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Runoff Computation on River Omi Catchment Using Spatially Distributed Terrain

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Abstract: ***Rainfall runoff is an important component contributing significantly to the hydrological cycle, design of hydrological structures and morphology of the drainage system. Estimation of the same is required in order to determine and forecast its effects. Estimation of direct rainfall runoff is always efficient but is not possible for most of the location at desired time. Use of remote sensing and GIS technology can be used to overcome the problem of conventional method for estimating runoff caused due to rainfall. For the runoff computation, SCS method was adopted which is a function of rainfall (P), initial abstraction (Ia), and Potential maximum retention after runoff begins (S). Rainfall data were acquired from meteorological station near the study area, S is a function of CN which was chosen based on the land use characteristics of the study area and the soil type. Also, data for peak discharge were acquired which was related with computed runoff to obtained mathematical equation that relates runoff with discharge. This equation was then calibrated, stimulated and validated. The estimated monthly and yearly spatial runoffs using SCS method were obtained. The developed mathematical model was y = 11.49x2-116.82x+647.69 with a coefficient of regression of 98.61%. The developed model performs at 70% of coefficient of accuracy. The peak runoff of the catchment was obtained between the months of July –October. The mathematical relationship exist between discharged and runoff with 92% of coefficient of regression. The design of hydraulic structures within the catchments should make use of the value of peak runoff in the month of September.***

Keywords: Runoff, Discharge, rainfall data, computation, maximum retention

1. Introduction

Runoff computation is important in vast varieties of ways to determine the adequate flood and rainfall management and estimation of the same is required in order to determine and forecast its effects. In rainfall-runoff computation, not only is the generation of excess precipitation spatially distributed but also the precipitation itself, which has been a limitation for the use of the classic unit hydrograph model for years. The theory presented in this paper is an attempt to generalize the unit hydrograph method for runoff response, and to do so on a spatially distributed basis in which the runoff responses from subareas of the watershed are considered separately instead of being spatially averaged. Although the theory of linear routing systems presented in this article isnot bound to raster representations of the study area, the model proposed here is based on grid data structures. A grid data structure is a discrete representation of the terrain based on identical square cells arranged inrows and columns. Grids are used to describe spatially distributed terrain parameters (i.e. elevation, land use, impervious cover, etc.), and one grid is necessary per parameter that is to be represented. The density of grid cells should be large enough to resemble a continuous character of the terrain (Houston, 2001).

Starting from the digital elevation model (DEM), hydrologic features of the terrain (i.e. flow direction, flow accumulation, flow length, stream-network, and drainage areas) can be determined using standard functions included in commercially available geographic information system software that operates on raster terrain data. At present, DEM's are available with a resolution of 3 arc-seconds (approximately 90 m) for the United States, and 30 arc-seconds (approximately 1 Km) for the entire earth, etc. Since in the case of water draining under gravity a single downstream cell can be defined for each DEM cell, a unique connection from each cell to the watershed outlet can be determined. This process produces a cell-network, with the shape of a spanning tree, which represents the watershed flow system (John Powell, 2002).

According to Adhikari (2003), Flow routing consists of tracking the water throughout the cell-network. For this purpose, a two-parameter response function is determined for each cell, in which the parameters are related to flow time (flow velocity) and to shear effects (dispersion) in the cell. Flow-path response functions are calculated by convoluting the responses of the cells located within the reach. Finally, the watershed response is obtained as the sum of the cell responses to a spatially distributed precipitation excess. A de-convolution algorithm is used to estimate the precipitation excess from flow records instead of from precipitation records. This algorithm consists of de-convolving an observed hydrograph by an estimated watershed response function (unit hydrograph) to obtain the precipitation excess. The spatial distribution of the precipitation excess is assumed to be proportional to the runoff coefficient.

In order to provide an effective management of water, erosion and flood control, understanding the relationship between runoff and rainfall play a major role. It is important to carry out a detail runoff and rainfall analysis in a region or area where there is an incessant flooding and erosion and where there is a water shortage and drought prevailed. Especially in Ibadan of Southwest Nigeria where there has been an incessant flooding in recent time. Runoff is the rainfall minus the losses, where these losses are interception, infiltration, depression etc. And all these form of losses are sometimes called basin recharge. However, to have an effective runoff, some hydrological processes are involved.

