn., Earthscan Publications, London: 109-126, http://www.martindale.com/natural-resources-law/article-240640.html

Abolagba B. and Fajimi (2003). "Toward equitable and sustainable rural water supplies: A contingent valuations study in Brazil". *World Bank Economic Review* 4 (2) : 115-134.

Ameyaw, E. E., and Chan, A. P. C. (2015). Evaluation and ranking of risk factors in public private partnership water supply projects in developing countries using fuzzy synthetic evaluation approach. *Expert Systems with Applications, 42*: 23–51.

Baron B. (1996). Environmental Engineering 1, Water Supply Engineering, Laxmi publications (P) Ltd, Daryagani, New Delhi : 156 – 158.

Berta M. Alexander D. Roohi A. Abel B. and Joe M. (2015). State Water Agencies in Nigeria Performance Assessment.. *International Bank for Reconstruction and Development/The World Bank* .www.worldbank.org: 24-67.

Chandrasekar, K. (2011). "Workplace environment and its impact on organisational performance in public sector organisations", Alagappa University, Karaikudi, India. *International Journal of Enterprise Computing and Business Systems,* Vol. 1: 1-20.

Federal Republic of Nigeria Federal Ministry of Water Resources (FMWR), (2014). *The Project for Review and Update of Nigeria National Water Resources Master Plan* , Volume 5, National Water Resources Master Plan 2013 Official Dissemination Version: 15.

Guest, D. (1997), "Human resource management and performance: a review and research agenda", *International Journal of Human Resource Management*, Vol. 8 (3): 263-76.

Iliyas, M.H. (2006), "Strengthening the capacity of water utilities to deliver water and sanitation services, *environmental health and hygiene to low income communities," Water utilities project* No. 5. Ungogo Local Government, Kano town, Nigeria: 12- 26.

Ishaku H.T, Rafee, M. Majid, A. P. Ajayi, A. Haruna, (2011). "Water Supply Dilemma in Nigerian Rural Communities: Looking towards the Sky for an Answer", *Department of Urban and Regional Planning, Faculty of Built Environment, Universiti Teknologi Malaysia, Johor Bahru, Malaysia,* 2. *Department of Urban and Regional Planning, Federal University of Technology, Yola, Nigeria, Journal of Water Resource and Protection*, 2011, (3): 598-606

John-Dewole, O.O. (2012), Adverse Effects of Inadequate Water Supply on Human Health: a case study of Kajola Local Government in Oyo State, *Nigeria Greener Journal of Medical Sciences Vol.* 2 (5): 115-119.

Nwankwoala, H.O. (2011), "Groundwater resources of the Niger Delta: Quality implications and management considerations", *J. of International Review of Water Resources and Environmental Engineering*, Vol.6 (5):155-163.

Odjegba, E. E., Idowu, O. A., Oluwasanya, G. O., Ikenweiwe, N. B. and Martins, O. (2014) “Assessment Of Water Demand and Seasonal Variation of Bacteriological Content of Public Water Systems in Abeokuta, Nigeria.” Conference Proceedings of the 7th Annual Institute of Ecology and Environmental Studies International Conference, June 24 – 26, 2014, Obafemi Awolowo University, Ife, Nigeria 7,): 256 – 262

Odjegba E. Idowu, O. Ikenweiwe, B. (2015). Public Perception of Potable Water Supply in Abeokuta South west, Nigeria. *College of Environmental Resources Management, Federal University of Agriculture, Abeokuta.* Vol. 19 (1): 5 – 9

Okeke, I., Oyebande, L., and Odunuga, S. (2016). The application of rural threshold water consumption model in water supply studies. *Risk in Water Resources Management. Proceedings of Symposium* H03, IUGG 2011, Melbourne, Australia, July 2011, IAHS Publication : 235–240.

Purcell, J., Kinnie, N., Hutchinson, S., Rayton, B. and Swart, J. (2003),Understanding the People and Performance Link: Unlocking the Black-Box. Research Report, CIPD, London. Vol. 4 (5): 58-101

Pietrucha-Urbanik, K. (2015). Failure analysis and assessment on the exemplary water supply network. *Engineering Failure Analysis, 57*, 137–142. https://doi.org/10.1016/j.engfailanal.2015.07.036

Rad., M. Maxwe G.,(1995) “From Hand Pumps to Health: The Evolution of Water and Sanitation Programmes in Bangladesh, India and Nigeria”, United Nations Children’s Fund, New York, NY, U.S.A: 12 – 26

Rasheed, M.A., R.A. Youssef, E.I. Gaber, A.A. Abd El Kader, N.H. Abou-Baker, (2010). The Combined Effect of Organic and Chemical Fertilizers in Relation to Water Irrigation on Nutrients Uptake of Corn and Bean Plants. Plant Stress, 4(1): 64-71.

Stone R J. (2002), Human Resource Management 2nd Edition, Jhon Wiley & Sons 2002. 2. Fakhar Ul :12-45

Sojobi, A. O. (2016). Evaluation of groundwater quality in a rural community in North Central of Nigeria. *Environmental Monitoring and Assessment, 188*(3): 1–17.

Ufoegbune G. C., Eruola A. O., Awomeso J. A. and Idowu O. A. (2010). “Spatial analysis of municipal water supply in Abeokuta metropolis, South western Nigeria*”. Department of water resources management and agro-meteorology, University of Agriculture, Abeokuta,* 110001, Nigeria: 110 – 180

ASSESSMENT OF SEEPAGE IN OBA DAM USING FINITE ELEMENT METHOD

OLONADE K. A.[1*] and AGDEDE O. A.[2]

[1*]*Department of Civil and Environmental Engineering, University of Lagos, Nigeria*
olonade1431ah@gmail.com
[2]*Department of Civil Engineering, University of Ibadan, Nigeria*
oluwoleagbede@yahoo.com

*Corresponding Author: *olonade1431ah@gmail.com*

Received: 18 September 2018 *Accepted: 24 December 2018*

ABSTRACT: Seepage is a major cause of dam failure for causing internal errosion. Flow net method is common method to evaluate seepage for its simplcity but becomes rigurous with large dams. In this paper, Finite Element Method (FEM) was employed to study seepage behaviour in Oba dam. Oba Dam is a major source of water to a university community in Southwest, Nigeria. Finite Element formulation of the governing equations was developed and computer programme was written to solve it. The bottom of the dam was meshed using rectangular element mesh (160 elements), while the piezometric heads at nodal points were determined. Coordinates that defined the phreatic surface of the seepage were also evaluated. The results obtained were compared with those obtained from flow net approach, which served as control using t-Test technique. The results showed that the potential heads reduced from 5500 at the node 1 to 355 at node 160, which were about 2% lower than the values obtained from flow net (5390 and 348, respectively), while the coordinates of the phreatic surface ranged from 5.4 m to 2.4 m in the span of 36 m as obtained from FEM, but ranged from 5. 5 m to 2.2 m for the same span, using flow net method. Analysis of variance conducted on the obtained data indicated that there was no significant difference ($p > 0.05$) between the results. Thus, FEM would seemed appropriate for the study. The added advantage of the FEM is that simulation of the seepage problems of the dam becomes easier.

Keywords: Finite Element, seepage, Oba dam, piezometric head, phreatic surface.

INTRODUCTION

Dams are constructed for specific purposes, such as hydropower, navigation, flood control, water source, or recreation. Despite the fact that dams hold water for future use, the destructive effect of water on dams is enormous. Experience shows that mankind has feared and respected the destructive power of water. Thandaveswara (2009) collated cases of dam failure in selected countries and untold damages they have caused, which stressed that failure of dam could be catastrophe.

A number of factors have been identified as causes of dam failure. Punmia and Lal, (1992) attributed 40% of failure to hydraulic effect, 30% to seepage, while structural failure is responsible for the remaining 30%. In his study, Arora (2001) also reported that about 35% of failures of earth dams are due to hydraulic failures, while 30% are attributed to seepage failures and about 20% are as a result of structural failure. The remaining 7% of the failures are due to other miscellaneous causes such as accidents and natural disasters. All dams, especially earth dams, are prone to seepage as the impounded water seeks paths of least resistance through the dam and its foundation. Seepage becomes a concern, if it is carrying material with it, and should be controlled to prevent erosion of the embankment, or foundation, as well as damage to concrete structures (NDSPRNW, 2006).

The seepage of water through a media has long being studied and found to obey Darcy's law, which correlates the seepage quantity through soil to directly proportional to the permeability coefficient, hydraulic gradient and cross-sectional area. In the development of Darcy's law, it was assumed that the soil is isotropic and that the domain was saturated. But the law could be modified to study seepage through anisotropic and unsaturated domain, though the equations become more complex to solve (Rice and Duncan, 2010). Researchers have evolved different methods to study and monitor seepage in dams in order to forestall intending failure. Such methods include analytical, electric analogy and flow net techniques (Ali, S., and Fardin, 2005; Abdullahi et.al, 2000, and Fu and Jin (2009). Billstein et al. (1999) used experimental models to determine discharge, pore water pressure, seepage face and free surface profile.

More recently, FEM is being used due to advancement in computing system. Several authors such as Rushton and Redshaw (1979), Papagianakis and Fredlund (1984), Lam et al (1988), Potts and Zdravkovic (1999) as well as Darbandi et. al. (2007) had performed seepage analysis through an embankment dam using finite element method. In the work of Shivakumar et al. (2015), FEM was employed to determine seepage face of an earth dam, while varying Young Modulus and angle of internal friction of the material from which the dam was made of. Their results were compared to those obtained from the limit equilibrium method. They found that FEM was more precise. Agbede (1989) presented a computer simulation of the flow of groundwater through a porous medium in the Northern State of Nigeria.

Oba dam is located at the University of Ibadan, Nigeria. Since the movement of the university to its present site, the water supply within the university had been erratic until Oba dam was built across Oba River in 1972. The dam is located at the southeastern fringe of the university campus between sokoto road and the road leading to the Vice-Chancellor's lodge. The dam was constructed of earthen materials. Its length is 110 m with height 8.5 m. The estimated maximum length and depth of the pool were 700 m and 8.5 m respectively in the normal period of non-flood, while the maximum capacity water impounded was 227 million litres.

As at the time of study, there was no functional facility to monitor seepage history of the dam. Being an earth dam, it was susceptible to seepage and taken into consideration its immense importance to the university community. Thus, choosing it as a case study was worthwhile.

MATERIALS AND METHODS

Geological and Geophysical Data

Geological and geophysical studies of the dam embankment were investigated. Parameters measured were layer resistivity and thickness, coefficient of permeability. Compaction and soil characteristics were equally examined. The method described by Telford, et al., 1990 was followed.

Meshing of the bottom of the dam

The bottom of the dam was meshed into 133 rectangular shaped elements with 160 nodal points (Figure 1).

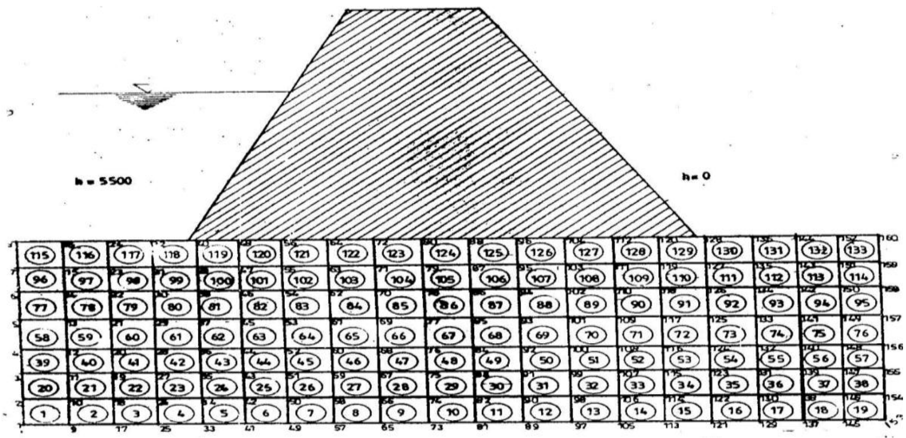


Figure 1: Region of seepage flow under the dam meshed into 133 elements with 160 nodal points.

Finite Element Formulation for the Steady State of Seepage Flow

In 2-dimensional steady state anisotropic seepage flows are:

$$V_x = -k_x \, {\partial h}/{\partial x} \qquad (1)$$

$$V_y = -k_y \, {\partial h}/{\partial y} \qquad (2)$$

For isotropic $\mathrm{k_x} = \mathrm{k_y}$

During seepage, continuity condition is satisfied (i.e. inflow = outflow). This is represented in equation 3

$$\frac{\partial V_x}{\partial x} + \frac{\partial V_y}{\partial y} = 0 \qquad (3)$$

substituting velocities in terms of heads, the equation becomes

$$k_x \frac{\partial^2 h}{\partial x^2} + k_y \frac{\partial^2 h}{\partial y^2} = 0 \quad in\ \Omega \qquad (4)$$

For a 2-dimensional domain Ω. The boundary conditions are

$$h = \bar{h} \quad on\ \Gamma_e \quad and \quad \frac{\partial h}{\partial n} = \bar{q} \ \ on\ \Gamma_n \qquad (5)$$

$\bar{h}$ and $\bar{q}$ denote known variable and flux boundary conditions. n, in equation 2.4, is the outward normal unit vector at the boundary. Γ_e and Γ_n are boundaries for essential and natural boundary conditions, respectively. For the well posed boundary value problem,

$$\Gamma_e \cup \Gamma_n = \Gamma \qquad (6)$$

and

$$\Gamma_e \cap \Gamma_n = \emptyset \qquad (7)$$

in which $\cup$ and $\cap$ denote sum and intersection respectively, and Γ is the total boundary of the domain Ω.

Integration of weighted residual of the differential in equation and boundary condition is

$$I = \int_{\Omega} w \left(k_x \frac{\partial^2 h}{\partial x^2} + k_y \frac{\partial^2 h}{\partial x^2} \right) d\Omega - \int_{\Gamma_e} w \frac{\partial h}{\partial n} d\Gamma \qquad (8)$$

The weak formulation for equation (2.7) as described by Kwon and Bang, 2000 is given as

$$I = \int_{\Omega} \left(k_x \frac{\partial w \partial h}{\partial x \partial x} + k_x \frac{\partial w \partial h}{\partial y \partial y} \right) d\Omega + \int_{\Gamma_n} w \frac{\partial h}{\partial n} d\Gamma \qquad (9)$$

The first volume integral becomes a matrix term while the line integral becomes vector terms.

