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USING MUSKINGUM TO CALCULATE RIVER KADUNA FLOOD OUTFLOW

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ABSTRACT: *Flood is now a global nuisance that need a solution in order to save the lives and properties of communities living in flood prone areas. Communities living near River Kaduna, in northern Nigeria, have experienced almost yearly occurrence of flood in their areas. Lives and properties worth millions have been lost in recent years, which mean that there is urgent need for some mitigation measures to be taken, to avoid further catastrophe. For this reason, research work was carried out in order to see how the flood in the river can be routed, so as to give the people certain period of time to evacuate some of their properties and run into safety. The routing of the flood was carried out using Muskingum, and an equation was developed to calculate outflow in the river. A routing period of 6 hours was obtained. The model equation was used to calculate some outflows and the values obtained were compared with the measured values in* m^3*/sec. as follows: after 6 hours, measured value is 1028.9 while calculated value is 1036.2, after 12 hours, measured value is 1172.14 while calculated value is 1182.2, after 18 hours, the measured value is 1424.5 while calculated value is 1424.8, after 24 hours, measured value is 1582.5, while calculated value is 1592.0, after 30 hours, measured value is 1586.5, while calculated value is 1593.8, after 36 hours, measured value is 1480.45, while calculated value is 1480.9, after 42 hours, measured value is 1345.0 while calculated value is 1341.5 and after 48 hours, measured value is 1216.0, while calculated value is 1209.6. This concludes that the model equation is effective and can be successfully used to calculate flood outflow, especially if the values are missing.*

KEY WORDS: flood outflow, river Kaduna, Muskingum, model equation, calculated value.

INTRODUCTION

Until recently, when technology has brought many changes in the life of human beings, the approach to providing water, for whatever purpose, was simply: either locates close to water, as many cities (including Kaduna) did, or store water and transport it to wherever it is required. These are the reasons why many of our cities have rivers. This is the practice worldwide. For example, in London, the capital city of England, there is Thames River and in Washington D.C; the capital of the United States, there is Potomac River. In accordance with many factors, such as climate, location, vegetation, topography, etc, there are cases where by floods may occur in an area, with the river overflowing its banks and the result may be catastrophic, especially in the immediate neighbouring communities (Avemani and Ilaboya, 2007). Flood is a relatively high flow of water that overtops the natural or artificial banks in any of the reaches of a river, which often is associated with hazards. When banks are overtopped, water spreads over the floodplain and generally causes untold sufferings for the communities around the area. According to Chai (2010) hazard can be defined as "potentially damaging physical event, phenomenon or human activity that may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation".

With the exception of some floods generated by dam failure or landslides, floods are climatological phenomena influenced by the geology, geo-morphology, relief, soil, and vegetation conditions (Delphi, 2011). Although floods are natural phenomena, human activities and human interventions into the processes of nature, such as alterations in the drainage patterns from urbanization, agricultural practices and deforestation, have considerably changed the situation in whole river basins. Each hazard is characterized by its location, frequency and probability of occurrence in a specific region within a specific time and magnitude (Chai, 2010). A flood will saturate the soil that is above the ground water or water table. The water table is where soil is 100% saturated. Above the water table is below 100%, until after a flood (Adebayo and Salami, 2004).When rain falls on the surface of the earth, some of the water is evaporated and returns to the atmosphere, some of it infiltrates the soil and moves downward into the groundwater system, and some is intercepted by depressions and vegetation. Specifically, floods occur when soil and vegetation cannot absorb all the water; therefore, the remaining (excess) water then runs off the land in quantities that cannot be carried in stream or river channels or retained in natural ponds and constructed reservoirs. Periodic floods occur naturally on many rivers, including River Kaduna, forming an area known as the flood plain.

