# MODELING THE FLOODING OF AWARA RIVER IN ONDO STATE, SOUTHWESTERN NIGERIA

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**Abstract:** This study uses curve fitting techniques to formulate a model for the flow of water in Awara River in Ondo State. The model is formulated to reflect the interrelationship existing among the discharge of water, distance the water travels for a particular time range of continuous rainfall and the velocity of the flow of the water and the average rainfall. These are terms considered significant in predicting the distance covered by flooding at a particular time. A direct runoff generation using average rainfall on a yearly basis for the years (1985 – 2005), giving a total of 21 years was used to formulate the model. It was observed that the peak distance covered by the flood occurs in the month of September and the model takes the form of, $S = 1.78*10^{-5}(R) + 21.63*10^{-5}$

**Where:** S is the distance covered by the flood in metre and R is the monthly average rainfall in millimeter

**Keywords:** Awara dam, curve fitting, discharge, flooding, model, rainfall, velocity

## Introduction

A flood is an overflow of water that submerges land which is usually dry (Apel *et al*., 2004). Flooding may occur as an overflow of water from water bodies, such as a river or lake, in which the water overtops or breaks levees, resulting in some of that water escaping its usual boundaries (Apel *et al*., 2004). Floods can also occur in rivers when the flow rate exceeds the capacity of the river channel, particularly at bends or meanders in the waterway. Floods often cause damage to homes and businesses if they are in the natural flood plains of rivers. Floods are among the most devastating natural disasters that result into loss of lives yearly (Arthington *et al*., 1998; Alkema & Middelkoop, 2005). Flooding seriously affects people's lives and property. The frequency with which they occur is on the increase in many regions of the world (Akeroyd *et al*., 1998; Hall & Solomatine, 2010).

It is reported that flood disasters account for about a third of all natural disasters by number and economic losses. Nigeria is no exception to countries that experienced flooding in recent time. Many communities have suffered losses due to flood problem. The need and means to protect the environment is of great concern to man. Flood management is currently a key focus of many national and international research works 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 (Neuhold *et al*., 2009).

Flood problems in Nigeria have toll a new dimension in recent time. There is increasing vulnerability of populations and infrastructure to flooding and flood related hazards. More communities are now been affected in the country. Flooding is among the most devastating natural hazards in the world claiming more lives and causing damage to property and infrastructure than any other natural phenomena. One of the major causes of flooding in this area is excess rainfall which sometimes results into the damage of the dam thereby causing flooding. A better understanding and behavior of the flooding can be a base for management of flooding. Hence, there is a need to learn the basic concepts of flood modeling and understand the factors that cause flooding. This will enable us to understand the basic causes, effects, benefits, flow pattern or direction, behavior of flooding. Also some parameters will be calculated from available data with a set of mathematical formulas and the use of modeling as a process of imitating a real phenomenon or process like flooding (Casas *et al*., 2006; Bates *et al*., 1996; Prachansri, 2007).

### *Location and climate of the study area*

The proposed project is located at Akoko North East Local Government in the Northern Senatorial district of Ondo State on Longitude $7^0$ 30'and $8^0$ 00'E and Latitude $5^0$ 30'and $6^0$ 00' N (Fig. 1). The Dam which is already existing can serve as a renewable energy source for the running of the SHP that will be installed downstream of the dam. The dam was built in the 1950s for irrigation and to supply water to Ikare township, Arigidi, Ugbe, Arigidi-Imo, etc., all in Akoko North East Local government area of Ondo State. The Climate in the area consists of rainy season (April-November) and dry season (August-March).


**Fig. 1:** Map of Ondo State showing study area (modified after GSN)

### *Basic equations for hydrologic routing*

The passage of a flood hydrograph through a reservoir or a channel reach is a gradually varied unsteady flow. If we consider some hydrologic system with input *I(t)*, output *O(t)*, and storage *S(t)*, then the equation of continuity in hydrologic routing methods is given below:

