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Development of Hydrologic Flood Routing Model for Lower River Ogun Using HEC-RAS

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Abstract
Flood is a body of water that rise to overflow land, which is normally submerged. The water spills into the flood-plan which tend to be caused by heavy rain. There are cases of flooding in lower River Ogun with attendant loss of lives and damage of properties. In this study, a hydrologic flood routing model for lower River Ogun was developed. The developed model used a Muskingum approach. The twenty-five (25) years discharge data collected from 1995-2018 were used to estimate corresponding inflow using rational approach method. The outflow was computed using adopted routing period of 1 hour and dimensionless weighting factor of 0.17. The inflow was regressed against outflow and obtained a correlation coefficient of 0.998. Muskingum model which represents linear relationship between measured outflows and predicted outflows had highest coefficient of correlation in the year 2015, which exhibited good correlation. A routine storage capacity was carried out using regression. The value obtained from routed storage capacity was 4.50 x 10^7 m^3. The routed storage based on flood routing model could serve as a hydrological input in the development of flood routing by related water body. The developed flood routing is useful for predicting flood event and flood control works.

Keywords: *Flood routing, HEC-RAS, Hydrologic model, Lower River Ogun, Muskingum method*

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1. Introduction

In Nigeria, flooding and mitigation of its impacts are critical issues to be addressed. With the history of devastating floods which affected millions of human populations and caused fiscal losses, the importance of exploring more realistic flood risk mitigation measures for Nigeria should be paramount (Obeta, 2014). The growing number of flood victims and the constrained sustainable development caused by flooding within the country suggest that much of what is known as flood routing should be used to simulate flood wave movement through the river reaches and reservoirs. More critical, is the subject-matter of Nigeria being one of the most populated countries of the world, with the population size estimated to over 170 million people (World Bank, 2013). Considering the theory that population growth will drive potential flood risk, this population size along with future estimates, spurs interest towards building the capacities of human populations to cope with the flooding. Flood management is currently a key focus of many national and international research programmes with flooding from rivers, estuaries and the sea posing a serious threat to millions of people around the world during a period of extreme climate variability (Alabi *et al*., 2017).

The HEC-RAS software is a system that performs an analysis on one-dimensional steady and two-dimensional river flow of hydraulic and hydrologic computation. It is an integrated system of software, designed for interactive use in a multi-tasking, multi-user network environment (Prasuhn, 2008). The system is comprised of a graphical user interface, separate hydraulic analysis, and data storage management capabilities. HEC-RAS will be used in this study because of its capability of generating a large range of hydrologic and hydraulic responses from a typical river system. With only a single entry of river geometry and flow data is sufficient to model steady flow, unsteady and water quality analysis (Adewale *et al*., 2010). At present, no attention is paid on model for flood routing for Lower River Ogun, this calls for concerted efforts to develop hydrologic and hydraulic flood routing model for Lower River Ogun using HEC-RAS model.

Flood routing is a technique of investigating the flow hydrograph at the downstream point of catchment with sound information regarding hydrograph at its upstream. It is an approach to estimate how the magnitude and celerity of flood wave varies than that at the inflow point as it moves along the catchment (Subramanya, 2008). Flood routing along the catchment is a function of basin characteristics such as slope, length of channel, channel roughness, downstream control and initial inflow condition (Rahma *et al.*, 2017). The hydrologic modelling is based on continuity equation while hydraulic modelling is based on combination of continuity and momentum equation which is known as Saint-Venant equation (Larsson, 2017). Muskingum Cunge method has been used for river routing in the past by various researchers because of its high accuracy over other methods. Muskingum Cunge routing method is based on simplification of convective diffusion equation which is the combination of continuity and momentum equation (Brunner, 2016).