This gives the relationship between material stiffness $[k]$, quantity of flow $[Q]$ and the nodal piezometric head $[h]$, which can be expressed as a set of simultaneous equations as

$$[k][h] = [Q] \qquad (10)$$

Determination of Nodal Heads and Coordinates of Phreatic Surface Using FEM

In solving equation 2.9 to determine nodal heads and phreatic surface coordinates, computer programme (SEEP2D1 and SEEP2D2), using FOTRAN 90 language, was written and ran.

Input data for the programs

- **SEEP2D1**
  i. Number of nodal points
  ii. Number of elements
  iii. Number of gauss points
  iv. Coordinates of the nodal points at the lower and upper boundaries.
  v. Heads at the boundary nodes
  vi. Nodal points of the boundary elements where Q=0.
  vii. The number of nodes that made up an element.
  viii. Materials permeability in both x and y axes.

- **SEEP2D2**
  i. Width of the dam the base
  ii. Inclination of left slope (degrees)
  iii. Inclination of right slope (degrees).
  iv. Upstream water level (m)
  v. Downstream water level (m).

Boundary Conditions

From Figure 1, the boundary conditions for the problem were:

$$h_8 = h_{16} = h_{24} = h_{32} = h_{40} = 5500$$

$$h_{128} = h_{136} = h_{144} = h_{152} = h_{160} = 0$$

$q = 0$ on the boundary 1-8

on the boundary 153-160

on the boundary 1-153

on the boundary 48-120

Total number of isoparametric elements = 133

Total number of nodal points = 160

The assemblage matrix size = 150 x 160

Determination of Nodal Heads and Coordinates of Phreatic Surface Using Flow Net Method

Flow net diagram were drawn for seepage under the dam and through the dam. Thereafter, the piezometric heads were determined at each nodes (Figure 1) using the method described by Casagrande (1925). Also determined were the coordinates of the flow line (phreatic surface) for the seepage through the dam. Figure 2 shows the flow net and phreatic surface. The results obtained in 2.3 and 2.4 were compared by testing for any significant difference. Descriptive statistics and t-test were conducted using SPSS statistical software.

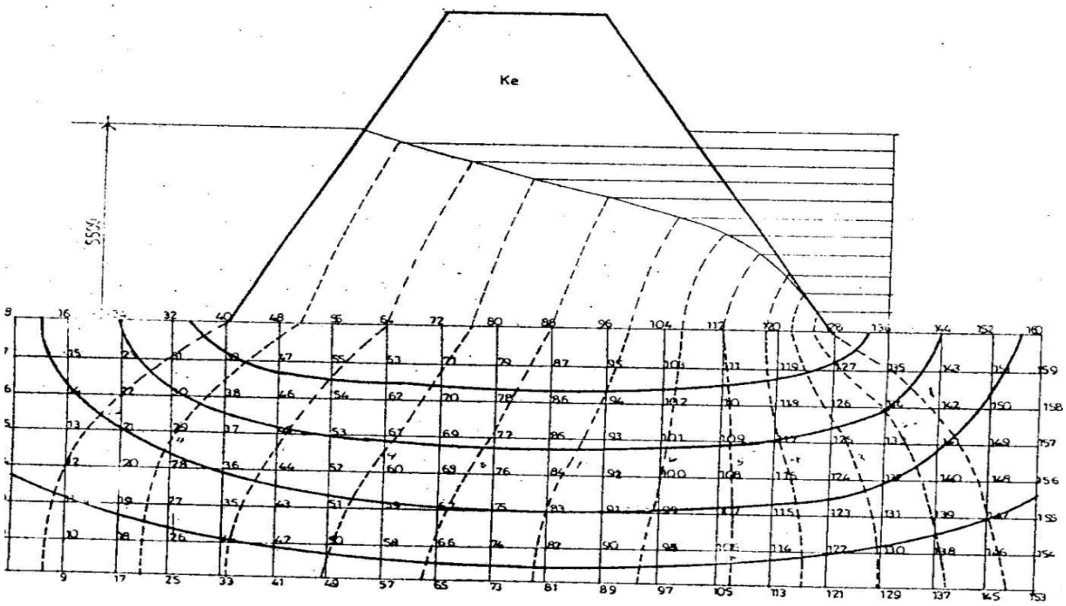


Figure 2: Flow net and phreatic surface through Oba dam

RESULTS AND DISCUSSION

Geological and Geophysical Properties of the Dam Embankment

The geological survey of the embankment revealed that the lithology of the bedrock within the dam area and beyond (up to 50 m) was quartzite schist while the material from the embankment was 'hard' near the surface (N = 30) to very 'stiff' clay material below and between 3.0 m – 8.0 m (N = 15 – 30). The dam had no cut-off as part of its foundation. The implication of this was that the dam embankment was well compacted to prevent high degree of seepage. Furthermore, the coefficient of permeability in both directions (X– and Y- axes) was $1.2 \times 10^{-5}\ cm/s$. This showed that the material from which the embankment was made was isotropic.

In Table 1, the summary of geophysical properties of the dam embankment area and Oba river catchment area are presented. The layer resistivity varied with layer thickness with low resistivity at the 1st layer (top soil) for the two areas (dam embankment and river catchment area), indicating that they consisted of loose sandy soil with traces of clay. However, the resistivity became infinity at the third and fourth layers for dam embankment and river catchment areas, respectively showing that the layer were of hard basement (bedrock). There were relatively low resistivity at 2nd and 3rd layers of the river embankment areas; these layers were suspected to have been fractured or weathered. The same reason may be responsible for the low resistivity at the 2nd layer (10.0 - 13.1 m) in the dam embankment area.

Table 1: Geophysical properties of the dam embankment and river catchment area

Layer Level	Dam Embankment Area			Oba River Catchment Area		
	Layer Resistivity (Ωm)	Layer Thickness (m)	Soil composition	Layer Resistivity (Ωm)	Layer Thickness (m)	Soil composition
1st Layer	190 – 460	0.6 – 2.8	Sandy-clay	80 – 1500	0.6 – 3.5	Sandy-clay
2nd Layer	15 - 80	10.4 – 13.1	Clay, sandy-clay & silt	12 – 490	3.5 – 24	Clay and silt
3rd Layer	∞	13.2 – 14.2	Rock	35 - 878	24.0 – 36.4	Clay and silt
4th Layer	na	na	na	4551 - ∞	> 36	Rock

* na – not available

Nodal Heads and Coordinates of the Phreatic Surface

Potential heads at the 160 nodes of the element mesh were determined from the program SEEP2D1. Figure 3 shows the values of the potential heads at various nodes as determined from the program. It is observed that the potential heads reduced with the depth, indicating that the surface of the dam is more prone to seepage when compared to the base. Also, at the downstream surface, the nodal head was found to zero (node 160) but increased to 335 at node 153, suggesting that there was more hydraulic pressure at the node, which may prone to seepage.

5500	5500	5500	5500	5500	4780	4480	4230	3975	3671	3375	3088	2700	2110	1600	0	0	0	0	0
5410	5370	5246	5030	4860	4565	4355	4100	3850	3590	3342	3040	2708	2112	1608	1010	460	330	169	120
5370	5245	5077	4860	4610	4400	4130	4010	3760	3510	3248	2960	2655	2110	1692	1225	840	420	250	165
5288	5160	4990	4700	4480	4155	4062	3892	3580	3375	3130	2870	2581	2155	1735	1390	1010	630	335	212
5265	5070	4860	4600	4400	4190	3975	3724	3550	3300	3040	2830	2538	2150	1820	1480	1140	760	425	254
5240	5030	4820	4612	4315	4100	3890	3630	3425	3170	2950	2740	2490	2200	1862	1523	1180	846	450	270
5200	4990	4780	4569	4273	4020	3810	3590	3380	3130	2950	2750	2450	2210	1900	1560	1220	885	580	335
5200	4990	4780	4570	4270	4020	3760	3590	3300	3130	2920	2700	2410	2200	1900	1523	1270	885	550	335

Figure 3: Potential heads at 160 nodal points obtained from FEM

This is an indication that seepage was suspected through the foundation of dam embankment. These results were compared with those obtained from flow net approach. Table 2 shows the results of the statistical analysis conducted on the results. Due to the means of the two results and the magnitude of t-value [t(159) = 0.349, p > 0.005], it can be concluded that there was no statically significant difference in the potential heads obtained from FEM as compared to those of flow net.

Coordinates (x,y) that define the phreatic surface (flow line) as obtained from FEM is plotted and compare to that obtained from flow net (Figure 4). As can be seen the graphs are not significantly different from each other. The direction of the graphs depict direction of flow of water. Indicating flow from higher potential at nodes 8, 24, 32 and 40 (Figure 2) to lower potential at nodes 128, 136, 144, and 152 across the dam embankment. It can be deduced that both FEM can be used as tool to monitor seepage in earth dams.

Table 2: Paired Samples test between FEM and Flow net results

			Pair 1
			FEM – Flow Net
Paired Differences	Mean		0.050
	Std. Deviation		1.811
	Std. Error Mean		0.143
	95% Confidence Interval of the Difference	Lower	-0.233
		Upper	0.333
t			0.349
df			159
Sig. (2-tailed)			0.727

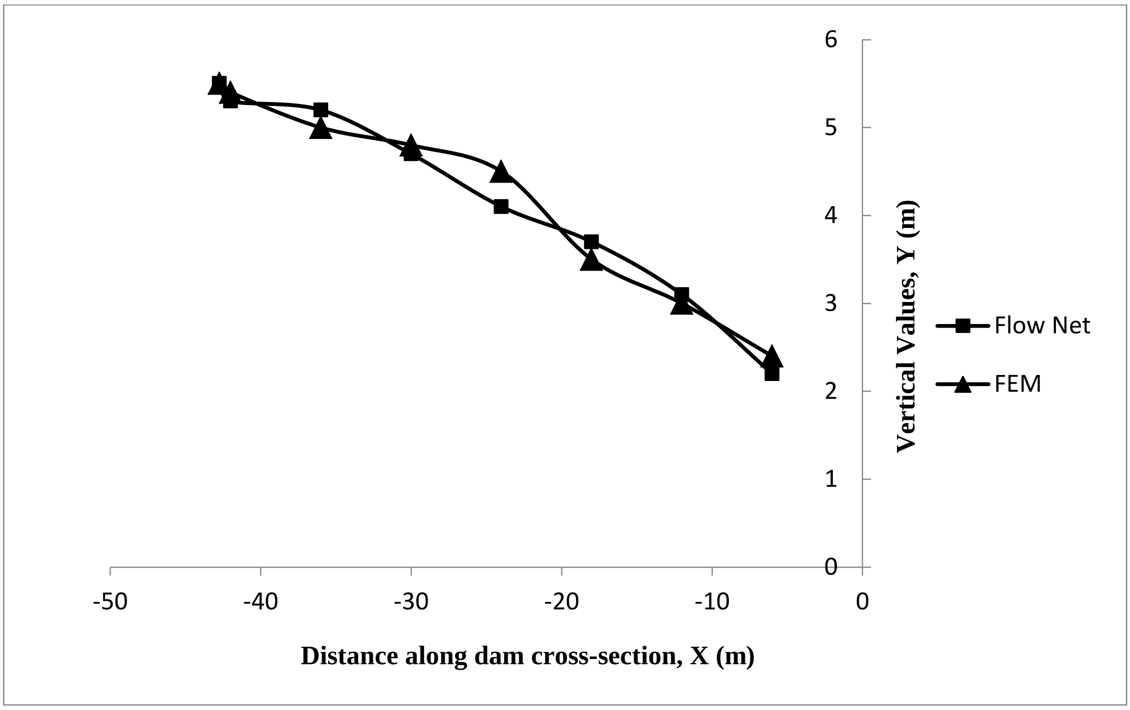


Figure 4: Phreatic surface as determined from flow Net and FEM

CONCLUSION

In this study, Finite Element Method (FEM) was used to determine the potential heads at 160 nodal points of the Oba dam. The method was equally employed to obtain coordinates of the flow line through the dam. These were repeated with the use of conventional method (flow net method). The study, thus, concludes that:

i. Finite element program (SEEP2D1 and SEEP2D2) can be used to monitor seepage in homogeneous and isotropic earth dams as applied to Oba dam.
ii. The results obtained using FEM were comparable perfectly with those obtained from flow net approach.
iii. Finite element method affords easy techniques to simulate seepage in earth dams, for proactive approach to forestall failure.
iv. There is need to develop the technique further for interactive window based application for easy deployment.

REFERENCE

Abdallah.L, Makawi.H., Mohammed Al-sheriaded (2000), 'Evaluation and Rehabilitation of Dam Seepage Problems, Case Study: Kfrrein Dam' ,*Journal of Engineering Geology* , 56: 335-345.

Agbede, O.A. (1989). 'Computer Simulation of Groundwater Flow through a Porous Media, *Modelling, Simulation and Control*, AMSE Press, 19(1): 11-26.

Ali, S., and Fardin, J. (2005). 3D Steady State Seepage Analysis of Embankment Dams, *Electronic Journal of Geotechnical Engineering* (EJGE), 10: 232 - 240.

Arora K.R. (2001). 'Irrigation Water Power and Water Resources Engineering'. Naisarak India: Standard Publishers.

Billstein, M., Sevensson, U., and Johansson, N. (1999). Development and Validation of a Numerical Model of Flow through Embankment Dams - Comparisons with Experimental Data and Analytical Solutions", *Transport in Porous Media*, 35(3): 395-406.

Casagrande, A. (1961). Control of Seepage through foundations and abutments of dams, *Geotechnique*, XI: 61-181.