$$I - O = \frac{dS}{dt} \qquad (1)$$

**Where:** I(t)= inflow hydrograph, O(t)= outflow hydrograph, S(t)= storage

If the inflow hydrograph, *I(t)* is known, this equation cannot be solved directly to obtain the outflow hydrograph, *O(t)*, because both *O* and *S* are unknown. A second relation, the storage function is needed to relate *S, I, and O*. The particular form of the storage equation depends on the system; a reservoir or a river reach. The effect of reservoir storage is to redistribute the hydrograph by shifting the centroid of the inflow hydrograph to the position of that of the outflow hydrograph in time. When a reservoir has a horizontal water surface elevation, the storage function is a function of its water surface elevation or depth in the pool. The outflow is also a function of the water surface elevation, or head on the outlet works. By combining these two functions, $S = f(O)$ we get a single valued storage function (for rivers it becomes a loop: not single valued). For such reservoirs, the peak outflow occurs when the outflow hydrograph intersects the inflow hydrograph. Because maximum storage occurs when

$$I - O = \frac{dS}{dt} = 0 \quad (2)$$

As the horizontal water surface is assumed in the reservoir, the reservoir storage routing is known as Level Pool Routing. The outflow from a reservoir (over a spillway) is a function of the reservoir elevation only. The storage in the reservoir is also a function of the reservoir elevation. Further due to passage of the flood wave through the reservoir the water level in the reservoir changes with time $h = h(t)$ and hence the storage and discharge change with time. It is required to find the variations of *S, h, and O* with time for given inflow with time. In a small time interval Δt the difference between the total inflow and outflow in a reach is equal to the change in storage *(ΔS)* such that:

$$\bar{I}\Delta t - \bar{O}\Delta t = \Delta S \quad (3)$$

**Where:** $\bar{I}$ = average inflow in time Δt, $\bar{O}$ = average outflow in time Δt.

**Materials and Methods**

Data was obtained from the "Detailed Project Report for Awara Dam/Oyimo River Hydro Power Development, Ikare-Akoko (North-East LGA), Ondo State by UNIDO Regional Centre for Small Hydro Power in Africa, Abuja, Nigeria (UNIDO-RC-SHP). The data obtained for this study was used in investigating the Average Velocity, Celerity and the Distance covered by water (Rainfall) for every 3hrs interval (Jan-Dec) and consequently a simple linear model was developed to predict the distance (m) covered by the water by using the plots obtained from Microsoft Excel. The technique used in developing the model involves a curve fitting technique using Microsoft Excel with which multiple fits can be created, plotted and compared. The distance covered by water for every 3 h (i.e. 3, 6, 9, 12, 15, 18, 21, and 24 h) was obtained by dividing the Average Discharge ($m^3/s$) by the Catchment Area ($m^2$) and multiplying it by the time frame in seconds(s) (Simon 1981) as:

$$\frac{Average\ Discharge\left(m^3/_s\right)}{Catchment\ Area\ (m^2)} X(Time(hrs)X60X60)s \quad (4)$$

***The model equation***

In this study, a model equation was derived for the distance covered by the flood for every 3hrs by plotting a graph of the average rainfall (mm) by the distance covered (m). The targeted model equation was derived by finding the average of all the equations gotten from plotting Average Rainfall (mm) against Distance covered in 3 h $D_3$(m), Distance covered in 6 h $D_6$(m), Distance covered in 9 h $D_9$(m), Distance covered in 12 h $D_{12}$(m), Distance covered in 15 h $D_{15}$(m), Distance covered in 18 h $D_{18}$(m), Distance covered in 21 h $D_{21}$(m) and Distance covered in 24 h $D_{24}$(m).

**Results and Discussion**

Using the available catchment Area and Average Discharge from Table 1, the distance covered by the flood in intervals of 3 h was calculated for each month in Table 2 and the graph was plotted against the average rainfall.

Figs. 2 and 3 show the average discharge in all the months and indicating the peak discharge for the months. Figs. 4 and 5 show that if rain falls continuously for 3 h, the peak distance covered by the flood is 87.4875 x $10^{-5}$ m and it occurs in the month of September while, the lowest distance covered by the flood is 1.22545 x $10^{-5}$ m and it occurs in the month of February. Figs. 6 and 7 show that if rain falls continuously for 6 h, the peak distance covered by the flood is 17.4975 x $10^{-5}$ m and it occurs in the month of September while, the lowest distance covered by the flood is 2.45089 x $10^{-5}$ m and it occurs in the month of February.