2. Materials and methods

2.1 Description of study area

The Lower River Ogun rises in Oyo state near Shaki, and flows through Ogun state into Lagos state (Nihinlola, 2004). It lies between longitude 2° 28′ 33" and 3° 48′ 08" Easthing and Latitude 6° 37′ 10" and 9° 26′ 39" Northing with catchment area of about 23,000 km^2. Ogun River takes its source from Igaran hills at an elevation of about 530 m above mean sea level and flows directly southwards over a distance of about 480 km before it discharges into Lagos lagoon (Olatunji, 2012). Lower River Ogun is a big river cutting cross three states with more than twenty (20) tributaries, one of which is Oyan River. Its major tributary is south of Abeokuta area (Oyegoke and Sojobi, 2012). River Onigbongbo and Ewekoro, lie within North of Abeokuta that flows southward into Oyan River which supplies water to Abeokuta and its environments (Ikenweirwe *et al.*, 2007). The map of the study area which shows the flow path and the sampling point of the river is presented in Fig. 1.

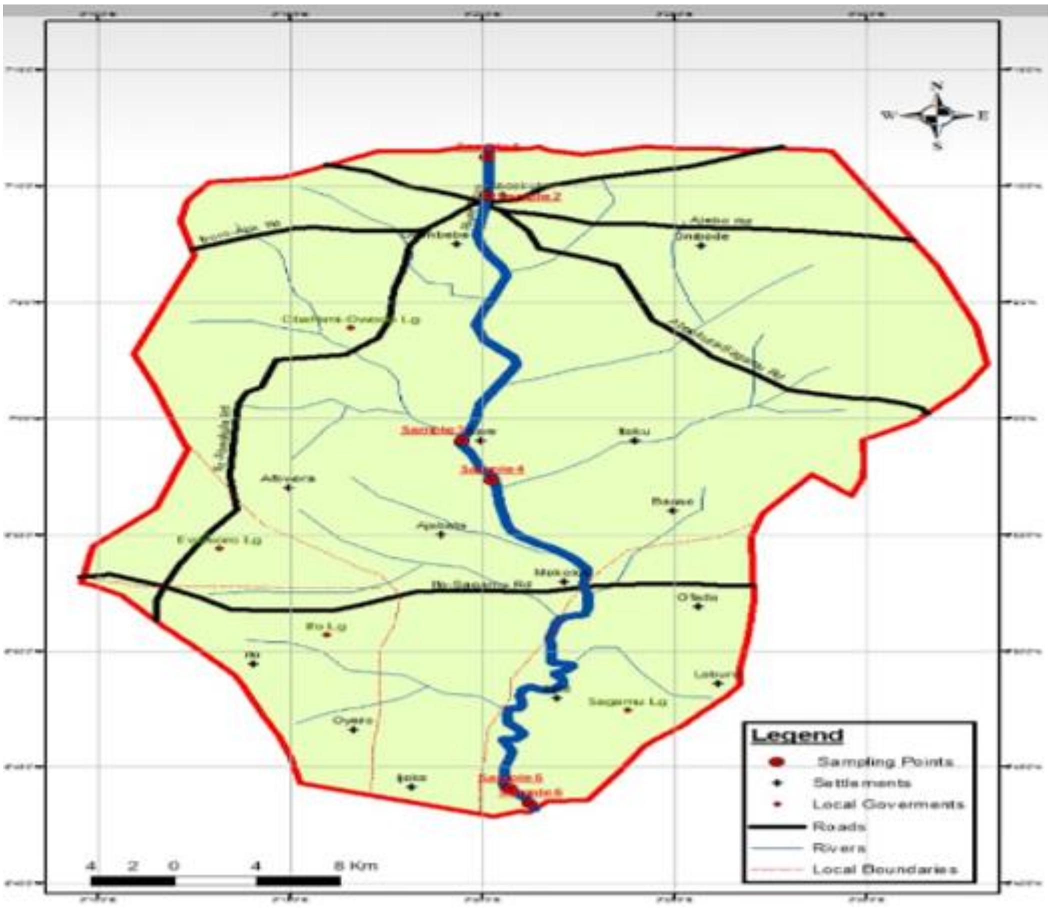

Fig. 1: Hydrological map of Ogun State showing sampling station

2.2 Muskingum method

In muskingum routing method, the predicted outflow and measured outflow were modelled on Lower River Ogun in order to indicate the release period that will allow effective storage and to prevent excessive flood at the downstream section of the river. The modelled equation was in the form of Equation (1)