Darbandi, M., Torabi S. O., Saadat, M., Daghighi, Y and D. Jarrahbashi (2007). A Moving-Mesh Finite-Volume Method to Solve Free-Surface Seepage Problem in Arbitrary Geometries, *Int. J. Numer. Anal. Meth. Geomech.* 2007; 31:1609–1629 published online 30 April 2007 in Wiley Inter Science (www.interscience.wiley.com). DOI: 10.1002/nag.611

Fu, J.F. and Jin, S. (2009). A Study on Unsteady Seepage Flow through Dam. *Journal of Hydrodynamics* 21(4), 499-504.

Lam, L., Fredlund, D.G., and Barbour, S.L (1988). "Transient Seepage Model for Saturated and Unsaturated Systems: A Geotechnical Engineering Approach." *Canadian Geotechnical Journal*. 24(4): 565-580.

FEMA (Federal Emergency Management Agency) 2006. The National Dam Safety Program Research Needs Workshop: Seepage Through Embankment Dams proceedings, Available at: https://www.fema.gov/media-library/assets/documents/2478

Papagianakis, A.T. and Fredlund, D.G. (1984), "A Steady State Model for Flow in Saturated and Unsaturated Soils." *Canadian Geotechnical Journal*. 21(3): 419-430.

Potts, D.M. and Zdravkovic, L. (1999). Finite Element Analysis in Geotechnical Engineering: Theory. Thomas Telford, Great Britain.

Punmia B. C. and Lal P. B. B. (1992). Irrigation and Water Power Engineering. 12th Ed. J. udpur India. Laxmi Pupblications (P) Ltd.

Rice J. D. and Duncan, M. (2010). Deformation and Cracking of Seepage Barriers in Dams Due to Changes in the Pore Pressure Regime," *Journal of Geotechnical and Geoenvironmental Engineering*, vol. 136(1): 16–25, 2010.

Rushton, K.R. and Redshaw, S.C., (1979). Seepage and Groundwater Flow: Numerical Analysis by analog and digital methods, John Wiley & Sons, Great Britain.

Shivakumar S. A., Shivamantha, C. H. S and Dodagoudar G. R. (2015). Seepage and Stability Analyses of Earth Dam Using Finite Element Method, *Aquatic Procedia 4* (2015) 876 – 883.

Telford, W. M., Geldart, L. P., and Sheriff, R. E., (1990).' Applied Geophysics'. Cambridge University Press

Thandaveswara, B.S. (2009). 'History of dam failures', Indian Institute of Technology, Madras. Available at: https://nptel.ac.in/courses/105106114/pdfs/Unit41/41_2.pdf.

INVESTIGATION OF THE SUITABILITY OF WATER FROM THE RECEIVING STREAM OF THE OBAFEMI AWOLOWO UNIVERSITY WASTE STABILIZATION PONDS FOR IRRIGATION PURPOSE

OLADEPO, K. T.[1*], JEJE, J. O.[2], JIMOH, A. A.[3] ADEJUMO B. K.[4] AND SHOBOWALE, A. O.[5]

Department of Civil Engineering, Obafemi Awolowo University, Ile-Ife
[1]koladepo@oauife.edu.ng
[2]jemails@yahoo.co.uk
[3] jaawhao@yahoo.com
[4]abamidelekazeem@yahoo.com
[5] shobowaleafolabi@yahoo.com

*Corresponding author: *koladepo@oauife.edu.ng*

Received: 4 October 2018 *Accepted: 24 December 2018*

ABSTRACT: This study assessed the quality of water samples from the effluent-receiving stream of the Obafemi Awolowo University waste stabilization ponds with a view to establishing their suitability for irrigation purpose. Twelve samples were collected Sampling was carried out during the dry season (November to February) at 12 sampling points located along the effluent-receiving stream. The samples were immediately stored in 2 litres plastic bottles and tightly covered. The samples were analyzed for the major cations (sodium, calcium, magnesium and potassium), anions (chloride, sulphate and bicarbonate), and physico-chemical parameters (temperature, pH, total dissolved salts and electrical conductivity). Based on the results of these analyses, irrigation quality parameters such as sodium adsorption ratio (SAR), percentage of sodium (Na%), magnesium hazard (MH), permeability index (PI), residual sodium carbonate (RSC) and Kelly's ratio (KR) were computed. The mean values of SAR, Na% and RSC were 0.16, 10.27% and 0.69 meq/l, respectively. The data obtained were employed in plotting the Wilcox and US salinity diagrams. In general, the water samples from the receiving stream were found suitable for irrigation purpose.

Keywords: irrigation water quality, dry season, sodium hazard, soil permeability, total salt concentration

INTRODUCTION

Irrigation water is supplied to supplement the water available from rainfall and the contribution to soil moisture from groundwater; and in many areas of the world the amount and timing of rainfall are not adequate to meet the moisture requirements of crops, hence, the need to supplement with irrigation (Osunbitan et al., 2005). In the southwestern part of Nigeria, the climate is made up of two seasons: wet and dry seasons. The wet season lasts from April to October while the dry season lasts from November till March (Hayward and Oguntoyinbo, 1987). Hence, it is often necessary to employ irrigation whenever it is desirable to cultivate any crop during the dry months.

Wastewater is a valuable source of plant nutrients and organic matter. Nevertheless, it may contain undesirable chemical constituents and pathogens that pose negative environmental and health impacts. At the same time, a number of risk factors have been identified in wastewater reuse, some of them are short term (e.g., microbial pathogens) whereas others have longer-term impacts that increase with the continued use of recycled water (e.g., salinity effects on soil). So, many guidelines have been developed to give quality criteria and guidance on how treated wastewater (effluents) should be reused for irrigation purposes (Abdul Hameed et al., 2010). The characteristics of an irrigation water that seem to be most important in determining its quality are total concentration of soluble salts, relative proportion of sodium to other cations (magnesium, calcium, and potassium), concentration of boron or other elements that may be toxic, and under some conditions, the bicarbonate concentration as related to the concentration of calcium plus magnesium (Oke and Aladejana, 2012).

The Obafemi Awolowo University campus has two waste stabilization ponds which are located in the southwestern part of the institution. The ponds were constructed in 1967 and became operational in 1968. The ponds receive wastewater and sewage from the students' hostel and the academic area. Only one pond receives influents at a time and wastewater and sludges are retained in the pond for about two weeks (Ogunfowokan et al., 2005). The effluent-receiving stream originates from Adefakin hills in Ile-Ife and it is a tributary to Opa river (Figure 1). Some peasant farmers along the course of the stream use water from the stream to water their food crops, especially vegetables, during the dry season (Ogunfowokan et al., 2005). In this study, water samples collected from the effluent-receiving stream were analysed with a view to determining their suitability for irrigation purpose.

Pillai and Khan (2016) reported that irrigation practice is mainly dependent on water quality, type of soil and type of crop. Oladepo et al. (2017) has enumerated the parameters which can be utilized to verify the suitability of water for irrigation as the salinity index (measured by the electrical conductivity), sodium hazard (measured by the sodium adsorption ratio, SAR), sodium percentage (Na%), chloride hazard (measured by the Cl^- ions), magnesium hazard (MH), permeability index (PI), residual sodium carbonate (RSC) and Kelly's ratio (KR). These parameters have been applied in discussions on suitability of groundwater samples for irrigation purpose in various literatures such as Ramesh and Elango (2012), Ibraheem and Khan (2017), Hassan (2017) and Kurdi and Eslamkish (2017). The expressions for these parameters are given in the following equations (Oladepo et al., 2017):

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \tag{1}$$

$$Na\% = \frac{(Na^{+} + K^{+}) \times 100}{Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}} \tag{2}$$

$$MH = \frac{Mg^{2+} \times 100}{Ca^{2+} + Mg^{2+}} \tag{3}$$

$$PI = \frac{(Na + \sqrt{HCO_3^{-}}) \times 100}{Ca^{2+} + Mg^{2+} + Na^{+}} \tag{4}$$

$$RSC = (CO_3^{2-} + HCO_3^{-}) - (Ca^{2+} + Mg^{2+}) \tag{5}$$

$$KR = \frac{Na^{+}}{Ca^{2+} + Mg^{2+}} \tag{6}$$

MATERIALS AND METHODS

Location of sampling points

Pond X was in operation during the course of the study. Sampling was carried out during the dry season (November to February). The sampling points were located along the effluent-receiving stream (Plate 1). Sampling point SR represents the reference point upstream at 50 m before the point of discharge of the effluent into the stream and serves as the control. Sampling points, S0 to S9 have separation distances of 100 m; S10 was 33 m from S9 and it was at the point of confluence of the receiving stream with the Opa River (Figure 1).

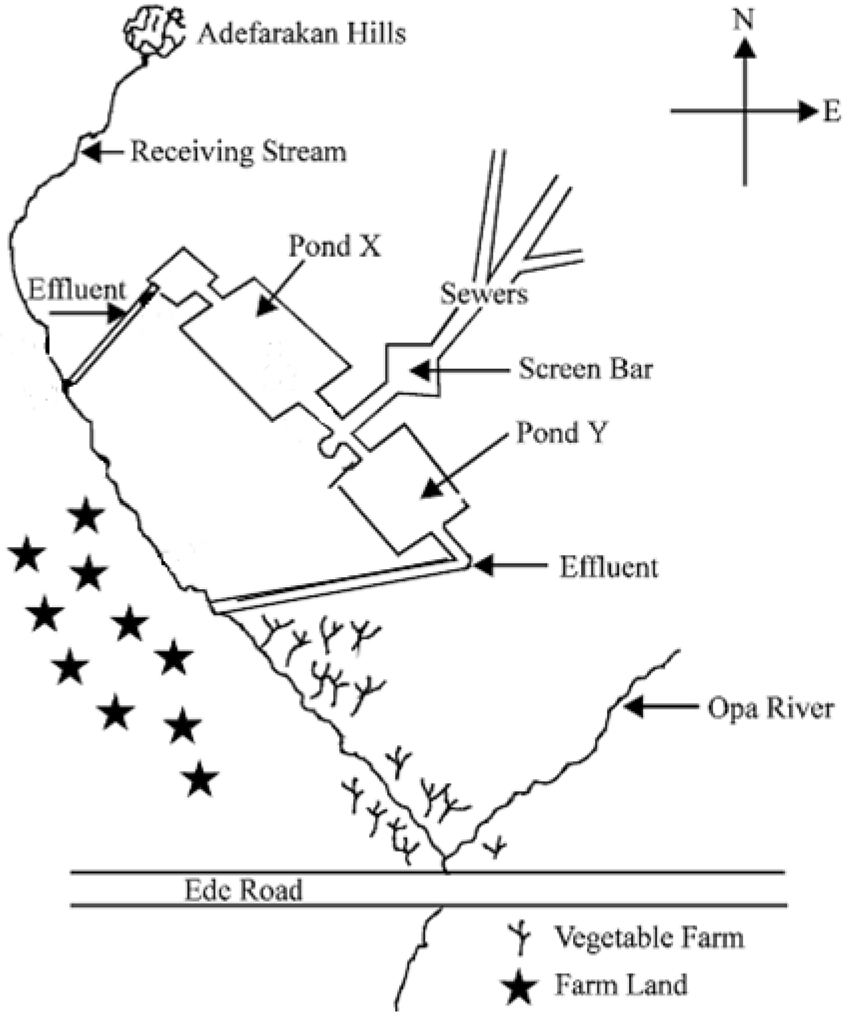


Figure 1: Waste stabilization ponds and the receiving stream (Adapted from Ogunfowokan et al., 2005)

Sample Collection and Analysis

Twelve samples of water were collected altogether along the receiving stream. The temperatures and pH of the samples were determined in situ while water samples for the analysis of other physicochemical parameters were collected in two-litre plastic bottles. At each sampling point, the bottles were rinsed three times with the water sample before the bottles were filled with 2 litres of the water sample. The plastic bottles were properly labelled. The pH was determined by using pH meter (Extech Instruments, Model 407227) while the temperatures of the samples were determined by using a mercury-in-glass thermometer. Calcium (Ca^{2+}) and Magnesium (Mg^{2+}) were determined titrimetrically using standard EDTA, while Chloride (Cl^-) was determined by standard $AgNO_3$ titration. Bicarbonate (HCO_3^-) was determined from total alkalinity by titration with H_2SO_4. Sodium (Na^+) and Potassium (K^+) were determined by flame photometry; Nitrate (NO_3^-) and Sulphate (SO_4^{2+}) were determined using colorimetric method. The total dissolved solid (TDS) was determined by gravimetric method (dried at 105^OC). Electrical Conductivity (EC) was determined by using conductivity meter (DBK Instruments, Model 5008/3).