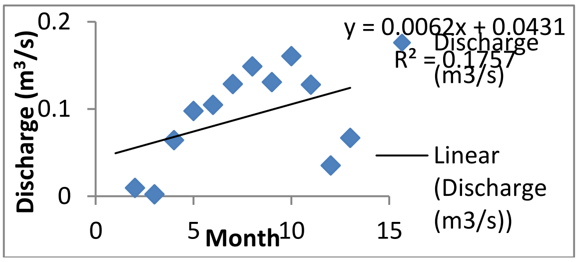


**Fig. 2:** Plot showing the average discharge versus Month

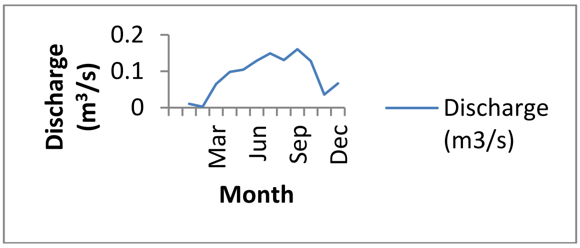


**Fig. 3:** Plot of the discharge versus month showing the peak discharge

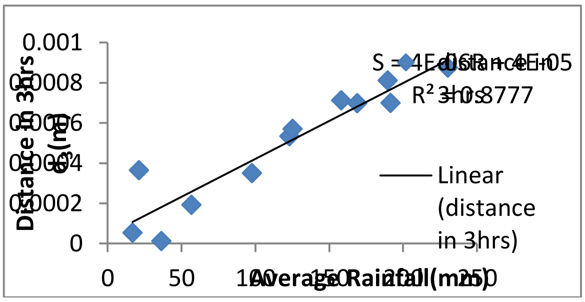


**Fig. 4:** Plot of the distance covered by the flood (m) in 3 h versus average rainfall (mm)

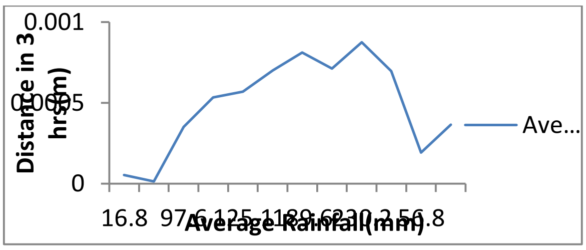


**Fig. 5:** Plot of distance covered by flood (m) in 3 versus average rainfall (mm) showing peak rainfall

**Table 1: Basic data, catchment area and the 25 years average rainfall**

| Month | Catchment Area ($m^2$) x$10^6$ | 25 yrs Monthly Average Rainfall (mm) | Average Depth(m) | Discharge ($m^3$/s) | Velocity V (m/s) x$10^{-8}$ | Average Velocity Ū (m/s) | for β=1.67 Celerity C (m/s) |
|---|---|---|---|---|---|---|---|
| Jan | 1.984 | 16.8 | 10.50 | 0.0098 | 0.494 | 9.6874578 | 16.1780545 |
| Feb | 1.984 | 36.4 | 10.50 | 0.0022511905 | 0.114 | 9.6874578 | 16.1780545 |
| Mar | 1.984 | 97.6 | 10.50 | 0.064333333 | 3.243 | 9.6874578 | 16.1780545 |
| Apr | 1.984 | 123 | 10.50 | 0.097891111 | 4.934 | 9.6874578 | 16.1780545 |
| May | 1.984 | 125.1 | 10.50 | 0.104666667 | 5.276 | 9.6874578 | 16.1780545 |
| Jun | 1.984 | 191.5 | 10.50 | 0.128533333 | 6.479 | 9.6874578 | 16.1780545 |
| Jul | 1.984 | 189.6 | 10.50 | 0.148933333 | 7.507 | 9.6874578 | 16.1780545 |
| Aug | 1.984 | 158.1 | 10.50 | 0.1308 | 6.593 | 9.6874578 | 16.1780545 |
| Sep | 1.984 | 230.2 | 10.50 | 0.160717778 | 8.101 | 9.6874578 | 16.1780545 |
| Oct | 1.984 | 169 | 10.50 | 0.128066667 | 6.455 | 9.6874578 | 16.1780545 |
| Nov | 1.984 | 56.8 | 10.50 | 0.035271111 | 1.778 | 9.6874578 | 16.1780545 |
| Dec | 1.984 | 16.8 | 10.50 | 0.066866667 | 3.370 | 9.6874578 | 16.1780545 |