Several factors contribute to flooding. Key elements are rainfall intensity and duration, and the discharge at that time. If there is prolonged high rainfall, rainwater infiltrates into the water table and causes the water table to rise to the surface. This water may initially form pools and if the water still has nowhere to drain to, it will eventually flood. When rainfall stops, the water table will eventually drop, and the flooding will stop as this water is able to infiltrate the soil surface and into the water table. When the discharge of a river increases, the channel may become completely full. Any discharge above this level will result in the river overflowing its banks and causing a flood (Encarta, 2009). The stage at which the river will overflow its banks is called bankfull stage or flood stage**.** For example, the flood stage of the Mississippi River at New Orleans is 5 metre. Discharge that produces a stage over 5 metre will result in the water nearing the top of the levee with potential flooding of the city of New Orleans (the top of the levee is actually at 7 metre above sea level).(Encarta, 2003). The last flooding that occurred in 2012 in Kaduna, just like the previous ones in the area, was generally caused by high tides and storm surges associated with heavy intensity and durable rainfall. As a result, River Kaduna overflow its banks spilling flood waters into the adjoining properties (houses, farmland, shops, mechanical workshops etc) along its flood plain across the city of Kaduna, especially the areas and communities that are located around the river bank.

The water stages in the channel and damages to properties along the floodplain were unprecedented, lives were lost, properties worth millions of Naira were destroyed while thousands of people were rendered homeless in the City by the ravaging flood which brought the socio-

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economic activities of the city to standstill for days before the flood waters recedes. The study area as mentioned earlier is a section of River Kaduna. The area covered started from Rafin Guza (Upstream) to Kabala Costain (Downstream). Kaduna is situated in the Northern part of Nigeria, and it experiences a tropical continental climate. This type of climate is characterized by two distinct seasons of dry and wet. The dry season sets in October and last till April of the following year while the wet season starts around late April and last till October. Kaduna temperature is high throughout the year with mean minimum temperature at 23^0C and mean maximum at about 34^0C. The annual average rainfall is 1185mm with maximum rainfall between July, August and September (NIMET, 2013). Kaduna River is one of the biggest rivers in northern Nigeria that passes through Kaduna city. Developments have caused several settlements and locations of industries close to the river banks and farming activities in the flood plains.

A section of Kaduna town

LITERATURE REVIEW

Inability of man to accurately predict flood events has been a critical problem despite the fact that flooding has been on earth much longer than man. Stevens (1998) gave account of the ancient El-Amana in Egypt and of various ancient encounters between flood and man dating back to 2,957 BC and 747 BC respectively. Also, floods can be described as the most expensive and challenging natural hazard experienced by human beings, especially in developing country like Nigeria, where disaster management is not properly handled. Flood behaviour is influenced by a range of factors such as: catchment, floodplain topography and rainfall occurrence (Ajayi et al, 2011). Notwithstanding the cause of a flooding, the fact remain that there is need to control it. And in order to control a flood, there is need to have an estimate of maximum flood which would occur in the area under consideration, during a specified period of time in the future. Unfortunately, it is very difficult to obtain such a data (Mekawi, 2010). In general, man can do little to prevent major flood, but he may be able to minimize damage to life, crops and other properties within a community. For this reason, man has made many attempts to protect himself from flooding. For example the method of constructing large mounds, in order to have a place of escape, is thousands of years old, and is still applied in some rural communities of the world. In fact even the method of protecting an entire area by building a dike, levee, etc, date back to the early middle ages (Adetoyi, 2007). In recent years, researchers have found out that, the first thing to do, to avert the loss of lives and properties, that may be caused by flood occurrence, is to find a solution, at least to reduce the intensity and the magnitude of the flood. Among the solutions, is to find a way to route the flood before it reach a community, so that they can save their lives and some of their properties by evacuation before the flood reach their community. This phenomenon is known as flood routing and there are many ways in which flood routing is carried out (Mekawi, 2010). Flood routing generally refers to the prediction of river condition or flood stage at the downstream section from the changes or modifications or construction made at an upstream section. This means that, if we change the downstream conditions, then one can say we are routing the flood. The idea of flood control is to increase the capacity of the river or channel to carry flood which means, whatever would have spilled to the sides as flood will be well curtailed or confined within the river channel (Ilaboya et al, 2011).