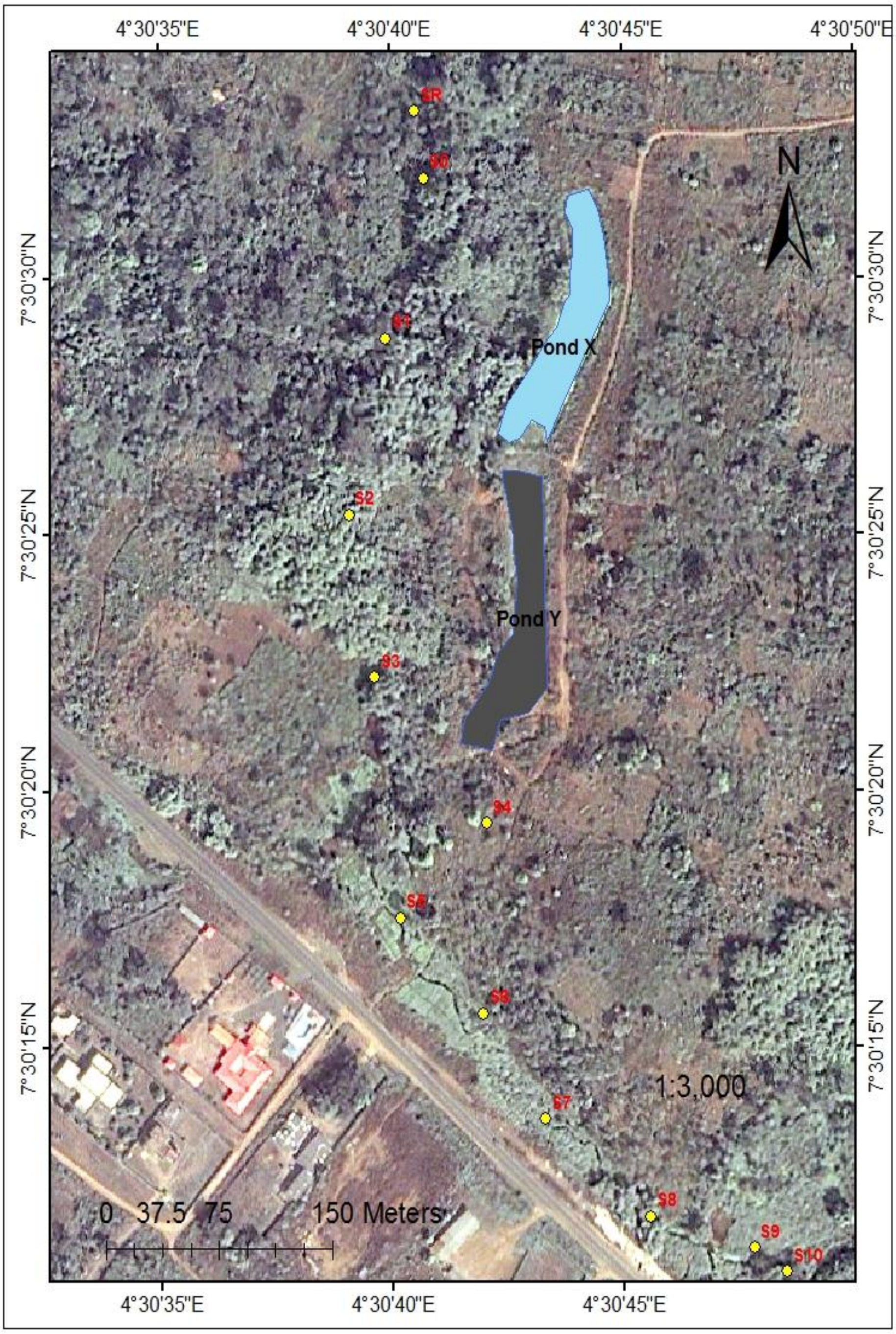


Plate 1: Location of sampling points

RESULTS AND DISCUSSION

Table 1 shows the descriptive statistics of the physicochemical parameters observed in the water samples from the receiving stream. Table 2 shows a summary of the irrigation water quality parameters of the water samples which were computed by using Equations 1 to 6.

Table 1: The descriptive statistics of the physicochemical parameters

Parameters	Min	Max	Mean	Standard deviation
Ca^{2+} (mg/l)	-0.86	11.50	3.82	±3.77
Mg^{2+} (mg/l)	4.56	6.91	5.14	±0.70
Na^{+} (mg/l)	1.70	2.15	1.96	±0.13
K^{+}(mg/l)	5.00	10.50	7.13	±1.60
HCO_3^-(mg/l)	27.00	64.00	37.36	±8.78
EC(µS/cm)	193.00	310.00	229.07	±39.23
NO_3^-(mg/l)	0.10	1.98	0.75	±0.47
SO_4^{2-} (mg/l)	4.99	18.26	11.90	±4.15
Cl^- (mg/l)	14.00	24.99	17.07	±3.39
pH	6.70	7.37	7.12	±0.18
TDS (mg/l)	40.00	260.00	137.14	±63.18
Temp (^oC)	24.00	28.00	25.29	±2.31

Table 2: The descriptive statistics results of the water indices of the wastewater

Water indices	Min	Max	Mean	Standard deviation
SAR	0.12	0.18	0.16	±0.02
KR	0.08	0.19	0.15	±0.04
RSC (meq/l)	0.27	0.88	0.69	±0.15
Na%	6.13	12.35	10.27	±2.02
MH	45.47	108.18	73.82	±16.34
PI	114.21	225.01	187.83	±38.94

Hydrogen Ion Activity (pH)
pH is a measure of the balance between the concentration of hydrogen ions and hydroxyl ions in water. The pH of water provides vital information in many types of geochemical equilibrium or solubility calculations (Prasanth et al., 2012). The values of the analysed pH varied from 6.70 to 7.37 with an average value of 7.12, which indicates that the water is slightly alkaline in nature. The normal pH range for irrigation purpose is

from 6.5 to 8.5. Irrigation water with a pH beyond the normal range may cause a nutritional imbalance or may contain a toxic ion (Ayers and Westcot, 1985).

Salinity Hazard

The most significant water quality guideline on crop productivity is the water salinity hazard as measured by electrical conductivity (Oke and Aladejana, 2012). The electrical conductivity (EC) of the water varied from 193.00 to 304.00 µS/cm with a mean value of 229.07 µS/cm and the total dissolved solids (TDS) varied from 40.00 to 260.00 mg/l with an average value of 137.14 mg/l. The salinity hazard result shows no degree of restriction on the use of this stream water for irrigation indicating no effect on the plant growth and no possibility of salt build-up in the soil (Ayers and Westcot, 1985). The primary effect of high EC reduces the osmotic activity of plants and thus interferes with the absorption of water and nutrients from the soil (Tatawat and Changel, 2008).

Sodium Hazard

Sodium content is the most troublesome of the major constituents and an important factor in irrigation water quality evaluation. Excessive sodium leads to development of an alkaline soil that can cause soil physical problems and reduce soil permeability. Furthermore, irrigation water containing large amounts of sodium is of special concern due to absorbed sodium by plant roots which is transported to leaves where it can accumulate and cause injury. However, there is a restriction in use of overhead sprinklers method with water containing a high level of sodium salts because these salts can be absorbed directly by plant leaves and will produce harmful effects (Abdul Hameed et al., 2010). Sodium concentration in the samples varied from 1.70 to 2.15 mg/l with an average value of 1.96 mg/l, indicating no degree of restriction for sensitive crops on the use of the water for irrigation. Sensitive crops include deciduous fruits, nuts, citrus; avocados and beans, but there are many others. In the case of tree crops, sodium in the leaf tissue in excess of 0.25-0.50 percent (dry weight) is often associated with sodium toxicity (Ayers and Westcot, 1985).

Sodium hazard is also usually expressed in terms of the sodium adsorption ratio (SAR). SAR is calculated from the ratio of sodium to calcium and magnesium. The latter two ions are important since they tend to counter the effects of sodium. Continued use of water having a high SAR leads to a breakdown in the physical structure of the soil. Sodium is adsorbed and becomes attached to soil particles. The soil then becomes hard and compact when dry and increasingly impervious to water penetration. The degree to which irrigation water tends to enter into cation- exchange reactions in soil can be indicated by the value of SAR.The SAR of the samples varied from 0.12 to 0.18 with a mean value of 0.16. The SAR values of the samples were less than 10 and fell into the class excellent; none of the samples fall under the remaining classes of SAR. Therefore, the wastewater is free from sodium hazard and suitable for irrigation purpose. Total salt concentration of irrigation waters should not be used as a single criterion to prevent it in irrigation use. Even water with high salt concentration can still be used for irrigation without endangering soil productivity. High sodium content common to recycled water can cause deflocculating (breakdown) of soil clay particles, severely reducing soil aeration and water infiltration and percolation. In other words, soil permeability is reduced by irrigation with water high in sodium (Rao, 2006). Therefore, the best measure of the likely effect on soil permeability is when the water's SAR is considered together with its EC. In this respect, the US salinity diagram (Figure 2) which is based on the integrated effect of EC (salinity hazard) and SAR (alkalinity hazard) has been used to assess the suitability of water for irrigation. When the data of EC and SAR were plotted on the US salinity diagram, most of the water samples fall in the class of C1S1 indicating low salinity with low sodium water, which can be used for irrigation on almost all types of soils, without risk of exchangeable sodium.

Sodium Percentage (Na%)

Water with Na% greater than 60 percent may result in sodium accumulations that will cause a breakdown of the soil's physical properties (Belkhir and Mouni, 2012). The calculated values of Na% varied from 6.13% to 12.35% with a mean value of 10.27%, indicating no degree of restriction on the use of the water for irrigation. When the concentration of sodium ion is high in irrigation water, Na^+ ion tends to be absorbed by clay particles, displacing Mg^{2+} and Ca^{2+} ions. This exchange process in soil reduces the permeability and eventually results in soil with poor internal drainage. Hence, air and water circulation are restricted during wet conditions and such soils are usually hard when dry (Ayers and Westcot, 1985). The Wilcox diagram was used to relate Na% and EC. It is reported that salinity and sodicity are the principal water quality concerns in irrigated areas receiving such water. Saline-sodic irrigation water, coupled with limited rainfall and high evaporation, may increase soil sodicity significantly. In general, when sodium is an important component of the salts, there can be a significant amount of adsorbed sodium making the soil sodic (Wilcox, 1948). Based on the Wilcox diagram (Figure 3), all the water samples fell in the field of excellent to good and are suitable for irrigation purpose.

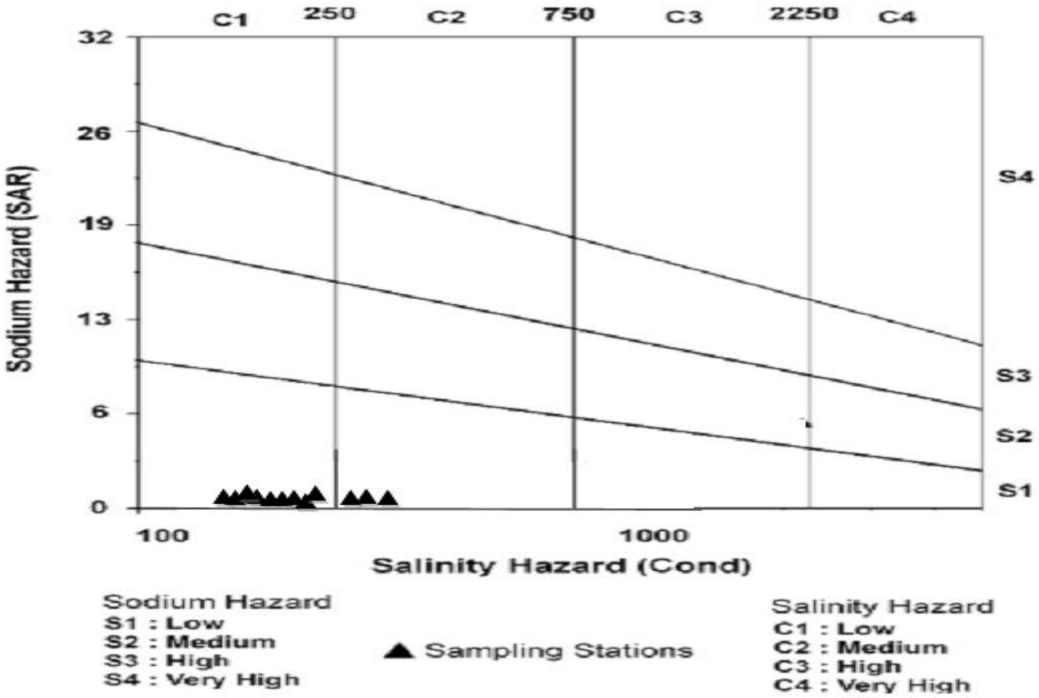


Figure 2: US salinity diagram of the water samples

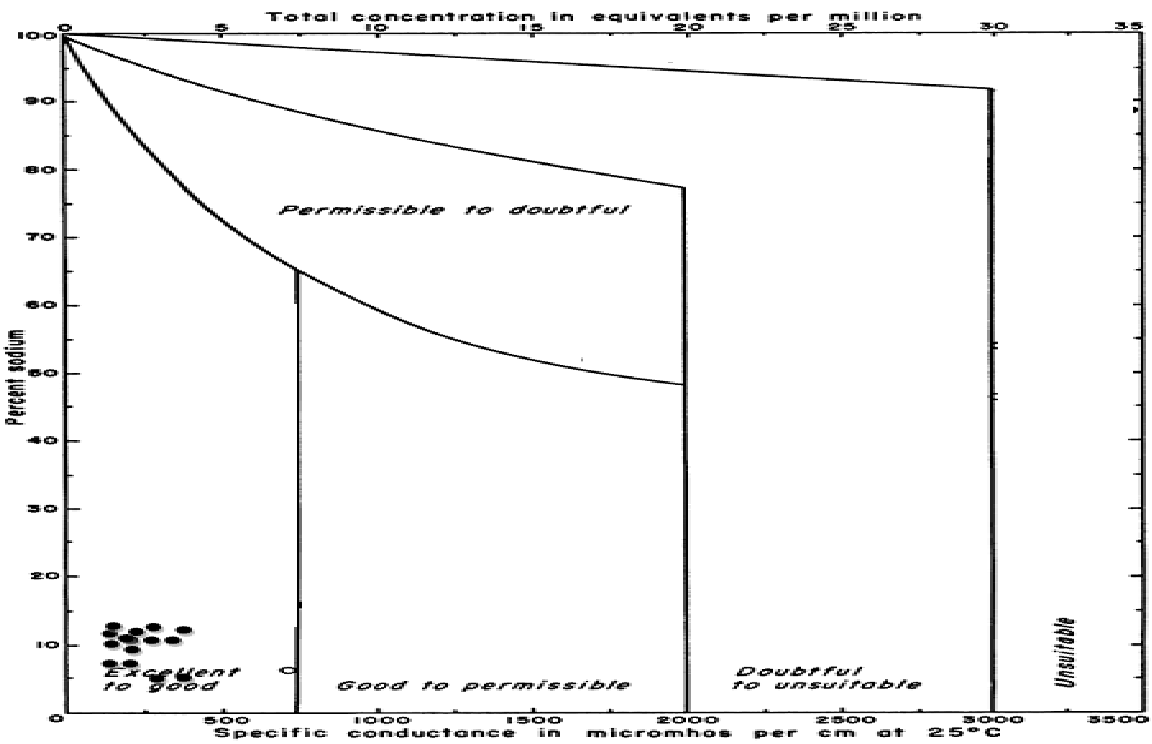


Figure 3: The Wilcox diagram of the water samples

Chloride Hazard

The most common toxicity is from chloride (Cl^-) in the irrigation water. Cl^- is not adsorbed or held back by soils, therefore it moves readily with the soil-water, is taken up by the crop, moves in the transpiration system, and accumulates in the leaves. If the Cl^- concentration in the leaves exceeds the tolerance of the crop, injury symptoms develop such as leaf burn or drying of leaf tissue. Normally, plant injury occurs first at the leaf tips (which is common for chloride toxicity), and progresses from the tip back along the edges as the severity increases. Excessive necrosis (dead tissue) is often accompanied by early leaf drop or defoliation (Abdul Hameed et al., 2010). The obtained Cl^- ion concentration of the samples varied from 14.00 to 24.99 mg/l (with a mean value of 17.07 mg/l) representing no degree of restriction on the use of the stream water in irrigation. Chemical analysis of plant tissue is commonly used to confirm chloride toxicity. The part of the plant generally used for analysis varies with the crop, depending upon which of the available interpretative values is being followed. However, for irrigated areas, the chloride uptake depends not only on the water quality but also on the soil chloride, controlled by the amount of leaching that has taken place and the ability of the crop to exclude chloride. Crop tolerances to chloride are not nearly so well documented as crop tolerances to salinity (Ayers and Westcot, 1985).