**Table 2: Average rainfall and distance covered by water for every 3 h interval in a day (Jan – Dec)**

| Average Rainfall (mm) | Distance in 3 h $d_3$(m) x$10^{-5}$ | Distance in 6 h $d_6$ (m) x$10^{-5}$ | Distance in 9 h $d_9$(m) x$10^{-5}$ | Distance in 12 h $d_{12}$(m) x$10^{-5}$ | Distance in 15 h $d_{15}$(m) x$10^{-5}$ | Distance in 18 h $d_{18}$(m) x$10^{-5}$ | Distance in 21 h $d_{21}$(m) x$10^{-5}$ | Distance in 24 h $d_{24}$(m) x$10^{-5}$ |
|---|---|---|---|---|---|---|---|---|
| 16.80 | 5.33468 | 10.6694 | 16.004 | 21.3387 | 26.6734 | 32.0081 | 48.000 | 42.6774 |
| 36.40 | 1.22545 | 2.45089 | 3.6763 | 4.90179 | 6.12723 | 7.35268 | 11.000 | 9.80357 |
| 97.60 | 35.0202 | 70.0403 | 105.06 | 140.081 | 175.101 | 210.121 | 315.20 | 280.161 |
| 123.0 | 53.2875 | 106.575 | 159.86 | 213.150 | 266.438 | 319.725 | 479.60 | 426.300 |
| 125.1 | 56.9758 | 113.952 | 170.93 | 227.903 | 284.879 | 341.855 | 512.80 | 455.806 |
| 191.5 | 69.9677 | 139.936 | 209.90 | 279.871 | 349.839 | 419.807 | 629.70 | 559.742 |
| 189.6 | 81.0726 | 162.145 | 243.22 | 324.290 | 405.363 | 486.436 | 729.70 | 648.581 |
| 158.1 | 71.2016 | 142.403 | 213.61 | 284.807 | 356.008 | 427.210 | 640.80 | 569.613 |
| 230.2 | 87.4875 | 174.975 | 262.47 | 349.950 | 437.438 | 524.925 | 787.40 | 699.900 |
| 169.0 | 69.7137 | 139.427 | 209.14 | 278.855 | 348.569 | 418.282 | 627.40 | 557.710 |
| 56.80 | 19.2000 | 38.4000 | 57.600 | 76.8000 | 96.0000 | 115.200 | 172.80 | 153.600 |
| 21.20 | 36.3992 | 72.7984 | 109.20 | 145.597 | 181.996 | 218.395 | 327.60 | 291.194 |

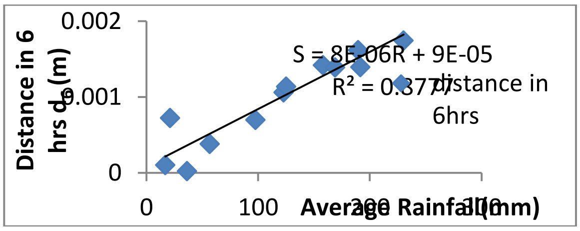


**Fig. 6:** Plot of the distance covered by the flood (m) in 6 h versus average rainfall (mm)

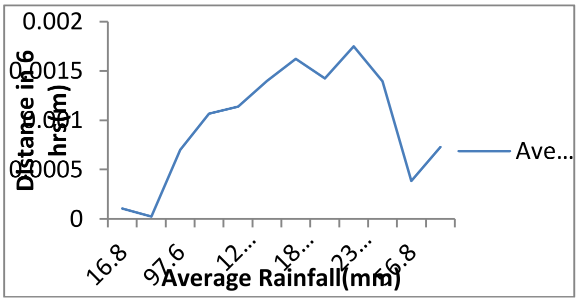


**Fig. 7:** Plot of distance covered by flood (m) in 6 h versus Average rainfall (mm) showing peak rainfall

Figs. 8 and 9 show that if rain falls continuously for 9 h, the peak distance covered by the flood is 26.24625 x $10^{-5}$ m and it occurs in the month of September, while the lowest distance covered by the flood is 3.67634 x $10^{-5}$ m and it occurs in the month of February. Figs. 10 and 11 show that if rain falls continuously for 12 h, the peak distance covered by the flood is 34.995 x $10^{-5}$ m and it occurs in the month of September, while the lowest distance covered by the flood is 4.90179 x $10^{-5}$ m and it occurs in the month of February.