2. Methodology

3.1 Study Area

This project is carried out within the catchment area of River Omi located within Iddo Local Government area of Ibadan. It lies approximately between Longitude 3^0 28′45″ - $4^0$10′14 ″ East and Latitude 7^0 01′44″/7^0 45′28″ North of the equator. The river is approximately 14.5 km long with frequent flooding experience in Ibadan the catchment area of the river is around 123.53km square and the river elevation ranges between 0.50 – 2 meter spot height above mean sea level.

River Omi is an alluvial river with channels and flood plains that are self-formed in unconsolidated or weakly-consolidated sediments. The morphology of alluvial river reach is controlled by combination of sediment supply, substrate composition, discharge, and vegetation and bed aggradations. River Omi is very useful to the neighborhoods for domestic, agricultural and waste disposal purposes. River Omi geographical information map is shown in (fig 3.1).

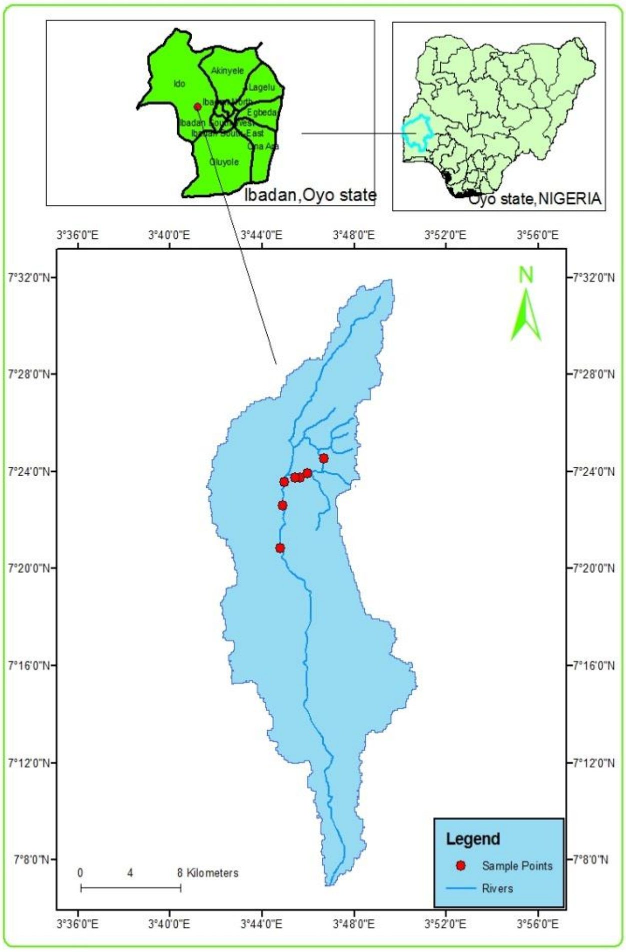

Figure 3.1: Showing Study Area

3.2 Data Needed

The Survey of River Omi will be used for the demarcation of the watershed line. The rainfall data of the whole northwestern part of the state from 1905 to 2013 will likewise be needed in the study. The rainfall data will be collected from Meteorological Department in the state (IITA). The land use and land cover map will be prepared using hybrid classifier for IRS 1C LISS III satellite imagery of appropriate resolution. The soil information is also needed. Finally, the slope map is very essential as it could be used in understanding flow direction, accumulation and basin of the study area through the use of the slope.

The rainfall data required for the purpose of this project will be obtained from the metrological station near the study area. The rainfall data needed will be for period of 100 years (1912-2013) for accuracy. The data will be included in the appendix at the completion of the project.

The runoff curve number was selected based on the land use of study area, infiltration rate which was gotten from table 2.1 and the soil type.

3.3 SCS Runoff Curve Number Method

SCS rainfall runoff model, developed by United States Department of Agriculture (USDA) provides an empirical relationship estimating initial abstraction and runoff as a function of rainfall, soil type and land-use. The water balance equation is expressed by

$$Q = \frac{(p-I_a)^2}{(p-I_a+S)} \qquad (3.1)$$

Where;
Q = Runoff (in),
P = Rainfall (in),
S = Potential maximum retention after runoff begins (in),
And
I_a = Initial abstraction (in)

3.4 Runoff Computation

Runoff was computed for a period of four decades (40 years) by inputting the rainfall data, curve number and considering other geographical and hydrological factors including land use / land cover, slope and soil type into the model.

$$Q = \frac{(P-0.2S)^2}{(P+0.8S)}$$
$$S = \frac{1000}{CN} - 10 = \frac{1000}{77} - 10 = 2.99$$
$$I_a = 0.2s = 0.2(2.99) = 0.598$$
$$Q_{1974} = \frac{(3.78-0.598)^2}{(3.78+2.392)} = 1.64in$$