Magnesium Hazard (MH)

Generally, Ca^{2+} and Mg^{2+} maintain a state of equilibrium in most waters. Both Ca^{2+} and Mg^{2+} ions are associated with soil aggregation and friability, but they are also essential plant nutrients. High concentration of Ca^{2+} and Mg^{2+} ions in irrigation water can increase soil pH, resulting in reduction of the availability of phosphorous (Al-Shammiri et al., 2005). Water containing Ca^{2+} and Mg^{2+} higher than 10 meq/l (200 mg/l) cannot be used for agriculture (Abdul Hameed et al., 2010). The observed results show that none of the samples have values of MH exceeding 200 mg/l, thereby making the water suitable for irrigation purposes. High MH values (>50 %) have an adverse effect on the crop yield as the soil becomes more alkaline (Prasanth et al., 2012). The calculated values of MH show that the concentration of the Mg^{2+} is higher than Ca^{2+} in the water. The MH values range from 45.47-108.18% (mean value is 73.82%).

Permeability Index (PI)

Based on the permeability index (PI), a water suitability classification for irrigation was calculated Accordingly, the PI is classified under class 1(>75%), class 2 (25 – 75%) and class 3 (<25%) orders. Class 1 and class 2 waters are categorized as good for irrigation with 75% or more of maximum permeability. Class 3 waters are unsuitable with 25% of maximum permeability (Ramesh and Elango, 2011). The calculated values show that the stream water fell under class 1 (>75%). Therefore, the water is suitable for irrigation.

Residual Sodium Carbonate (RSC)

Bicarbonate hazard is usually expressed in terms of RSC. In waters having high concentration of bicarbonates, there is tendency for calcium and magnesium to precipitate as the water in the soil becomes more concentrated. Residual carbonate levels less than 1.25 meq/l are considered safe. Waters with RSC of 1.25-2.50 meq/l are within the marginal range. Continued use of waters having RSC more than 2.5 meq/l leads to salt build-up which may hinder the air and water movement by clogging the soil pores and lead to degradation of the physical condition of the soil. Sodic soils could be used with gypsum addition and green manuring (Nishanthiny et al, 2010). The calculated RSC values varied from 0.27 to 0.88 meq/l with average value of 0.69 meq/l. The RSC values were less than 1.25 meq/l, hence the water is safe and suitable for irrigation purpose.

Kelley's Ratio (KR)

This is an important parameter based on the level of Na^+ against Ca^{2+} and Mg^{2+}. Good irrigation water based on this ratio should not exceed 1.0 (Oke and Aladejana, 2012). The computed KR have values less than 1.0 (<1.0) and therefore the water is suitable for irrigation purposes.

CONCLUSION

The suitability of the water samples collected from the effluent-receiving stream was investigated for irrigation purpose. The water indices employed in determining the suitability of those samples were SAR, MH, PI, KR, Na% and RSC. The interpretation of the results of physical and chemical analyses of the stream water revealed that majority of the water samples fall under C1S1 based on US Salinity diagram, indicating low salinity and low sodium, which makes the water suitable for irrigation purpose. The Wilcox diagram indicated that all the water samples fell in the field of excellent to good and thereby suitable for irrigation purpose. Based on these results, proper management of the water for irrigation and periodic monitoring of quality parameters are required to ensure successful, safe and long-term reuse of the stream water for irrigation purpose.

REFERENCES

Abdul Hameed M.J., Al-Sameraiy M.A., Kadhem A.J. and Abdul Majeed A. (2010), Evaluation of Treated Municipal Wastewater Quality for Irrigation, Baghdad, Iraq. Journal of Environmental Protection, 1: 216-225.

Al-Shammiri M., Al-Saffar A., S. Bohamad S. and Ahmed M. (2005), Waste Water Quality and Reuse in Irrigation in Kuwait Using Microfiltration Technology in Treatment, *Desalination, 185: 213-225*.

Ayers, R.S. and Westcot, D.W. (1985), Water Quality for Agriculture: Volume 1- Overview. [Online] Available: http://www.fao.org/docrep/003/t0234e/t0234e00.htm. Accessed on 19 July 2017.

Belkhiri L. and Mouni L. (2012), Hydrochemical Analysis and Evaluation of Groundwater Quality in El Eulma Area, Algeria, *Applied Water Science, 2:127-133.*

Hassan M. (2017), Evaluation of Groundwater Suitability for Drinking and Irrigation Purposes in Toba Tek Singh District, Pakistan, *Irrigation & Drainage Systems Engineering, 6(1):185.*

Hayward D.F. and Oguntoyinbo J.S. (1987), The Climatology of West Africa, Century Hutchinson, London.

Ibraheem A.M. and Khan S.M. (2017), Suitability Assessment of Groundwater for Irrigation Purpose in Veppanthattai Block, Perambalur District, Tamil Nadu, *World Scientific News, 81(2):81-93.*

Kurdi M. and Eslamkish T. (2017), Hydro-geochemical Classification and Spatial Distribution of Groundwater to Examine the Suitability for Irrigation Purposes (Golestan Province, North of Iran), *Paddy and Water Environment. 1-14. DOI:10.1007/s10333-017-0587-x.*

Nishanthiny S. C., Thushyanthy M., Barathithasan T. and Saravanan S. (2010), Irrigation Water Quality lbased on Hydro Chemical Analysis, Jaffna, Sri Lanka, *American-Eurasian Journal of Agricultural and Environmental Sciience, 7 (1):101-103.*

Ogunfowokan A.O., Okoh E.K., Adenuga A.A. and Asubiojo O.I. (2005), An Assessment of the Impact of Point Source Pollution from a University Sewage Treatment Oxidation Pond on a Receiving Stream-a Preliminary Study, *Journal of Applied Sciences, 5(1):36-43.*

Oke S. A and Aladejana J. A. (2012), Assessment of Shallow Groundwater Quality for Irrigation Purposes in Basement Complex Terrain of South-western Nigeria, *Journal of Hydrology for Disaster Management, 2:158-172.*

Oladepo K.T., Jimoh A.A. and Jeje J.O. (2017), Assessment of Groundwater for Irrigation Purpose in Ife North Local Government Area, Southwestern Nigeria, *Civil and Environmental Research, 9(8):55-64.*

Osunbitan J.A., Okunade D.A. and Fapohunda H.O. (2005), Evaluating the Quantity and Quality of Groundwater for Irrigation in the Basement Complex of Ile-Ife, Nigeria, *Journal of Environmental Hydrology, Volume 13 Paper 21.*

Pillai G. and Khan I.A. (2016), Assessment of Groundwater Suitability for Drinking and Irrigation Purpose in the Dimbhe Command Area of River Ghod, Maharashtra, India, *Journal of Geoscience and Environment Protection, 4:142-157.*

Prasanth S.V.S., Magesh, N.S., Jitheshlal K.V., Chandrasekar N. and Gangadhar K. (2012), Evaluation of Groundwater Quality and its Suitability for Drinking and Agricultural Use in the Coastal Stretch of Alappuzha District, Kerala, India, *Applied Water Science, 2:171–173.*

Ramesh K. and Elango L. (2011), Groundwater Quality and its Suitability for Domestic and Agricultural Use in Tondiar River Basin, Tamil Nadu, India, *Journal of Environmental Monitoring Assessment, 63:383–395.*

Rao N.S. (2006), Seasonal Variation of Groundwater Quality in a Part of Guntur District, Andhra Pradesh, India, *Environmental Geology, 49: 413-429*.

Tatawat R.K. and Chandel C.P.S. (2008), A Hydrochemical Profile for Assessing the Groundwater Quality of Jaipur City, *Journal of Environmental Monitoring and Assessment, 143: 337-343*.

Wilcox L.V. (1948), The Quality of Water for Irrigation Use, US Department of Agriculture, Technical Bulletin No. 962, Washington, D.C.

ASSESSMENT OF THE IMPACT OF HYDROPOWER GENERATION SYSTEM ON VARIOUS DOWNSTREAM COMMUNITIES IN NIGERIA

DIJI C.J.

Department of Mechanical Engineering, University of Ibadan, Ibadan
chuksdiji@gmail.com, cj.diji@mail.ui.edu.ng

Received: 12 October 2018 *Accepted: 24 December 2018*

ABSTRACT: Hydropower generating systems contributes 33% of the total installed commercial power capacity of the Nigerian electricity industry, from three large hydropower plants at Kainji, Jebba and Shiroro. The construction of the three dams resulted in the displacement of various communities that were eventually resettled and clustered around the reservoir basins, downstream river beds of the dams and the river supply sources. This study investigated the socio – economic impact of the dam development on the downstream communities through the changes of the post dam land use of the people, by utilizing preliminary field studies and GIS – based geospatial analysis of the land set imageries for 1968 and 2018. The study reported the land use changes that have occurred in the aspects of water bodies, forest covering and the areas used for human activities, predominantly farming and grazing. The study showed that for the three hydropower dam communities there has been a 50% increase of the land use area for farming and grazing and reduction by the same margin in the forest covering. However, with regards to the water body, while the Jebba and Kainji dam settlements experienced an increase of 1.7 – 2.0% in the water body, the Shiroro dam settlement experienced a 30% reduction in its water body. Shiroro also lost 69% of its forest cover over the last 42years.The study recommends the regulation of the human settlement activities around the dam reservoirs to reduce the impacts of climate change which has manifested itself in the form of persistent flooding.

Keywords: Hydropower, Downstream communities, land use changes, Nigeria.

INTRODUCTION

River basins and dams are one of the greatest legacies of human civilization and cultural heritage with several ancient and modern civilizations developing in the vicinity of great rivers due to the role of rivers in the provision of food to support livelihoods, inputs for industries and providing opportunities for commerce and navigation (Vannote, Minshall, Cummins, Sedell, & Cushing, 1980). The practice of river damming has increased tremendously in the last century with millions of reservoirs constructed globally (Smith, 1971; WCD, 2000) for the purpose of harnessing water for electricity generation, provision of water for domestic and industrial uses, food production, navigation, fisheries, and recreational as well as for flood control purposes (Graf, 2002; Snoussi et al., 2007).

Hydropower utilizes dams as water reservoirs to generate electricity through the conversion of mechanical energy to electrical energy. They are also for other purposes such as providing water for integrated agriculture, domestic or industrial use and to help control floods. Every year 3,800 cubic kilometre of freshwater is taken from the world’s lakes, rivers and aquifers (WCD, 2000). Dams are also expected to help improve the living conditions, economic activities, environment as well as social situations of their surrounding communities.

The economic benefits of reservoirs have been assumed to outweigh their costs in the past, this has provided the impetus and rationale for the expansion of reservoirs around the world (Beck, Claassen, & Hundt, 2012; Liu & Speed, 2009). However, large dams have also brought serious environmental and social consequences. Even though dams have generally brought tremendous benefits to nearby urban centres and large scale agricultural developments, river – dependent populations located in the downstream of hydropower dams have commonly experienced upheavals of their livelihoods, loss of food security, and other impacts to their physical, cultural and spiritual well – being.

River flow altered by large hydro dams often disrupts or destroys downstream habitats and life cycles cues for fish and other river species, as well as fishing, cropping and grazing systems that rely on flood plain ecosystems.

While downstream river – dependent communities may benefit from some degree of flood protection and enhanced irrigation opportunities provided by dams, adverse impacts are far more common and usually outweigh the benefits to downstream people, resulting in reduction of their incomes and livelihoods. The nature, duration and severity of these impacts usually vary from one dammed river to another. In some of the cases, the wave of social disruption and human health impacts following dam construction largely passed within a decade, but in other cases dam-induced impacts have persisted through multiple generations.

In some cases, impacts may be mitigated by alternative sources of food or employment; in other cases, they may not. And in some cases, the environmental effects of dams are detectable for only a short distance downstream, while in others those effects remain significant through hundreds of river kilometres. What the majority of cases have in common, however, is the failure to account for these impacts and their consequences on downstream populations.

This paper reports the study of the ecological and environmental impacts of the development of the Nigerian hydropower system on the downstream communities that resulted from the dam operations. The study focuses on the three major hydropower systems in Nigeria - Jebba, Kainji and Shiroro hydropower dams; and highlights the post dam land use and the socio – economic life of the displaced people.

MATERIALS AND METHODS

The study utilized preliminary primary and secondary data from field visits and other previous studies on the three hydropower dams, as well as geospatial analysis and statistical data analysis of land set imageries for 1986 and 2018 to detect changes in land use/land cover in order to analyse the socio – economic and environmental impact of hydropower dams on various downstream communities in their area of operation. The geospatical analysis is based on GIS (Geographic Information System), a spatial decision support system/tool which integrates both computer hardware and software for collecting, analysing and displaying geographically referenced data to solve complex problems (ESRI, 2005); utilising Band 2, Band 3 and Band 4 land set imageries. The statistical data analysis was carried out using ArcGIS 10.3 software.

RESULTS AND DISCUSSIONS

The Study Area

Figure 1 below shows the location of the three hydroelectric power dams.