Figures 12 and 13 show that if rain falls continuously for 15 h, the peak distance covered by the flood is 43.74375 x $10^{-5}$ m and it occurs in the month of September while, the lowest distance covered by the flood is 6.12723 x $10^{-5}$ m and it occurs in the month of February. Figs. 14 and 15 show that if rain falls continuously for 18 h, the peak distance covered by the flood is 52.4925 x $10^{-5}$m and it occurs in the month of September while, the lowest distance covered by the flood is 7.35268 x $10^{-5}$ m and it occurs in the month of February. Figs. 16 and 17 show that if rain falls continuously for 21 h, the peak distance covered by the flood is 78.74 x $10^{-5}$ m and it occurs in the month of September while, the lowest distance covered by the flood is 11.01 x $10^{-5}$ m and it occurs in the month of February.

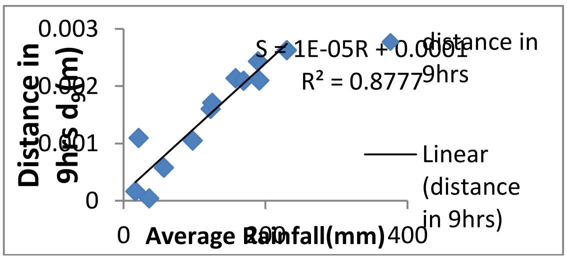


**Fig. 8:** Plot of the distance covered by the flood (m) in 9 h versus average rainfall (mm)

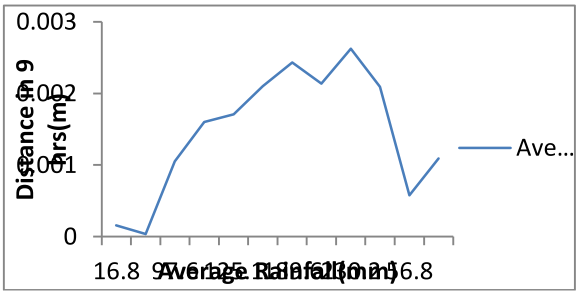

**Fig. 9:** Plot of distance covered by flood (m) in 9 h versus average rainfall (mm) showing peak rainfall

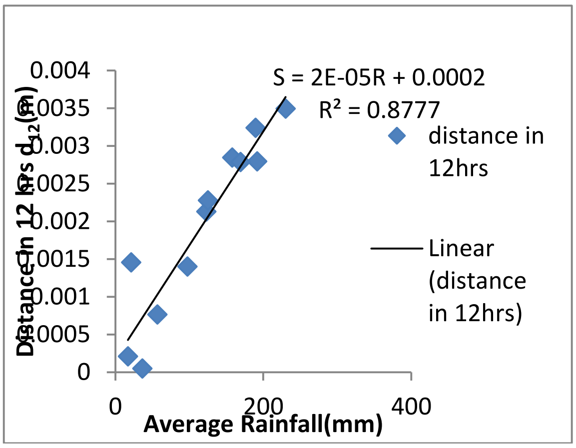


**Fig. 10:** Plot of the distance covered by the flood (m) in 12 h versus average rainfall (mm)

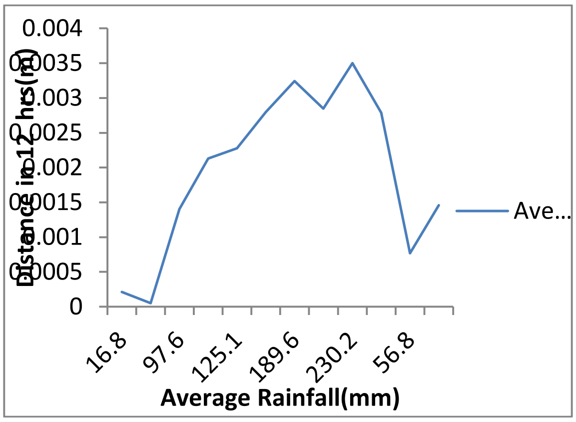