Therefore, if one look at the whole process, the aim is to store the water in the river temporarily and let off slowly as the flood subsides, so as to control peak time, the effect of the flood at the downstream section of the river. In order to ensure the success of the process, enough flood water should be stored at the upstream section of the river, and then release it at an appropriate time. The release period of water must be properly calculated and defined, so that the relationship between the inflow and outflow can be constantly be determined. Generally, flood routing methods are classified as hydrologic and hydraulic. In this research, hydrologic method using Muskingum equation will be used. Hydrologic methods are generally based on the solution of the conservation of mass equation and a relation of storage and discharge in a stream reach or reservoir. This method combines the continuity equation with some relationship between storage, outflow and inflow. In general, hydrologic flood routing methods involve simplified numerical techniques, conservation of mass, and steady flow hydraulic. The method requires a relation of discharge and storage, which can be derived from water surface profiles (NRSC, 2014). A characteristic feature of the hydrological flood routing method is that they are spatially lumped, i.e. their equations only relate the flows at the ends of a stream reach, *Q*in and *Q*out, to the water volume *S* stored in the reach of, say, length *L* (Koussis, 2009). The conservation of mass equation states that inflow minus outflow is equal to change in storage between two locations and between two moments in time. By solving the conservation of mass and conservation of momentum equations, the most physically based solution may be reached (Safavi, 2006). Flood routing is important in the design of flood protection measures in order to estimate how the proposed measures will affect the behavior of flood waves in rivers so that adequate protection and economic solutions can be found (Mahdavi, 2005). As noted by Gasiorowski, 2009, several factors should be considered when evaluating the most appropriate routing method for a given situation. The factors that should be considered in the selection process include backwater effects, floodplains, channel slope, hydrograph characteristics, flow network, sub critical and supercritical flow.

Muskingum method

This method was developed in 1938 in connection with design of flood protection schemes in the Muskingum River Basin, Ohio, in the United States of America. It is based on the differential equation of storage. The storage is expressed as a linear function of inflow and outflow involving two parameters (Mekawi, 2010). This is a widely used method of hydrological routing as it models the storage volume of flooding in a river channel by a combination of wedge and prism storage (Sharad and Sudheer, 2008). Muskingum is the method of flood routing that this research will use to route the flood in River Kaduna, using the available data in Table 3.2.The storage in the channel reach consists of two parts, namely, the prism storage and the wedge storage. The prism storage is formed by a volume of constant cross-section along the length of prismatic channel. Assuming that the cross-sectional area of the flood flow is directly proportional to the discharge at the section, the volume of prism storage is equal to KO, where K is a constant of proportionality, evidently possession dimensions of time and the O is the outflow. The wedge storage may be taken as a fraction of the volume of the prism (Danacova and Szolgav, 2007).

From continuity equation, we have:

$$\boldsymbol{I - O = \frac{\Delta s}{\Delta t} = I = O + \Delta s / \Delta t} \quad \text{……………………} \textbf{Equation 2.0}$$

Where I = inflow

O = outflow

ΔS//Δt = rate of change of storage

Also, storage in wedge = $\mathbf{KX\,(I - O)}$**……….Equation2.1**

Storage in prism = **KO………………………Equation 2.2**

Therefore total storage will be: $\mathbf{S = KX\,(I - O)} = \boldsymbol{KO}$**……Equation 2.2**

K = storage factor = Travel time through the reach.

The water surface in a channel reach is not only parallel to the channel bottom but also varies with time. As stated above, the volume in storage for a channel reach consist of wedge and prism. Prism storage is the volume that would exist if uniform flow occurred at the downstream depth that is the volume formed by an imaginary plane parallel to the channel bottom drawn at the outflow section water surface. On the other hand, wedge storage is the wedge like volume formed between the actual water surface profile and the top surface of the prism storage. At a fixed depth at a downstream section of a river reach the prism storage is constant while the wedge storage changes from a positive value at an advancing flood to a negative value during a receding flood (Balaz et al, 2010). To apply Muskingum routing to a reach, it is first necessary, to determine values for the parameters K and x which are used to describe the storage characteristics of the channel reach. The parameter K is storage constant expressing the ratio between storage and discharge and is usually expressed in hours. It may also be viewed as the lag or travel time through the reach. The dimensionless parameter x is indicative of the relative importance of inflow and outflow to storage. The values of the K and x for the reach and the value of the outflow from the reach at the start are needed. After getting all the values of mean storage and cumulative storage, a graph is plotted. Any of the graphs that gave the most linear relationship, the Muskingum K value will be calculated from the slope of the graph (similar to the one in Fig.3.0).