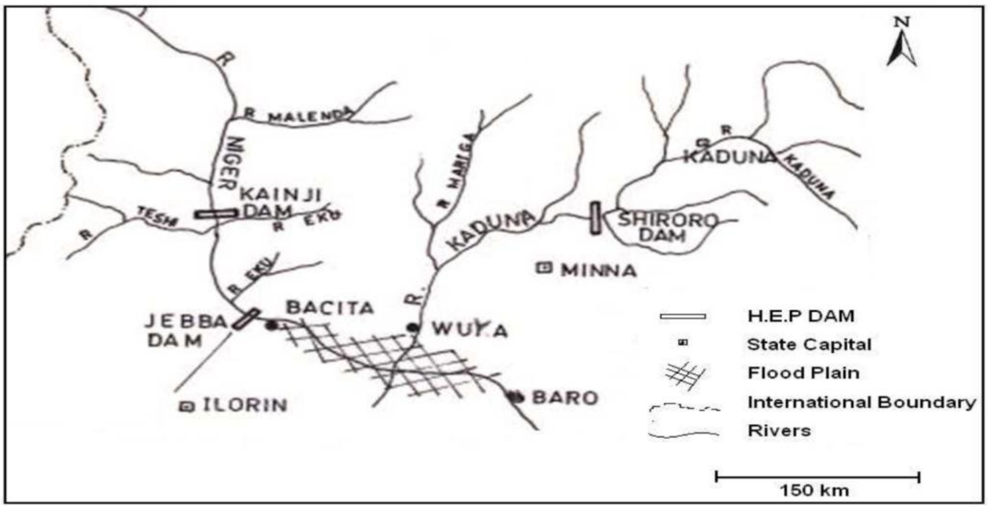


Figure 1: Location of the three hydroelectric power dams.

Geographically, the Kainji hydropower plant (KHPP) is located in New Bussa town, Niger State and was completed in 1968 with a rated capacity of 750MW. The lake created behind the dam span between latitude 90 8' to 100 7' and between longitude 40 5' to 40 7' E with reference point 9.45N and 4.38E northeast of the federal capital Territory (FCT, Abuja) (Dukiya, 2013). The KHPP has a 136 km long reservoir holding approximately 15 billion m^3 of water. The main dam is 550m long with a height of 64 m and covers an area of 480 sq. Miles. The dam available head ranges between 23.8 m and 41.2 m according to the water level in the reservoir.

The Jebba hydropower plant (JHPP) is located approximately 100 km south of the Kainji dam and is 670m long and 42 m high with a reservoir capacity of 3.22 billion m^3. It has an installed capacity of 578MW with a maximum head of 29.3 m.

The Shiroro hydropower plant (SHHP) is located approximately southwest of Kaduna River and was commissioned in 1990 with a capacity of 600MW. It is located 550m downstream of the confluence of Kaduna river with its tributaries of River Dinya on latitude 90 58' 25" North and longitude 60 50' 6" East. The dam is of rock type and stands 115 m high above the original riverbed elevation across Shiroro gorge for a crest length of 700 m. SHHP has a surface area of about $320km^2$, with a maximum length of 32 m and total storage capacity of 7 billion m^3 (suleiman and Ifabiyi, 2015).

Hydrology and Water Resources

The dam reservoirs of Lake Kainji and Lake Jebba are both located on the River Niger and serves as the main source of water for Kainji and Jebba hydropower plants (HPPs), while the Kainji Lake forms the head reservoir for both HPPs. The main water courses which contribute to the KHPP and JHPP dam catchments are the Niger, Olli, Kaduna, and Gurara rivers and several tributaries that flow into them.

The river flow regime of the River Niger is characterised by two distinct flood periods occurring annually – white and black floods. The black flood derives its flow from the tributaries of the river Niger outside Nigeria in the period October to May and arrives at the Kainji reservoir in November and lasts until March at Jebba after attaining a peak rate of about 2,000 m^3/sec in February (Oyebande et al, 1980). The white flood is heavily laden with silts and other suspended particles and flows during the period of June to September and reaches Kainji in August usually attaining a peak rate of 4,000 - 6,000 m^3/sec during the September/October period in Jebba.

The annual flow into the Kainji and Jebba dam reservoirs may reach about 80,000 million m^3 in a year of high flow, out of which 47,000 million m^3 is obtained from the white flood and the balance 33,000 million m^3 is obtained from the black flood. However a recent bathymetry survey (SMEC, 2014) indicated that the storage capacities of both reservoirs have declined – 11% and 14% for Kainji and Jebba respectively; which indicates some degree of high sedimentation of the dams since their construction.

The Shiroro dam reservoir is located in the river Kaduna catchment, which is the only river feeding the dam. The Shiroro River has fifteen drainage tributaries among its watershed and these tributaries are rivers Dinya, Sarkinpawa, Guni, Erena and Muyi (Adie et al, 2012; Eze, 2006). These tributaries flow in the North – south direction and then meander in the Northwest to Southwest direction. This river has a low base flow problem and the volume of the river swings from raging torrents in the rainy season and drying up during the dry season (Kuti et al, 2015). The River Kaduna catchment is located in the Guinea Savannah zone of the country with the climate in the catchment consistent with the rest of the country. The dry season is between the month of November and March, while the rainy season commences in April or May and last till October (Jimoh and Ayodeji, 2003). The average rainfall in the catchment is about 1204.91 mm, with average of about 110 days per year receiving a rainfall amount of 0.1 mm (Okafor et al, 2017). Annual temperature around the reservoir varies between 27 and 350^0 C (Suleiman and Ifabiyi, 2015).

Land use and Downstream Communities

The flood plain around the Kainji, Jebba and Shiroro hydropower reservoirs are very fertile and extensively farmed with soils being regularly replenished by flood waters. Flatter slope within their catchment has favoured ease of access and construction, and efficient supply of water and other services. Thus, despite being potential hazards for floods people have consistently settled around the plains of these hydro dams.

There are about one hundred and forty one (141) settlements within the Kainji dam plain comprising mostly of the initial 40,000 to 50,000 people that were originally living in 239 hamlets, villages and towns, while there are fourteen (14) settlements within the Jebba dam flood plains and comprise some 6,099 people in the original 42 villages. The Kainji and Jebba dams reservoirs catchment covers three states of the federation – Niger, Kwara and Kebbi states and comprise 438 settlements of a total population of 437, 212 people living in 44, 432 households. The Shiroro hydro dam reservoir catchment is made up of three local governments in Niger State – Shiroro, Muye and Gurara, with population of 235,665; 103,461 and 90,879 respectively (NPC, 2010).

Land Use Changes (1986 – 2018)

The land use changes and the changes that have occurred in the same period in terms of changes in the size of the water body, forest and farmland/grasslands that have taken place in the three hydropower dams' settlements over the period 1986 to 2018 are shown in Figures 2a, 2b and Table 1(Kainji Dam); Figures 3a, 3b and Table 2 (Jebba Dam) and Figures 4a, 4b and Table 3(Shiroro Dam).

Kainji Hydropower Dam Settlement

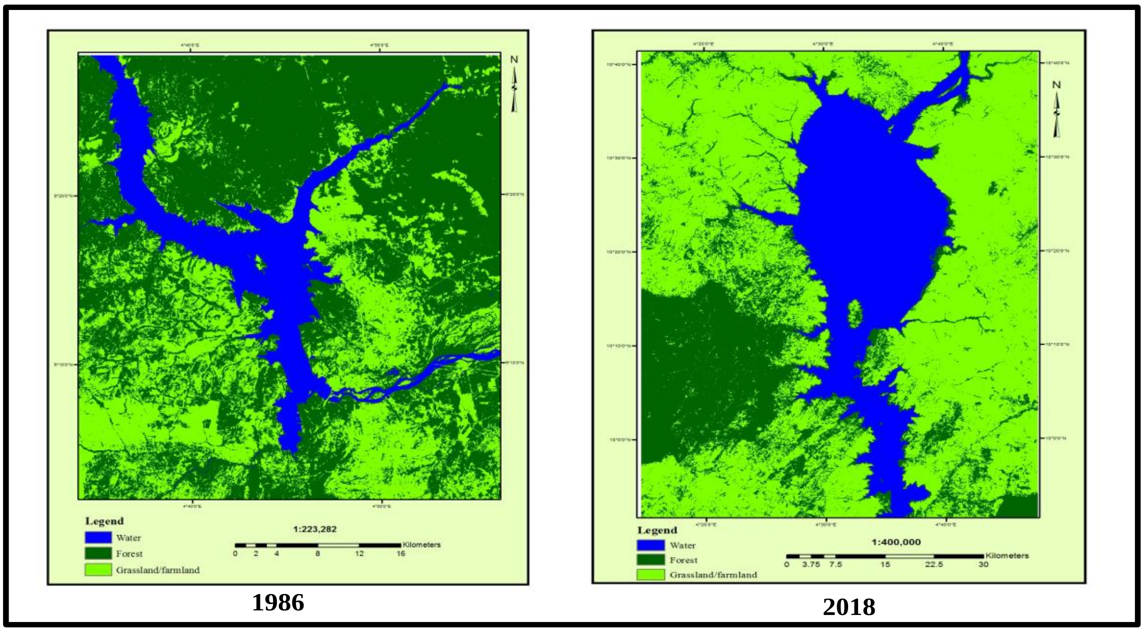


Figure 2a: Land use characteristics of the Kainji Dam Settlement (1986 & 2018)

Table 1: Land use changes at the Kainji Dam settlement

YEAR	LAND USE CHARACTERISTICS (HECTARES)		
	Water Body	Forest	Farmlands/Grassland
1986	109233	433833	85157
2018	111938	149539	366436
% Changes	+2.5	-65.5	+330.30

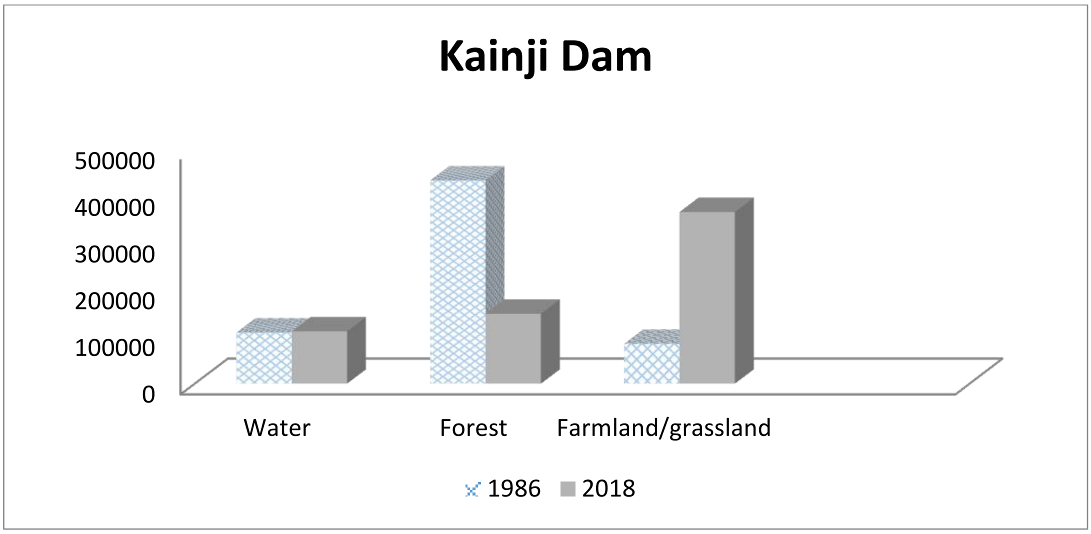
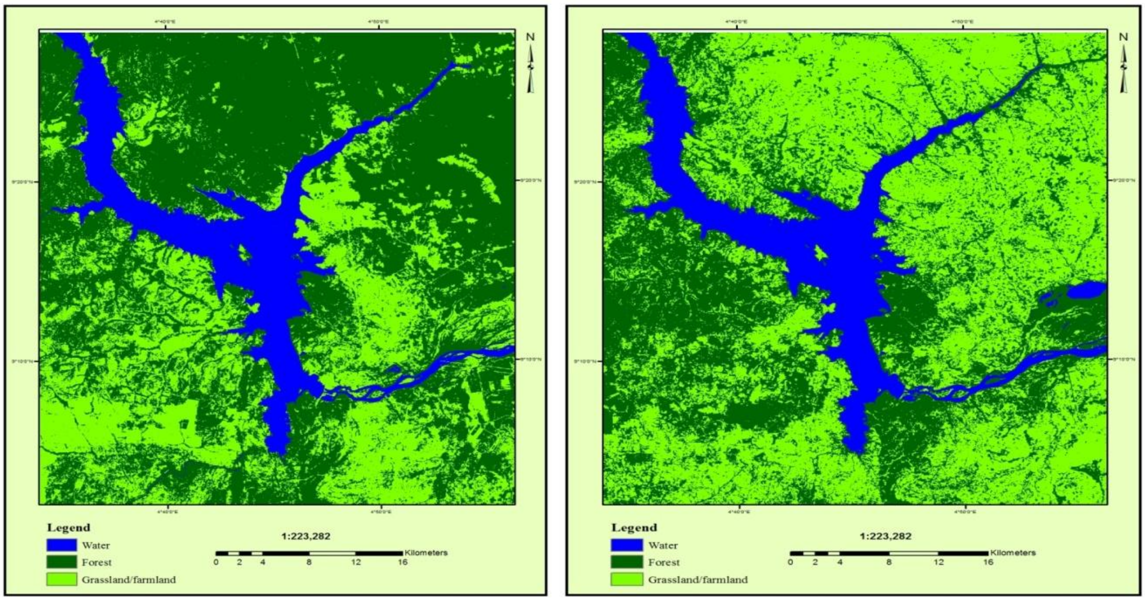


Figure 2b: Diagrammatic representation of the changes in the land use of Kainji dam settlement 1986 – 2018.