**Fig. 11:** Plot of distance covered by flood (m) in 12 h versus average rainfall (mm) showing peak rainfall

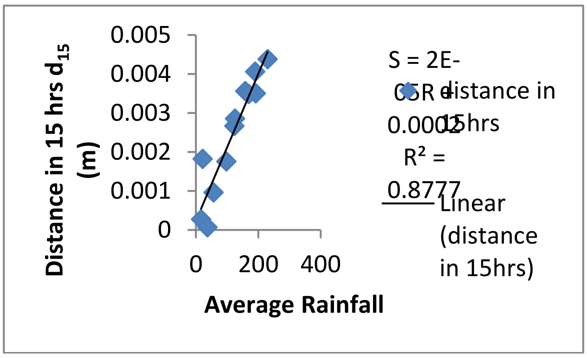


**Fig. 12:** Plot of the distance covered by the flood (m) in 15 h versus average rainfall (mm)

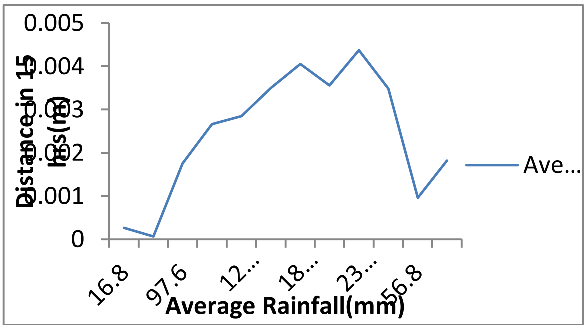


**Fig. 13:** Plot of distance covered by flood (m) in 15 h versus average rainfall (mm) showing peak rainfall

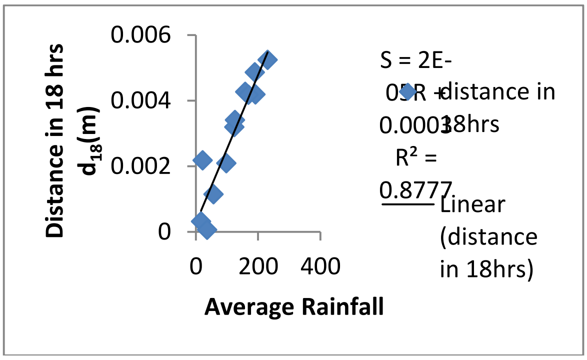


**Fig. 14:** Plot of the distance covered by the flood (m) in 18 h versus average rainfall (mm)

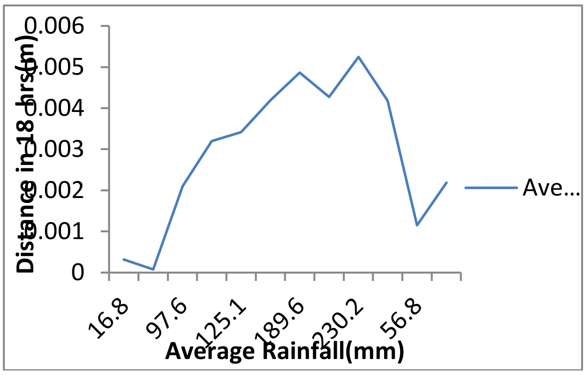


**Fig. 15:** Plot of distance covered by flood (m) in 18 h versus average rainfall (mm) showing peak rainfall

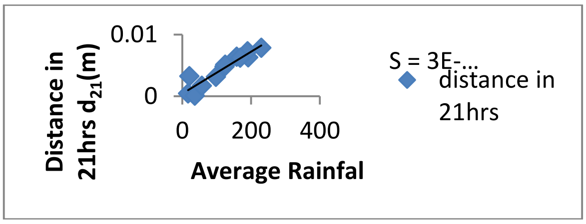


**Fig. 16:** Plot of the distance covered by the flood (m) in 21 h versus average rainfall (mm)

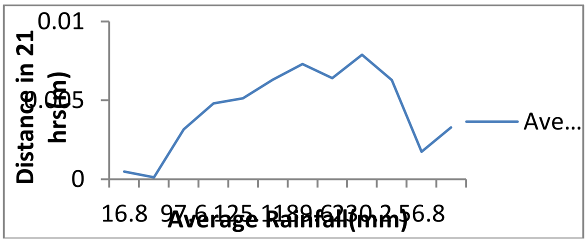


**Fig. 17:** Plot of distance covered by flood (m) in 21 h versus average rainfall (mm) showing peak rainfall

Figures 18 and 19 show that if rain falls continuously for 24 h, the peak distance covered by the flood is 699.9 x $10^{-5}$ m and it occurs in the month of September while, the lowest distance covered by the flood is 9.8 x $10^{-5}$ m and it occurs in the month of February.

Figure 20 shows the distance covered by water against the average rainfall for every 3hrs interval between January and December.