Where;
Q = Runoff *(in)*
S = Potential Maximum Retention after Runoff Begins *(in)*
I_a = Initial Abstraction *(in)*
P = Rainfall *(in)*

3.5 Procedure Involved in Obtaining Relationship between Peak Runoff and Peak Discharge

Step 1: after the runoff has been obtained as explained above, the value of peak discharge for needed year (s) will then be acquired.
Step 2: plot a graph of peak discharge against corresponding peak runoff to obtain equation that relates the two parameters (peak runoff and peak discharge).
Step 3: from the obtained equation, calibrated discharges shall be known and these will be simulated with respect to the actual discharge in order to increase/enhance the accuracy of the equation determined.
Step 4: validation of the equation by obtaining discharge from the simulated equation using known peak runoff of a certain year.

Note: peak runoff and peak discharges of the year (s) are considered because these values represent worst conditions that can be experienced and it's safer to consider these values during any hydraulic design.

3. Result and Discussion

4.1 Analytical Result of Estimated Runoff

From the result obtained, we observed a close relationship between the runoffs for four (4) decades. The peak runoff gotten from the graph (Fig 4.1) shows us the years which Ibadan experienced flooding (1980 and 2011) in which the runoff for these years was found to be higher than others. This shows the importance of runoff computation and prediction which will help in the prevention of future disaster that can be caused by flooding.

Also, from (Fig 4.2 and 4.3) the relationship between rainfall and runoff shows that not all rainfall leads to runoff because of several external factors that may have affected the movement of the runoff. Large amount of rainfall maybe lost naturally (due to percolation, interception by plants). Urbanization also contributes to rainfall leading to high runoff. Degradation of trees and development of environmental structures also lead to change in runoff. All these but not limited to contribute to runoff of an area and this should be accounted for adequately.