Jebba Hydropower Dam Settlement



1986 **2018**

Figure 3a: Land use characteristics of Jebba Dam in 1986 and 2018

Table 2: Land use changes at the Jebba Dam settlement

	LAND USE CHARACTERISTICS (HECTARES)		
YEAR	Water Body	Forest	Farmlands/Grassland
1986	23402.6	120508	62555.6
2018	23807.7	78742.2	103770
% Changes	+1.73	- 34.66	+65.88

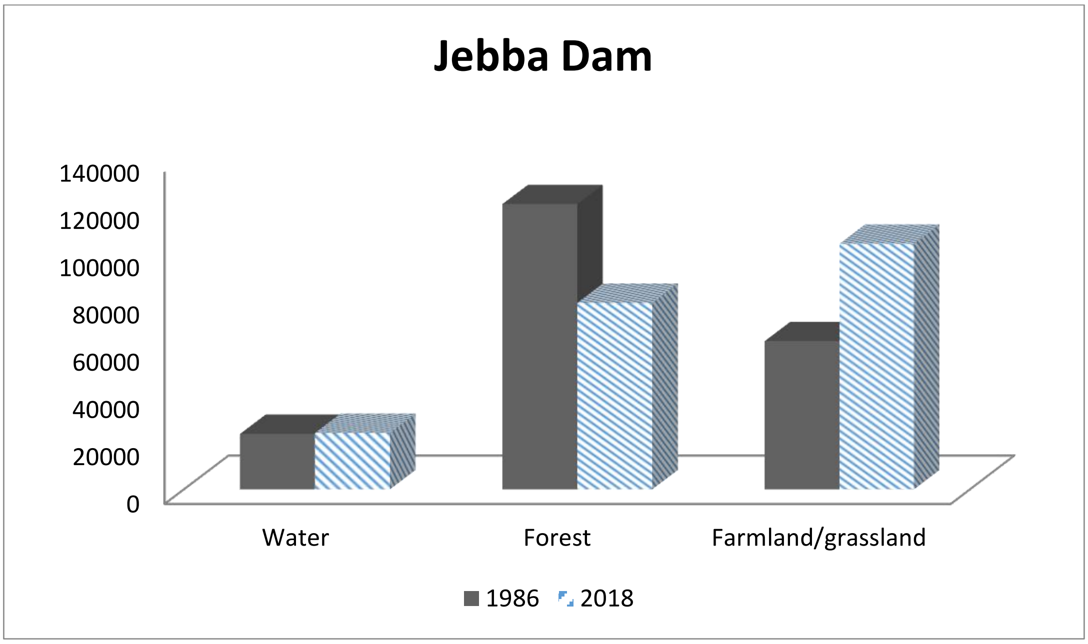
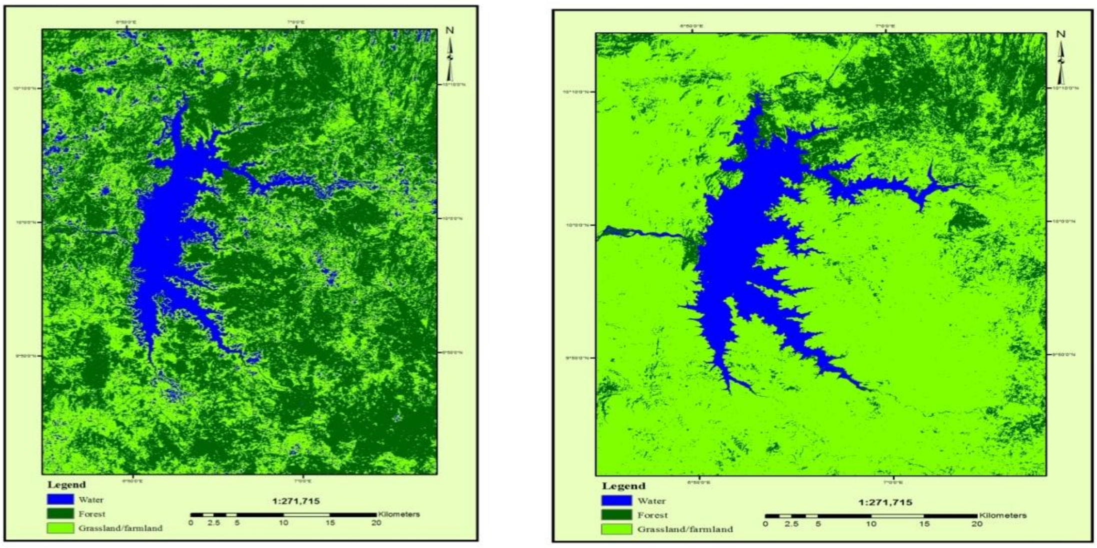


Figure 3b: Diagrammatic representation of the changes in the land use of Jebba dam settlement 1986 – 2018

Shiroro Hydropower Dam Settlement



1986 **2018**

Figure 4a: Land use characteristics of Shiroro Dam in 1986 and 2018.

Table 3: Land use changes at the Shiroro Dam settlement

YEAR	LAND USE CHARACTERISTICS (HECTARES)		
	Water Body	**Forest**	**Farmlands/Grassland**
1986	32843.5	156927	111932
2018	25122.9	48520	227989
% Changes	-30.73	-69.08	+50.90

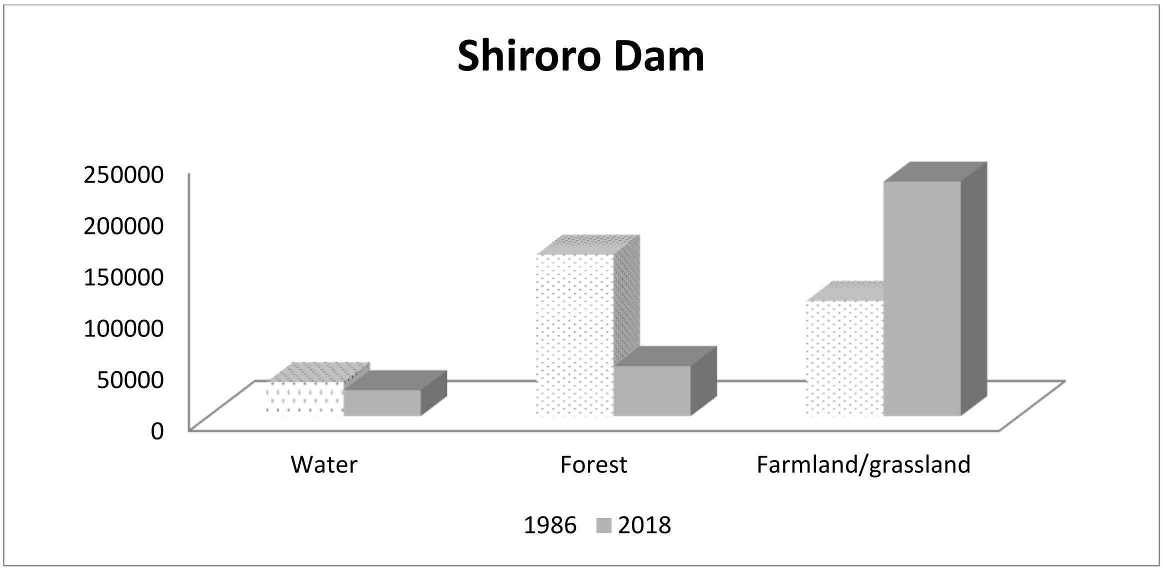


Figure 4b: Diagrammatic representation of the changes in the land use of Shiroro dam settlement 1986 – 2018

The figures 2 – 4 and Tables 1 – 3 above shows that all the three hydropower power dam settlement have witnessed increased human activities in the form of farming and grazing activities, which has grown by over 50% however while the water body has grown marginally in the Jebba and Kainji dam settlements, the water body of the Shiroro dam settlement has declined and shrunk by over 30% in the period under consideration.
The tables and figures also shows that the forest covers in the three dam settlements have reduced considerable by half, while Shiroro dam settlements has lost two – thirds of its forest covers. The loss of forest covers is a major cause of the high flooding reported in the hydropower dam settlements. From the rate of depreciation of the forest covers and increase in human activities in the downstream communities, there is a need to come up with regulations to control human activities in the dam reservoirs to reduce the impacts of climate change especially flooding which have persisted in the study area.

CONCLUSIONS

The study examined the land use changes that have occurred over the past 42 years in the three hydropower dam settlements of Kainji, Jebba and Shiroro using the GIS methodology. The study showed that due to the activities and operations of the hydropower stations, there has been an increase in human activities especially farming and grazing and major decrease in the forest covers, a major cause of climate change and persistent flooding in the settlements.

ACKNOWLEDGEMENT

I wish to express my appreciation to the African Climate Leadership Programme (AFriCLP), an initiative of theInternational Development Research Centre (IDRC) , Canada and implemented by the University of Nairobi and the Institute of Resource Assessment (IRA) of the University of Dar es salaam for sponsoring this study.

REFERENCES

Adie, D. B., Ismail, A., Mohammed, M. M., and Aliyu, U. B. (2012). Analysis of the water resources potential and useful life of Shiroro Dam, Nigeria, Niger. J. Basic Appl. Sci., 20, 341–348.

Beck, M. W; Claassen, A. H., and Hundt, P. J. (2012). Environmental and livelihood impacts of dams: common lessons across development gradients that challenge sustainability. *International Journal of River Basin Management*, *10*(1), 73–92. http://doi.org/10.1080/15715124.2012.656133.

Dukiya JJ (2013) Spatial analysis of the impacts of Kainji hydropower dam on the downstream communities an overview: *A journal of Geoinformatics and Geostatist* 4 (4) : 105 – 113.

Eze, J. N.: Vulnerability and adaptation to climatic variability and extremes. A case study of flooding in Niger State, MSc dissertation, School of Geography and Environmental Studies, University of Witwatersrand, Witwatersrand, South Africa, 153 pp., 2006.

Jimoh, O. D. and Ayodeji, O. S.: Impact of the Gurara River (Nigeria) interbasin water transfer scheme on the Kaduna River at Shiroro dam, in: Water resources systems: Hydrological risk management and development, edited by: Blosch, G., Franks, S., Kumagai, M., Musiake, K., and Rosbjerg, D., Proceedings of Sapporo Symposium, July 2003, Sapporo, 277–286, 2003

NPC. (2010). Population *Distribution by Sex, States, LGAs, and Senatorial Districts*. Abuja: Federal Republic of Nigeria

Okafor, G. C., Jimoh, O. D., and Larbi, K. I.: Detecting changes in hydro-climatic variables during the last four decades (1975 – 2014) on downstream Kaduna river catchment in Nigeria, Atmos. Clim. Sci., 7, 161–175, 2017.

Oyebande L, Sagua VO, Ekpenyong JL (1980) The effect of Kainji dam on the hydrological regime, water balance and water quality of the river Niger. The influence of man on the hydrological regime with special reference to representative and experimental basins lahs – Aish Publication 130.

Suleiman, Y. M. and Ifabiyi, I. P.: The role of rainfall variability in reservoir storage management at Shiroro hydropower dam, Nigeria, Monoma Ethiop. J. Sci., 7, 55–63, 2015.

Vannote, R.L., Minshall, G.W., Cummins, K.W., Sedell, J.R., Cushing, C.E. 1980. The river continuum concept. Can. J. Fish. Aquat. Sci., 37: 130-137

WCD. (2000). *Dams and Development - A New Framework for Decision-Making*. World Commission on Dams. Retrieved from http://www.internationalrivers.org/files/attachedfiles/ world_ commission_ on_ dams_ final_ report.pdf.

PHYTOREMEDIATION OF CADMIUM USING WATER HYACINTH PLANTED IN SURFACE FLOW CONSTRUCTED WETLAND

BADEJO A.A*[1], FOLORUNSHO T.P[2], NKESHITA C. F[3], NWOSU G[4]

Department of Civil Engineering, Federal University of Agriculture, Abeokuta, Nigeria

[1]badejoaa@funaab.edu.ng
[2]Temitayo67@yahoo.com
[3]chufid@yahoo.com
[4]alumek93@yahoo.com

* Corresponding author: badejoaa@funaab.edu.ng

Received: 1 October 2018 *Accepted: 24 December 2018*

ABSTRACT: Release of heavy metals into the environment due to industrialization has become a global concern. This study investigated the effectiveness of water hyacinth (*Eichhiornia crassipes*) planted in Surface Flow Constructed Wetland for removing Cadmium in wastewater. The macrophyte was exposed to two different concentration of cadmium (60.14 and 40.91 mg/L) for a retention period of 28 days in a Surface Flow Constructed Wetland (SFCW); samples were taken in triplicate at 7th, 14th, 21st, and 28th days to determine Cadmium, pH and Electrical Conductivity (EC) using standard methods. The removal efficiency and bio-concentration factor (BF) were also determined. Results showed considerable decrease in the concentration of cadmium and EC with increase in pH. The maximum removal efficiency was 75.24%. The concentration of cadmium in the plant exposed to 60.14 mg/L was 5500 mg/Kg with bio-concentration factor of 92 while the concentration of cadmium in the plant exposed to 40.91 mg/L was determined to be 6746 mg/Kg and the bio-concentration factor was 165 after harvesting. This study showed that water hyacinth could be a good phytoremediation agent for the removal of cadmium using SFCW.

Keywords: Cadmium, Surface Flow Constructed Wetland, Water hyacinth, phytoremediation

INTRODUCTION

The increase in industrial activities contributes greatly to the rise in water pollution; this endangers the terrestrial and aquatic life of the environment thereby contributing to climate change. The toxicity of metal pollution has been studied to be slow and endless, as these metal ions are non-bio-degradable and can only be transformed from one oxidation state or organic complex to another (Salehzadeh, 2013; Garbisu and Alkorta, 1997).

Human exposure to heavy metals occurs through various routes among which are inhaling of dust or fume and involuntarily ingestion through food and drink. There are instances where metals are vaporized (mercury vapor in the manufacture of fluorescent lamps) and inhaled by humans (Hu, 2002). The heavy metals that constitute main threat to human health are associated with exposure to lead, cadmium, mercury and arsenic (Dimple, 2014).

Cadmium emissions arise from two major categories which include natural and man-made or anthropogenic sources. Cadmium emissions occur to the three compartments of the environment- air, water and soil, in some cases there are considerable transfer between the three compartments after initial deposition. Cadmium pollutes the environment through the emission of cadmium smelter by industry or by the introduction of cadmium into sewage sludge, fertilizers, and groundwater. This results in ingestion of contaminated foodstuffs (like grains, cereals, and leafy vegetables). The relative inability of human beings to excrete cadmium, severe respiratory irritation and weakening of the bones in humans are the health consequences of cadmium exposure. Hu (2002) concluded that the risk exists now at lower levels of exposure than previously thought.