$$y = Ax + C \quad (1)$$

where y = Predicted outflow (m^3/s), x = Measured outflow (m^3/s), C = Constant of regression equation. The regression analysis was used to model channel storage in order to alleviate flood of Lower River Ogun. The nature of the flow in the River Ogun is a non-uniform gradually unsteady flow. To determine the regime of flow for upstream of the channel, Froude number (F_r) was used.

$$F_r = \frac{V}{\sqrt{gy_1}} \quad (2)$$

$$V = \frac{Q_o}{(b + Zy_o)y_o} \quad (3)$$

where V is the average velocity (m/s), y_1 is the depth of flow in upstream (3.61m), g is the acceleration due to gravity (9.80m/s^2), b is the bed width (118.98m), and y_o is the normal depth (64.24m).

In a channel routing where non-uniform flow is the case, to determine the normal depth (y_o), a reference discharge (Q_o) was selected for a maximum flood event and this was calculated from Equation (3) (Fleming and Braver, 2016).

$$Reference\ discharge\ (Q_o) = Q_b + 0.5(Q_p - Q_b) \quad (4)$$

where Q_b is the Minimum discharge (193.02m^3/s), Q_p is the Peak discharge (2300.01m^3/s), and Q_o was determined. The channel parameters (length, bed width, side slope, bed slope, manning coefficient, reference discharge) were determined from Equation (4). The rate of movement of watercourse was estimated by considering Equation (5) (Ogbonna, 2015).

$$\varphi = \frac{(Q_o n)}{b^{\frac{8}{3}} S_o^{\frac{1}{2}}} \quad (5)$$

Using channel parameters, the area of flow was obtained from Equation (6).

$$A = b + (Zy_o)y_o \times 15 \quad (6)$$

$$Velocity\ (V) = \frac{Reference\ Discharge}{Area} \quad (7)$$

where S_o is the side slope of the channel (0.00034). Fr was obtained from Equations (2) and (3) in order to indicate the channel flow characteristic whether it is subcritical nor supercritical based on Froude number, if $F_r < 1$ it is subcritical, if $F_r > 1$ it is supercritical. The wave celerity (c) was obtained from Equation (8).

$$C = \beta V16 \quad (8)$$

β was assumed to be 0.5 (Chow, 1959). The storage for Lower River Ogun was estimated using Equation (9):

$$Storage = Area \times Velocity \times Time \quad (9)$$

The governing equations were adopted as outlined by Aketoyon (2010).

3. Results and discussion

3.1 Cumulative storage of Lower River Ogun

The result of the storage capacity of Lower River Ogun using Muskingum method is presented in Table 1 to 3. In 1995, the storage varies from (1.63-1.83) x 10^9 m^3 with the highest storage capacity in the month of September. This is as a result of rainy period. The storage capacity for the year 1996 varies from (1.60-55.1) x 10^9 m^3 with the highest value of storage observed in September. But in 1997, the highest storage was observed in October with 78.04 x 10^9 m^3. From 1997 to 2018, the storage capacity varied from (11.99-34.55) x 10^9 m^3 with the highest storage in the month of September and October all through the year of observation. This indicated that release period that would be allowed for effective storage and prevent the excessive flood at the downstream of Lower River Ogun gave highest storage capacity in the cumulative mean storage of the river. This is in line with the previous findings of Alabi et al. (2017) and Eruola et al. (2012).