MATERIALS AND METHOD

Mathematical Model

The whole concept of the model begins with the net storage along the river which is related to inflow and outflow values. Like it has been mentioned earlier, storage is very important aspect of flood and also very important in routing the flood. The model equation begins with the continuity equation. The model look at the storage at any given time't', from there, the storage in the channel is related to the discharge, prismatic storage, with the two parameters related to river stage. The storage is related to weighted exponential functions of the discharges flowing into (inflow) and out (outflow) of a river. Muskingum procedures account for channel storage only, and not total storage along a river reach which may include lateral inflows or outflows losses and temporal changes in bank storage. Parameters in the Muskingum models are typically derived by measured inflow and outflow discharge hydrographs which do, however, relate to changes in total storage along a river reach (Birkhead, 2000).

In this type of mathematical model, the storage can be calculated by expressing it in terms of discharge rather than depth. The research work, view the importance of inflow and outflow, as it affect storage in the flow of water (or even flood) in the river. For this reason, the outflow was chosen, and an equation that will calculate the outflow of water during flood is established. In the event of any flood, it is the excess water that came out (overflow) the river banks that cause destruction during any flood occurrence. And that water is no other than outflow. The outflow equation is expressed for a given time, by multiplying the routing coefficient C_1 with inflow at a certain time't', plus the routing coefficient C_2 multiplied by inflow at a time 't-1' plus routing coefficient C_3 multiplied by an outflow at certain time 't-1'. This can be represented as follows:

$Q_t = C_1\ I_t\ +\ C_2\ I_{t-1} +\ C_3\ I_{t-1}$ **…………Equation 3.0**

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Data collection

For any research of this kind, many years' hydrologic authentic data are essential, for the research to be made accurately and efficiently. Unfortunately, this research has met serious data collection problem. The above notwithstanding, about 30 years (1967 – 1997) hydrologic data were obtained from Kaduna State Water Board. As part of the efficiency, mentioned earlier, 30 year rainfall and inflow data were obtained, but for the inflow, there was only 10 year data available. In this kind of research, both inflow and outflow data are very essential and important. Since flood is also defined as the greatest main daily discharge measured in volume per unit time among the 365 (or 366) observations of the year, the research work, intended to use this type of data for Kaduna River to route the flood. However, in the absence of the required data for inflow (30 year), the research restrict the storage calculation (which is very important to plotting of graph) to only ten years, in order to give the research a credibility. Otherwise, the calculation should have been for 30 years.
After the equation of the model has been obtained, it was used to re-calculate the outflow, so as to compare with the one given by the Water Board, in order to see how near the values will be. At least the two values (the one from water board and the one calculated using the model equation) look quite similar.

Table 3.0: Inflow and Outflow values

Time (h)	Inflow (I)	Outflow (O)
0	1005.4	1005.4
6	1105.8	1028.9
12	1410.5	1172.14
18	1640.7	1424.5
24	1655.9	1582.5
30	1505	1586.5
36	1355.2	1480.45
42	1205	1345
48	1110	1216
54	1065	1129.5

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Table 3.1: Determination of Muskingum Parameters

Time (h) 1	**Inflow (I) 2**	**Outflow (O) 3**	**I – O 4**	**I-O$_{average}$ 5**	**Incremental Storage ΔS 6**	**Storage in the reach ∑△S 7**
0	1005.4	1005.4	0	-	-	-
6	1105.8	1028.9	78	39	9.75	9.75
12	1410.5	1172.14	239	159	39.75	49.5
18	1640.7	1424.5	215	227	56.75	106.25
24	1655.9	1582.5	73	144	36	142.25
30	1505	1586.5	-82	-4.5	-1.13	141.12
36	1355.2	1480.45	-125	-103.5	-25.88	115.24
42	1205	1345	-140	-132.5	-33.13	82.11
48	1110	1216	-106	-123	-30.75	51.36
54	1065	1129.5	-65	-85.5	-21.38	29.98