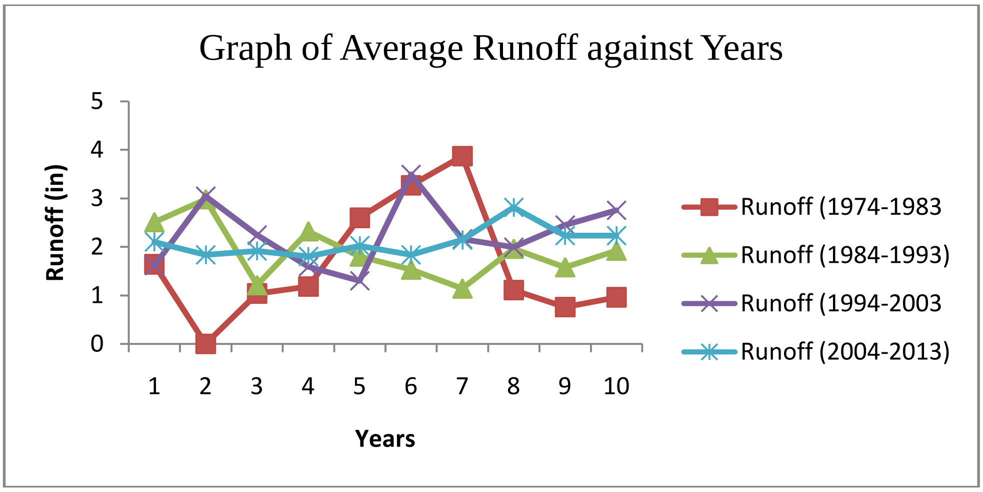

Figure 4.1: Showing Relationship between Average Runoff and Year

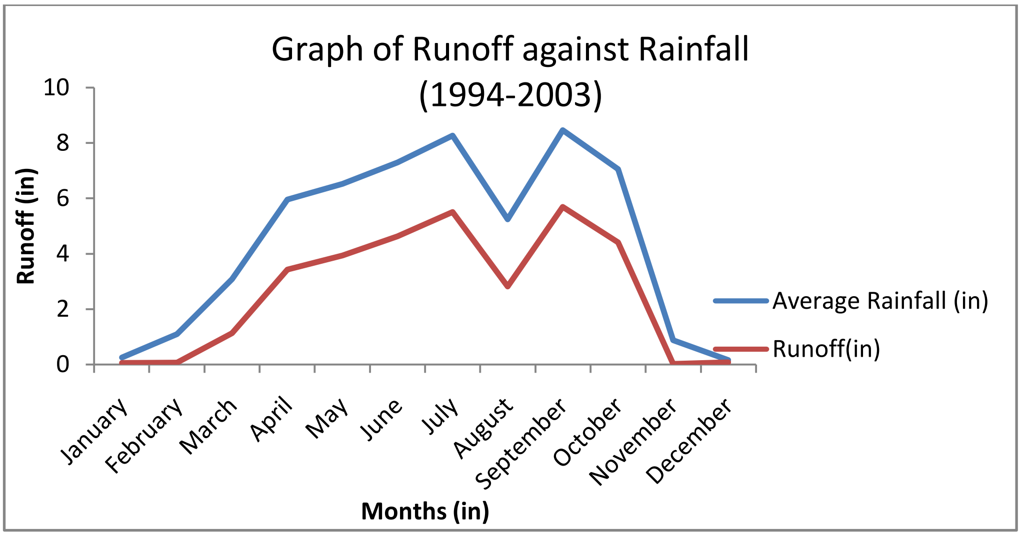

Figure 4.2: Showing Relationships between Rainfall and Runoff (1994-2003)

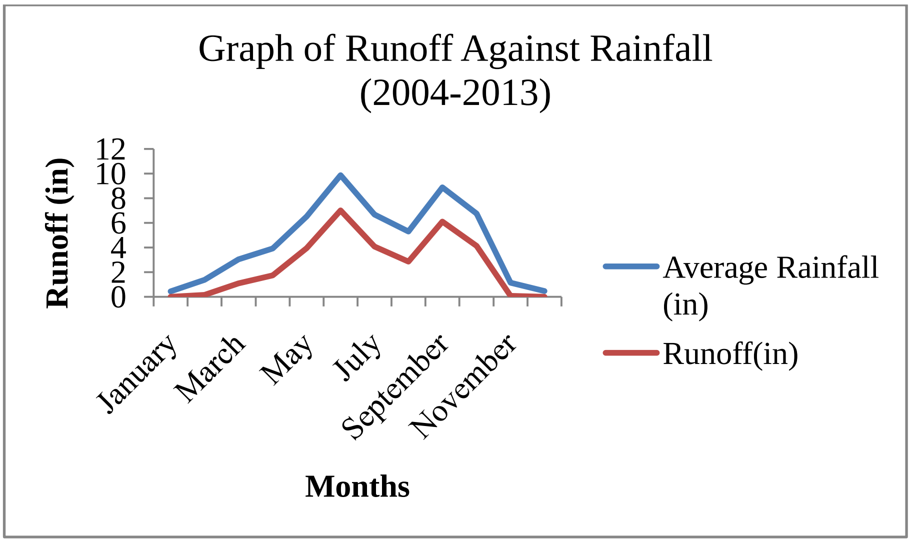

Figure 4.3: Showing Relationship between Rainfall and Runoff

4.2 Relationship between Peak Runoff and Peak Discharge

The pie chart (Fig 4.4) gives idea of the month with peak runoff for periods of four (4) decades. The months shown in the pie chart have the highest percentage runoff in a year, and the month with the highest runoff should be considered during hydraulic design so that the worst case scenario can be design against which will enhance the standard and quality of our hydraulic structure.

The hydraulic discharge (Fig 4.5) is used for generation of calibrated discharge which is used for simulation and validation of the measured discharge for seven (7) years. This equation has an accuracy of 70% and can be used for discharge calculation of our study area provided there is runoff data.