3.2 Inflow and outflow modelling of Lower River Ogun

The inflow and outflow relationship for the estimation of predicted outflow on Lower River Ogun was obtained by regressing inflow against outflow with Excel Software. This inflow and outflow modelling is a mathematical model describing the relationship between the inflow and outflow data. The developed inflow and outflow modelled equation on Lower River Ogun is presented in Table 4. The inflow and outflow were derived for the purpose of converting inflow data to predicted outflow. It was thus observed that the modelling equation was developed to estimate the relationship between inflow and outflow, in which the y in the equation is the predicted outflow and the x in the modelled equation is the measured outflow data. It was observed that regression equation y = 1.3x – 5.5 gave a more accurate result of coefficient of regression 0.998 therefore it should be adopted for the computation of predicted outflow. This is in consonance with previous work of Ogbonna (2017).

Table 1: Cumulative mean storage of Lower River Ogun for the year 1995

S/N	Inflow (m^3/s)	Outflow (m^3/s)	*Ix + (I – x) O* (m^3/s)	Storage (m^3)
1.	40042080	39617117.28	39689360.94	2381361656
2.	36167040	25474895.94	27292560.43	1637553626
3.	40872384	32716183.17	34102737.31	2046164239
4.	40046400	36281724.44	36921719.29	2215303157
5.	42479424	39206315.84	39762744.23	2385764654
6.	43338240	46672138.09	46105375.41	2766322525
7.	118492416	80487905.02	86948671.89	5216920313
8.	126420480	127716829.40	127496450.00	7649787000
9.	477601920	270111871.70	305385179.50	18323110790
10.	214004160	25681510.37	57696360.81	3461781648
11.	38594880	316315826.50	269103265.60	16146195940
12.	38309760	347159168.10	294654768.70	17679286120

Table 2: Cumulative mean storage of Lower River Ogun for the year 1996

S/N	Inflow (m^3/s)	Outflow (m^3/s)	*Ix + (I – x) O* (m^3/s)	Storage (m^3)
1.	39667104	39285292.56	39350200.50	2361012030
2.	36384768	25378702.17	27249733.38	1634984003
3.	40711680	32321280.93	33747648.77	2024858926
4.	40684896	36120112.62	36896125.79	2213767548
5.	41836608	45181050.16	44612494.99	2676749700
6.	44893440	51235269.91	50157158.83	3009429530
7.	135205632	45911505.53	22984957.44	1379097446
8.	186667200	97367673.59	112548593.10	6752915585
9.	1945848096	179426418.90	4797181040	28783086240
10.	179521920	1070420613.00	918967835.20	55138070110
11.	39216960	871959666.90	724393206.70	43463592400
12.	40042080	765706945.40	642344918.30	38540635100

Table 3: Cumulative mean storage of Lower River Ogun for the year 2018

S/N	Inflow (m^3/s)	Outflow (m^3/s)	*Ix + (I – x) O* (m^3/s)	Storage (m^3)
1.	39238560	39162748.29	39175636.28	2350538177
2.	38320128	60176229.28	56460692.06	3387641524
3.	45152640	52770118.51	51475147.16	3088508830
4.	39191040	66118863.59	61541133.58	3692468015
5.	304646400	172620639.10	14854112.50	8907246747
6.	252274176	208383703.00	215845083.40	12950705000
7.	237867840	233519165.40	234258440.10	14055506400
8.	393704064	315056111.10	328426263.10	19705575790
9.	4943380800	331191686.50	1115263836.00	66915830150
10.	540812160	2298080347.00	1999344755.00	119960685300
11.	237199104	2159503224.00	1832711524.00	109962691400
12.	43296768	1179690975.60	986503959.80	59190237590

Table 4: Inflow and outflow modelling of Lower River Ogun (1995-2018)