The inflow and outflow values were obtained from Table 3.0

Table 3.2: Calculating Storage values

(xI + (I – x)Q

Time (h)	**X = 0.1**	x =0.2	x = 0.3
0	-	-	-
6	1036.59	1044.3	1051.97
12	1195.95	1219.8	1243.45
18	1447.02	1468.5	1490.11
24	1589.84	1597.2	1600
30	1578.35	1570.2	1604.57
36	1467.93	1455.4	1442.86
42	1331	1317	1303
48	1205.4	1194.8	1184.2
54	1123.05	1116.6	1110.15

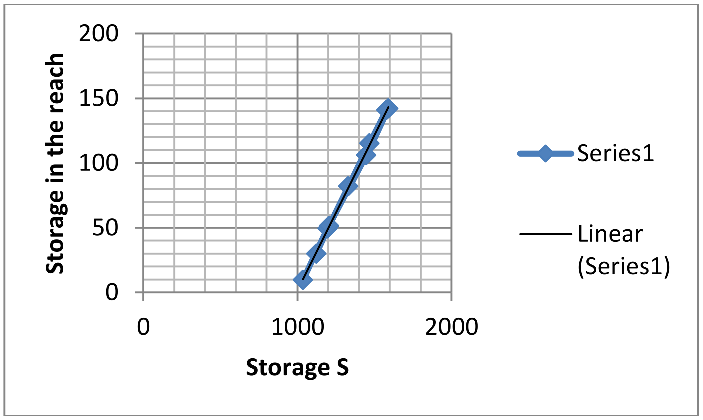

Fig 3.0 Graph of x= 0.1

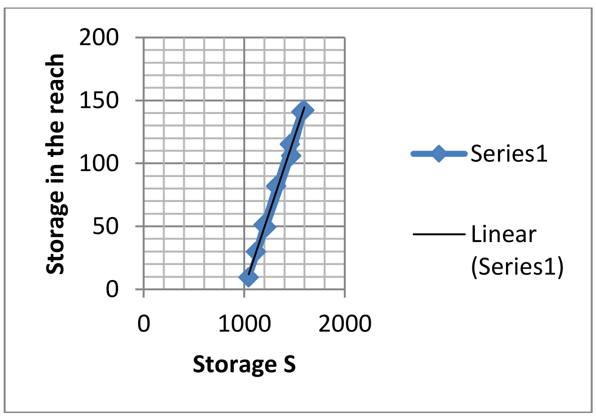

Fig 3.1 Graph of x = 0.2

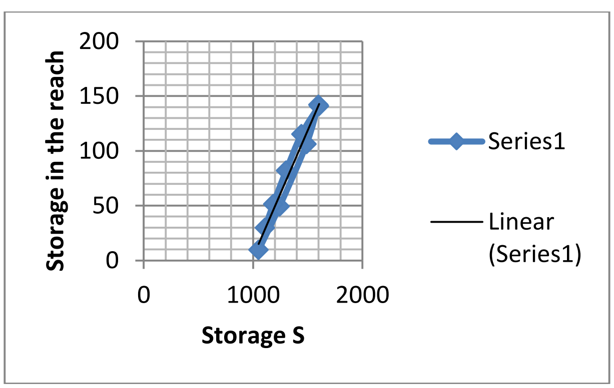

Fig. 3.2 Graph of x= 0.3

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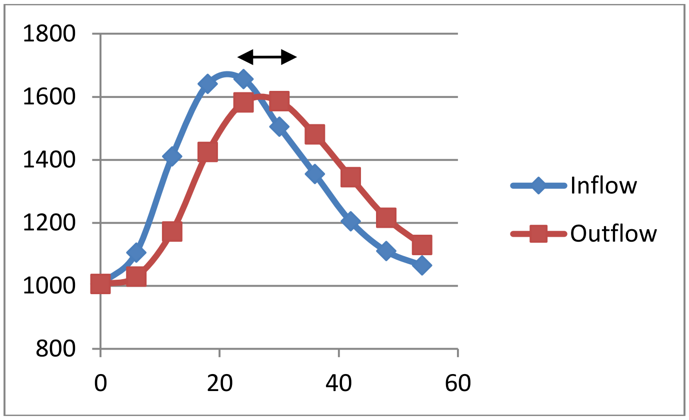