There are various methods available for removing heavy metal ions from aqueous streams according to Ahalya *et al., (*2003), they include Adsorption, Reverse Osmosis, Electrodialysis, Ultrafiltration, Ion-exchange, Chemical Precipitation, Biosorption and Phytoremediation. Phytoremediation engages natural means of removing heavy metals and it is a cost-efficient alternative to other methods. This involves the use of green plants for removal of contaminated soils, sediments and water. The plants reduce, assimilate, break down, or detoxify inorganic and organic pollutants from the environment or render them harmless (Mudgal *et al*., 2010; Aisien *et al.*, 2010).

Constructed wetlands (CW) adopts the principle of Phytoremediation, CW are biological wastewater treatment technology designed to duplicate natural processes occurring in wetlands under natural conditions. Treatment in CW occurs as a result of settling of suspended particles, oxidation of organic matter, photolysis, and uptake of nutrients by plants growing within the wetlands and metabolic activity by indigenous microorganisms (Home and Muthigo, 2013). CW are of different types, classified according to the water flow regime: Free Water Surface (FWS**)** and Subsurface Flow Systems (SFS) (Ghermandi *et al*., 2007). The green plant adopted in this study is Water hycinth (*Eichhornia crassipes*).

Eichhornia crassipes is a fast growing, floating aquatic macrophyte with a well-developed fibrous root system and large biomass which adapts easily to various aquatic conditions. Due to its well-known reproduction potential, it is often seen as constituting nuisance in the movement along the waterways. Water hyacinth contains more than 95% water, a high energy and protein content. Water hyacinth is considered to be an ideal candidate for use in the rhizofiltration of toxic trace elements from a variety of water bodies and plays an important role in removing and accumulating heavy metals from water.

This study therefore investigates FWS CW in removing Cadmium in wastewater using water hyacinth (*Eichhornia crassipes*) as macrophyte.

MATERIALS AND METHODS

The water hyacinth plant was obtained from Ojo River in Ojo waterside, Lagos, Nigeria (N60º27′13″, E30º12′12″) and stored in a water container before transplanting into the basin tanks. Analytical grade of Cadmium Aqueous solution ($3CdSO_4.8H_2O$) was obtained from Liberatus Laboratory Services Ltd., Camp, Abeokuta, Ogun State. Three basin tanks were obtained and the experiment was set up at the back of Civil Engineering Building, College of Engineering FUNAAB, Nigeria. The experimental setup is shown in Fig. 1.

Figure 1: Experimental Setup

Three pilot scale CW tanks were used for the experiment to serve as an impermeable membrane. The aquatic macrophyte used was *Eichhornia crassipes* which was planted on the pilot scale set up to simulate flow scenario in a surface flow constructed wetland. The three basin tanks were filled with 300 L of water; two of the CW tanks containing water were contaminated with two differently prepared analytical grades of cadmium sulphate while the third tank containing only water served as the control system. The three tanks have outlets at the bottom which was used to collect the water samples for analysis. The flow path was vertical by gravity, the plastic unit served as the impermeable membrane mounted on block units for stability

A stock solution of cadmium was prepared in distilled water in the laboratory using analytical cadmium sulphate. One hundred and fifty gram (150 g) and one hundred gram (100 g) of cadmium sulphate were measured using a measuring scale and dissolved in 1000 ml of distilled water separately in plastic bottles in the laboratory. The concentration of cadmium in the CW tanks 1 and 2 after been contaminated with the prepared solution was 60.14 and 40.91 mg/L respectively. The prepared stock solution of cadmium sulphate were applied to the CW tanks after the maturation of the macrophytes and stirred so that the concentration will be uniform.

Water samples were collected in triplicates through the outlet of the basin tanks for heavy metal analysis in the laboratory. The bottles that were used to collect the water samples were washed and rinsed with distilled water before collecting the samples. The sample collection was carried out in 7, 14, 21, and 28 days retention periods. Water lost through sample collection, evaporation, and transpiration in the basin tanks were replaced by addition with tap water. The *p*H, temperature and EC of the water samples collected were also determined. Laboratory analysis was done at SMO Laboratory, Challenge, Ibadan, Nigeria using standard procedures. The water samples collected were tested for their *p*H, and EC using APHA (1998). They were digested and analyzed in the laboratory for heavy metal concentration. Heavy metal concentration in the water samples were analyzed using the flame atomic absorption spectrometer. At the end of the experiment, the harvested macrophytes (water hyacinth) was taken to the laboratory and digested to determine the concentration of cadmium.

The ability of the plant to absorb or accumulate heavy metals into its biomass which provides an index of the ability of the plant to accumulate the heavy metals with respect to the metal concentration in the aquatic ecosystem was calculated according to Zayed *et al*., (1998) using

$$BCF = \frac{\textit{Concentration of metal in plant tissue}}{\textit{Concentration of metal in water}}$$

RESULTS AND DISCUSSION

The results of the *pH*, EC, and cadmium concentration for 0, 7, 14, 21, and 28 day retention period for the experimental system are shown in Tables 1 and 2.

Table 1: Result of the experimental system 1

S/N	Days	*p*H	EC (µS/cm)	Cadmium concentration (mg/L)
1	0	6.08±0.04	664.9±73.19	60.14±0.00
2	7	6.10±0.01	398.95±83.26	38.97±0.06
3	14	6.18±0.15	377.85±88.00	25.56±0.27
4	21	6.24±0.02	356.50±80.50	19.86±0.17
5	28	6.28±0.03	350.20±70.30	14.89±0.60

Table 2: Result of the experimental system 2

S/N	Days	*p*H	EC (µS/cm)	Cadmium concentration (mg/L)
1	0	5.95±0.02	701.65±55.15	40.91±0.00
2	7	6.05±0.02	483.45±43.73	27.04±0.05
3	14	7.00±0.02	459.15±37.79	18.04±0.01
4	21	7.27±0.03	430.40±26.56	16.54±0.35
5	28	7.33±0.01	425.15±20.06	15.62±0.12

The results showed that water hyacinth has the ability to absorb cadmium from aqueous solution. At the end of the experiment, the plant removed 75.24% of cadmium from experimental system 1 and removed 61.82% of cadmium from experimental system 2 in the wastewater. The reduction of cadmium in the third and fourth week was minimal compared to the first and second week of both experimental system. It was observed that the line of graph was approaching equilibrium when it is about to reach the third week. The uptake of cadmium by water hyacinth is dependent on many factors which include the *p*H of the water, nutrients available in the water, the initial concentration of the metal in the water, and the population of the plant. This study was in agreement with that of Felix *et al*., (2010) who studied the removal of heavy metals from aqueous solution.

David *et al*., (2003) opined that if the plant is saturated with the metal, there will be hindrance to lead uptake and if oversaturated, hindering mechanism will completely become dominant and there will be excretion of lead from the plant, thus increasing the concentration of lead in the water, this is responsible for the drop in uptake of Cadmium. Wahab *et al*., (2010) inferred that the phytoremediation efficiency of metals greatly depends on the concentration of such metals in solution, and the higher the concentration of the metals in the solution the lower the removal efficiency. According to Tolu and Atoke (2012) under natural conditions, nutrients deficiency, especially of phosphorus pose a natural limiting factor for the growth of water hyacinth, and if water has a high content of phosphorous, water hyacinth will grow at a very fast rate. Therefore, if such nutrients are available in water containing heavy metals, water hyacinth will grow at a faster rate and will be able to absorb more of the metals in its biomass.

Water hyacinth is known to survive in water with *pH* in the range 4 to 9. As the *p*H of water increases, the rate at which water hyacinth absorb cadmium into its biomass reduces. The *p*H of the water in the control system increased likewise that of the experimental system. The *p*H of the control system ranged between 7.00±0.04 to 7.42±0.01, and that of the experimental system 1 and 2 ranged from 6.08±0.04 to 6.28±0.03 and 5.95±0.02 to 7.33±0.01 respectively. Its growth is inhibited at *p*H below 4 and above 8.5.

The electrical conductivity of wastewater could be affected by several factors like temperature, the dissolved solids in water, salts present in water, and the metals in the water. The EC of the water in the control system kept increasing throughout the 28 days retention period and the EC ranged from 396.25±4.91 to 475.00±7.29 $\mu S/cm$

Bio-Concentration Factor (BCF)
The concentration of cadmium in the plant at the end of the experiment from experimental system 1 was 5500 mg/Kg with a bioconcentration factor of 92 while the concentration of cadmium in the plant at the end of the experiment from experimental system 2 was 6746 mg/Kg with a bioconcentration factor of 165. Unlike Liao and Chang (2004) who reported BCF values of more than 1000 in *Eichhornia crassipes* shoots at low Cd concentration and also Agunbiade *et al.*,(2009) who reported Cadmium BCF root and shoot values of 17 and 45 respectively in *Eichhornia crassipes* collected from metal-contaminated coastal waters.

CONCLUSION

Water hyacinth (*Eichhornia crassipes*) has the ability to absorb cadmium from aqueous solution. It can be used in environment technology in CW as it has been shown to be a good accumulator of cadmium. Despite the high initial concentration of cadmium in the water, it removed 75.24% of cadmium from experimental system 1 and removed 61.82% of cadmium from experimental system 2 in the water. The efficiency of water hyacinth was expressed in terms of variation in pH, EC, and the concentration of cadmium before and after the experiment. This system of treatment is cost effective and efficient for treatment of wastewater contaminated with cadmium.

REFERENCES

Abas, S. N., Ismail, M. H., Kamal, M. L., and Izhar, S. (2013) Adsorption Process of Heavy Metals by Low-Cost Adsorbent: A Review. World Applied Sciences Journal 28 (11): 1518-1530.

Abdul W. A., Syed I. S., Sarva M. P., and Awang S., (2014) The Comparison of Phytoremediation Abilities of Water Mimosa and Water Hyacinth. ARPN Journal of Science and Technology: 4(12) 722-731.

Abolanle S. A., Olusegun O. O., Joseph G. A., John A. O. Oyekunle, Winston O. D, Bhekie B. M, and Michael S. A, (2012) Removal of heavy metals from industrial effluents by water hyacinth (*Eichornia crassipes*). Journal of Environmental Chemistry and Ecotoxicology; 4(11), 203-211

Agunbiade, Foluso and Olu-Owolabi, Bamidele and Adebowale, K. O. (2009) Phytoremediation Potential of *Eichhornia crassipes* in Metal-Contaminated Coastal Water. Bioresource technology. 100. 4521-6. 10. 1016/j.biortech. 2009.04.011

A*PH*A (1998) Standard Methods for Examination of Water and Wastewater. 20th ed. American Public Health Association, Washington, DC, USA.

Aremu A.S., Ojoawo S.O, and Alade G.A., (2012) Nutrient Removal and Potential Applications of bye-products. Water hyacinth (*eichhornia crassipes*) culture in Sewage; 2(7); 103-114.

David T. W., Myint M. T., and Sein T., (2003) Lead Removal from Industrial Waters by Water Hyacinth. AU J.T., 6(4), 187-192.

Dimple L., (2014) Adsorption of Heavy Metals: A Review. International Journal of Environmental Research and Development, 4: 41-48.

Felix A. A., Oluwole Faleye, and Eki T. A., (2010) Phytoremediation of Heavy Metals in Aqueous Solutions. Journal of sciences, 17; 37-46.

Garbisu, C., Alkorta, I. (1997) Bioremediation: principles and future. Journal of Clean Technology Environment of Toxicol. & Occup. Med. 6: 351-366.

Ghosh, M and Singh, S. P. (2005) A review on Phytoremediation of heavy metals and utilization of its byproduct. Asian Journal on Energy and Environment. 6(04): 214-231.

Gomati S., Adhikari S., and Mohanty P., (2014) Phytoremediation of Copper and Cadmium from Water Using Water Hyacinth, Eichhornia Crassipes. International Journal of Agricultural Science and Technology (IJAST), 2(1); 1-7.

Home, P. G., and Muthigo, K. G. (2013) Assessment of The Efficiency of Different Mixes of Macrophytes in removing Heavy Metals from Wastewater Using Constructed Wetland. In Scientific Conference Proceedings.

Hu H. (2002) Human health and heavy metals exposure. In: McCally M, editor. Life support: the environment and human health. MIT press

Liao Wei-Shao and Chang Lian Wen (2004) Heavy Metal Phytoremediation by Water Hyacinth at Constructed Wetlands in Taiwan. Journal of Aquatic Plant Management. 42: 60-68.

Malik, A. (2007). Environmental challenge vis a vis opportunity: The case of water hyacinth. Environment International. 33: 122–138.

Mudgal, V., Madaan, N., and Mudgal, A. (2010) Heavy metals in plants: Phytoremediation: Plants used to remediate heavy metal pollution. Agri. Biol. J. Am. 1(1): 40-46.

Raji, K. A. (2008) Effect of *pH* and cadmium concentration on plant uptake by kenaf (*Hihiscus cannabinus*).

Sangya S., Kapil L., and Vriddhi N., (2015) Analysis of heavy metals removal by eichhornia crassipes (mart.) Solms. World Journal of Pharmacy and Pharmaceutical Sciences, 4(09); 732739.

Salehzadeh, J. (2013) Removal of Heavy Metals $Pb^{2+,}$ Cu^{2+}, $Zn^{2+,}$ Cd^{2+}, Ni^{2+}, Co^{2+} and Fe^{3+} from Aqueous Solutions by using *Xanthium Pensylvanicum*. Leonardo Journal of Sciences. Issue 23: 97-104.

Tolu O. A., and Atoke O. O., (2012) Achieving Environmental sustainability in wastewater treatment by phytoremediation with water hyacinth (eichhornia crassipes). Journal of Sustainable Development, 5(7); 80-90.

Wahab O. O.,and Liasu A. O., (2010) Phytoremediation potential of some heavy metals by water hyacinth. International Journal of Biological and Chemical Sciences, 4(2): 347-353.

Weiner, R. F. and Matthews, R. A. (2003) Environmental engineering. Fourth Edition