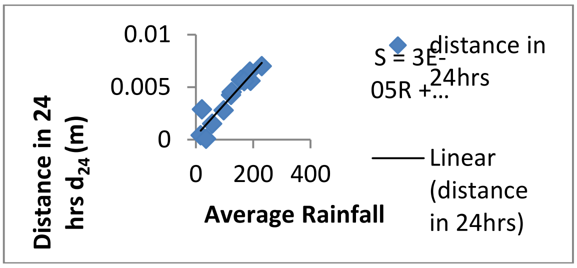


**Fig. 18:** Plot of the distance covered by the flood (m) in 24 h versus average rainfall (mm)

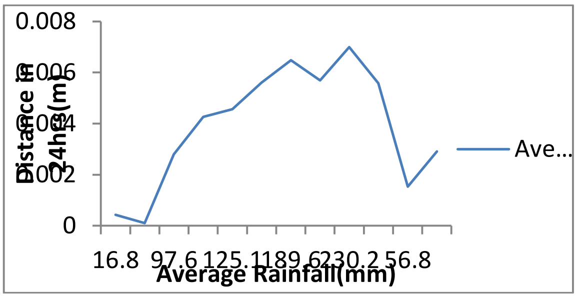


**Fig. 19:** Plot of distance covered by flood (m) in 24 h versus average rainfall (mm) showing peak rainfall

Generally, from Figs. 4-19, we can deduce that the flood peak occurs in the month of September, which means for the available data given of the Average rainfall, the month with the highest Average Rainfall is and the longest distance is September.

The Model equation was derived from finding the average of the equations gotten from Figs. 4, 6, 8, 10, 12, 14, 16, 18 and computed in Table 3. Hence the model equation takes the form:

$$S = 1.78*10^{-5}(R) + 21.63*10^{-5} \quad (5)$$

**Where:** *S* is the distance covered by the flood (m), and R is the average rainfall (mm)·

The above model can be used to predict the distance covered by the water vis-a-vis flood for any period of continuous rainfall.

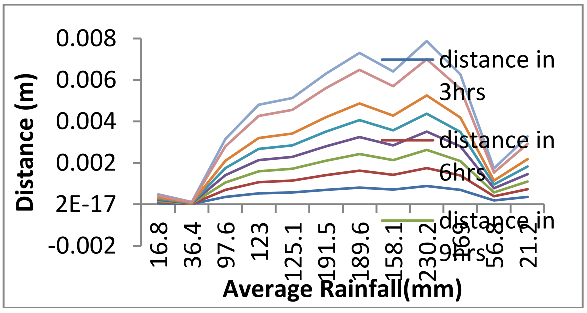


**Fig. 20:** Plot of distance (m) covered by water versus average rainfall for every 3 h interval (Jan – Dec)

**Table 3: Computed average model equations for 3 h intervals**

| S/N | Hours | A x $10^{-5}$ | B x $10^{-5}$ |
|---|---|---|---|
| 1 | 3 | 0.40 | 4.000 |
| 2 | 6 | 0.80 | 9.000 |
| 3 | 9 | 1.00 | 10.00 |
| 4 | 12 | 2.00 | 20.00 |
| 5 | 15 | 2.00 | 20.00 |
| 6 | 18 | 2.00 | 30.00 |
| 7 | 21 | 3.00 | 40.00 |
| 8 | 24 | 3.00 | 40.00 |
| | Average | 1.78 | 21.63 |

## Conclusion

In this work we have used curve fitting techniques to create a model for water flow in Awara river in Ondo State by imitating the connecting the discharge of water, distance the water travels for a particular time range of continuous rainfall and the velocity of the flow of the water and the average rainfall from available data of average rainfall of 21 years. We concluded that the peak distance covered by the water (or flood) increases with the increase in the period of the rainfall and volume of rain. The peak period was recorded in the month of September, which is the month with the highest rainfall. The distance covered by the flow for a particular period of rainfall can be easily determined from the model obtained in this work. This process would be duplicated for any river with known parameters. It is recommended that more data should be obtained in order to improve on and further modification of this model in order to have an accurate prediction of flooding both locally and the world at large.

## Acknowledgement

We will like to appreciate UNIDO Regional Centre for Small Hydro Power in Africa, Abuja, Nigeria (UNIDO-RC-SHP) for the data that was made available for this work.

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