Fig 3.3 Inflow and outflow hydrograph

This sign ↔ shown in the above graph, indicated a measure of six hours.
Looking at graphs in figures 3.0, 3.1 and 3.2, it can be observed that, among the three graphs, the one with x = 0.1(Fig.3.0) is almost a straight line. Therefore the best or correct value of x may be taken as 0.1.The slope K, of the line from the graph (x=0.1) can be calculated as follows:

$$K = \frac{142.25 - 82.11}{1589.84 - 1331} = \frac{60.24}{258.84} = 0.23 \text{ days}$$

Therefore K = 0.23 days x 24 = 6 hours
This (K=6 hours) tallies with the peak time of 6 hours in the inflow and outflow hydrographs (Fig 3.3).
Now, K = 0.23 days, X = 0.1, and time interval Δt = 0.25. These values shall be used to calculate the routing coefficients, when the model came up with an equation.

RESULTS AND DISCUSSION

4.1Results

Referring to equation 3 as follows:

$$Q_t = C_1 I_t + C_2 I_{t-1} + C_3 I_{t-1}$$

Where C_1, C_2, and C_3 are called the routing coefficients and are calculated as follows:

$$C_1 = -\frac{KX - 0.5\,\Delta t}{K - KX + 0.5\,\Delta t}$$

$$C_2 = \frac{K + 0.5\,\Delta t}{K - KX + 0.5\,\Delta t}$$

$$C_3 = \frac{K - KX - 0.5\,\Delta t}{K - KX + 0.5\,\Delta t}$$

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$$C_1 = -\frac{KX - 0.5\,\Delta t}{K - KX + 0.5\,\Delta t}$$

$$C_1 = -\frac{(0.23x0.1) - 0.5x0.25}{0.23-(0.23x0.1)+(0.5x0.25)} = -\frac{0.023-0.125}{0.23-0.023+0.125} = \frac{0.102}{0.332} = 0.307$$

$$C_1 = -\frac{(0.23\,x0.1) - 0.5\,x\,0.25}{0.23 - (0.23\,x\,0.1) + (0.5\,x\,0.25)}$$

$$C_1 = -\frac{(0.023) - 0.125}{0.23 - (0.023) + 0.25} = \frac{0.102}{0.332} = 0.307$$

$$C_2 = \frac{K + 0.5\,\Delta t}{K - KX + 0.5\,\Delta t}$$

$$C_2 = \frac{0.23 + 0.5\,x0.25}{0.23 - (0.23x0.1) + (0.5x0.25)} = \frac{0.148}{0.332} = 0.446$$

$$C_3 = \frac{K - KX - 0.5\,\Delta t}{K - KX + 0.5\,\Delta t}$$

$$C_3 = \frac{0.23 - 0.23x0.1 - 0.5\,x0.25}{0.23 - (0.23x0.1) + (0.5x0.25)} = \frac{0.082}{0.332} = 0.247$$

Check: $C_1 + C_2 + C_3 = 1.00$
$0.307 + 0.446 + 0.247 = 1.00$

Equation 3.0 can be used to calculate the outflow of the river, where only inflow is available. The determination of the outflow O_2 at the end of any time interval using the equation requires the value of O_1 (the outflow at the end of previous time interval) which is obtained in the earlier iteration. With a small loss of accuracy in the results, the outflow can be determined using only the inflow ordinate. Looking at examples from the data used for this research work, table 3.0 shows the inflow and outflow data. The inflow values can be used to calculate the outflow and the similarities in the two outflows can be observed.