Year	Regression Equation	Coefficient of Regression (R^2)
1995	y = 2x + 0.7	0.914
1996	y = 0.83x + 1.83	0.826
1997	y = 0.76x + 2.16	0.876
1998	y = 5.21x - 4.22	0.788
1999	y = 3.1x + 11.7	0.937
2000	y = 3.4x - 3.0	0.970
2001	y = 3.19x - 2.78	0.922
2002	y = 3.43x - 3.04	0.956
2003	y = 1.92x + 9.32	0.968
2004	y = 2.57x - 2.16	0.972
2005	y = 1.02x - 1.45	0.948
2006	y = 2.56x – 2.16	0.984
2007	y = 3.9x + 10.8	0.929
2008	y = 1.6x + 8.25	0.955
2009	y = x + 3.7	0.982
2010	y = 1.84x + 9.0	0.996
2011	y = 4.5x – 3.7	0.936
2012	y = 2.9x – 2.5	0.958
2013	y = 2.9x – 9.8	0.926
2014	y = 0.7x – 4.7	0.936
2015	y = 1.3x – 5.5	0.998
2016	y = 0.8x + 6.27	0.986
2017	y = 3.99x – 3.21	0.979
2018	y = 4.57x – 9.47	0.953

3.3 Computation of predicted outflow model of Lower River Ogun

The result of the computation of predicted outflow is presented in Table 5. The predicted outflow was computed for Lower River Ogun in order to know the storage capacity of the river which will prevent flooding of the river or the impacts of flooding from being more severe. The predicted outflow across the Lower River Ogun was high in November, 2015 with the value 3.86 x 10^8 m^3/s with the lowest predicted outflow in January with the value 0.7 x 10^8 m^3/s. The predicted outflow decreased from January to February, but increased from March to November and later decreased in December. This is due to variation in measured outflow. Since 3.86 x 10^8 m^3/s gave the highest and most accurate result of predicted outflow, the value should be adopted as a model for flood mitigation in Lower River Ogun. This is in line with previous findings of Oyegoke and Sojobi (2012).

3.4 Developed routed storage capacity of Lower River Ogun

Lower River Ogun reach is approximately 90 km long, bed width 118.98 m, side slope (z) 0.89, and average bed slope (S_0) is 0.00034. The channel bed is lined with mostly bare rock. Lower River Ogun has a trapezoidal cross-section with recent floodplain. The modelling across the river was considered. The results of nature of flow, reference discharge, area, velocity, celerity and routed storage capacity is presented in Table 6. It is observed from Table 6 that the Fr < l, this indicates that the river channel has a mild slope and the flow regime is characterized as gradually varied subcritical flow. The β is assumed to be 0.5. The routed storage capacity is 4.50 x 10^7 m^3, to guarantee a check against flooding, it is recommended that dredging is carried out to achieve the modelling storage capacity. This is in consonance with previous findings of Ogbonna (2017).

Table 5: Predicted outflow model for Lower River Ogun

S/N	Predicted Outflow (m^3/s)
1	77797557.86
2	67235158.56
3	80869908.60
4	84872709.73
5	184383109.80
6	247453009.00
7	248326619.30
8	71609694.96
9	192024597.50
10	307071895.50
11	386343177.80
12	254156241.90

Table 6: Computation of routed storage capacity

Parameters	Formula	Output
Froude Number (F_r)	$\frac{V}{\sqrt{gy_1}}$	0.10
Reference Discharge (Q_0)	$Q_b + (0.5 (Q_p – Q_b)$	1246.52 m^3/s
Accelerated Flow	$\frac{Q_0 n}{b^{8/3} S^{1/2}}$	0.0068 m^2/s
Area of Flow (A)	$(b + (zy_0))\ y_0 \times 15$	56876.40 m^2
Velocity (v)	$\frac{Reference\ Discharge\ (Q_0)}{Area\ of\ Flow\ (A)}$	0.22 m/s
Nature of Flow	$F_r < 1$	The flow of water in Lower River Ogun is gradually subcritical flow
Wave Celerity (C)	βV16	0.33 m/s
Routed Storage (S)	Area x Velocity x time	45046108.8 m^3

4. Conclusions

The following conclusions were drawn from the study:

a. The rate of outflow from the river channel did not exceed rate of inflow.
b. The routing parameter, the current factor did not exceed one
c. The predicted outflow is 4.5×10^7 m^3.
d. The routing model equation has coefficient of determination 0.998.

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