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Now, using the equation obtained in this model, the values of outflow can be calculated
The routing equation is:
$Q_t = C_1 I_t + C_2 I_{t-1} + C_3 I_{t-1}$
Replacing the routing coefficients C_1 , C_2 and C_3 , with their values, Q_t, will be:
Q_t= 0.37 I_t + 0.446I_{t-1} + 0.247x Q_{t-1}
From Table 3.1:
I_{t-1} = 1005.4, I_t = 1105.8, Q_{t-1} = 1005.4
To start with the first time (t) interval of 0 to 6 hours, the initial outflow O_1 is the same with I_1, therefore Q_t will be:
Q_t=0.37 x1105.8 + 0.446 x 1005.4 + 0.247 x 1005.4
= 339.48 + 448.41 + 248.33
$\mathbf{Q_t = 1036.2\ m^3/sec}$

The above value of outflow will be the $Q_{t-1}$for the next interval.
For time interval 6 to 12 hours, table 3.1 gave the following values:
I_t = 1410.5, I_{t-1} = 1105.8, Q_{t-1} = 1036.2
$Q_t = C_1 I_t + C_2 I_{t-1} + C_3 I_{t-1}$
Q_t=0.37 x1410.5 + 0.446 x 1105.8 + 0.247 x 1036.24
= 433.02 + 493.19 + 255.95
$\mathbf{Q_t = 1182.2\ m^3/sec}$

Similarly, the remaining inflows can be calculated as done above. Having calculated the inflow, using equation 3, there is need to compare what we calculated and what was given by Kaduna State Water Board in Table 3.0

Table 4.0: Comparing measured outflow and calculated outflow

Time (h)	Inflow (I)	Outflow (O)	Calculated Outflow
0	1005.4	1005.4	
6	1105.8	1028.9	1036.2
12	1410.5	1172.14	1182.2
18	1640.7	1424.5	1424.8
24	1655.9	1582.5	1592.0
30	1505	1586.5	1593.8
36	1355.2	1480.45	1480.9
42	1205	1345	1341.5
48	1110	1216	1209.6

Going through the measured outflow and the one calculated using equation 3, it can be observed that the differences are not very much. This confirmed that the equation is efficient and reliable.

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DISCUSSION OF RESULT

The known Muskingum routing method that utilize inflow and outflow discharge and neglecting bank storage provide good representation of the temporal reach storage. The method was used to successfully route the flood, and the appropriate graphs were drawn (Fig. 3.0 -3.2) with x = 0.1 (Fig.3.0) as the best that was almost a straight line. The K and x values were obtained. Also the routing coefficients of C_1, C_2 and C_3 were calculated and their sum gave the required value of 1.00. The equation was obtained from the model (equation 3), which was used to calculate the outflow values and compared with the values that were given by the Water Board. The differences between the two values are not much; this confirms that the model equation is reliable.

CONCLUSION AND RECOMMENDATION

Conclusion

Flood is now a global problem, and it is very important if effort can be made at least to reduce the consequences associated with its menace. This research work tried as much as possible to see how the flood water in River Kaduna can be routed in order to avoid calamity, in a situation when the flood occurred. The fact that the outflow values obtained using equation are very near to the measured outflow, is an indication of the validity of the research work. Therefore it can be concluded that the aim of the research of routing the flood has been achieved.

Recommendation

However, this model cannot be said to be perfect. For example, further research should be made in order to include bank storage since it accounts for some percentage of the temporal reach storage. This indicates that it has some significance. In order to achieve the objectives of the research work, the following are recommended:

- ✓ Updated and reliable hydrological data should always be made available in order to give researchers opportunity to come up with good results.
- ✓ At least, the Kaduna State Government should embark on de -silting River Kaduna, so that it can flow at a higher capacity than the present, this will help in reducing the occurrence of flood and its consequences.
- ✓ Kaduna State Government should discourage people from encroaching the banks of River Kaduna by stopping further construction of houses near the banks. This will reduce to some extent the number of casualties during any flood.
- ✓ More drainages and levees/dykes can be constructed, to check mate the occurrence of flood.
- ✓ More river stage gauges should be installed along the river course in order to get enough data on the river.
- ✓ A committee of experts should be appointed to monitor the flow of River Kaduna, especially during raining season, so as to ensure that should in case there will be flood, its menace can be reduced, by ensuring that the flood water is routed.

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