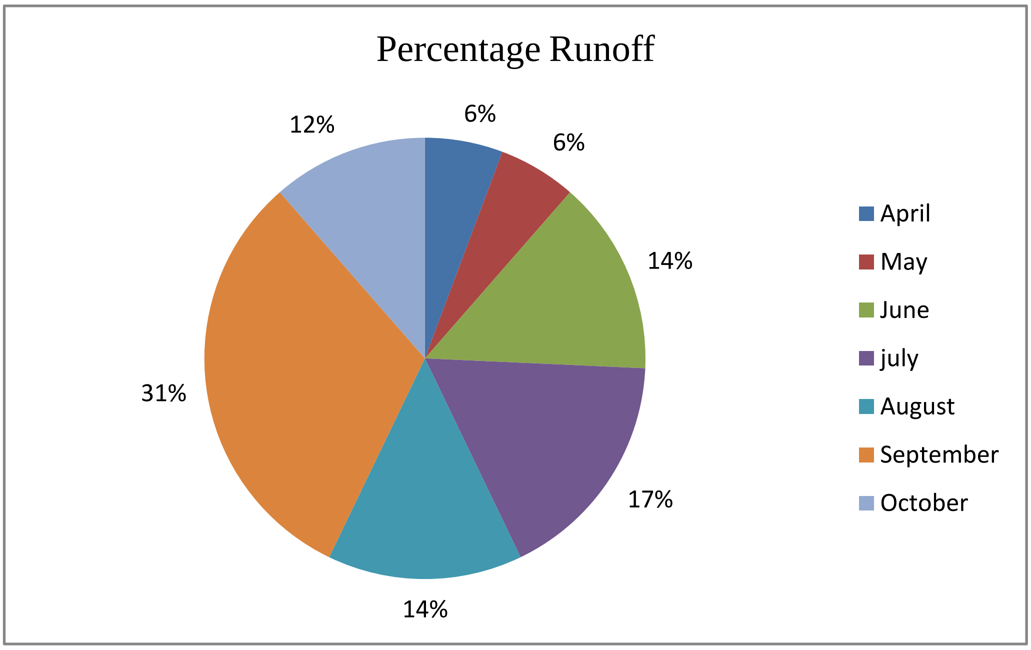

Figure 4.4: Showing the Months with High Runoff

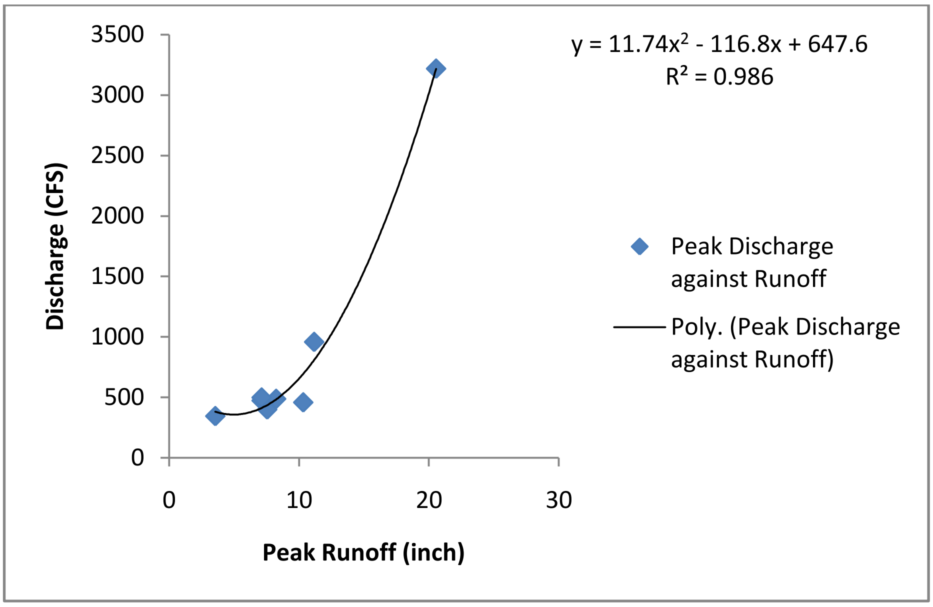

Figure 4.5: Showing Peak Discharge against Peak Runoff

The result obtained over the course of 7 years showing relationship between peak runoff and peak discharge from 1979 – 1986 in Table 4.7 gives us the maximum peak discharge in the year 1980 and having a relatively high runoff in the same year. The peak runoff value was calculated to be at about 3218.57(cfs) and peak discharge about 20.57(in) and this shows a great significant importance in what happened during 1980 flooding in Ibadan. The high value of runoff during this year leads to the disaster that occurred during the year. The relationship between measured discharged and simulated discharge from Table 4.8 shows the degree of accuracy between the two values of about 70%. Clear result from (Fig 4.6) shows the graphical relationship between measured discharged and simulated discharged.

Table 4.7: Showing Peak Runoff and Peak Discharge

Year	Peak Discharge(cfs)	Peak Runoff (in)
1979	958.58	11.17
1980	3218.57	20.57
1981	473.86	7.12
1982	345.24	3.55
1983	400.20	7.55
1984	487.90	8.24
1985	458.90	10.33
1986	498.90	7.12

Table 4.8: Showing Measured and Simulated Discharge

Year	Measured Discharge (cfs)	Simulated Discharge (cfs)
1990	197.76	190.40
1991	199.53	210.17
1992	171.98	157.34
1993	197.41	176.29
1994	174.10	191.32
1995	277.93	234.26
1996	220.01	197.85

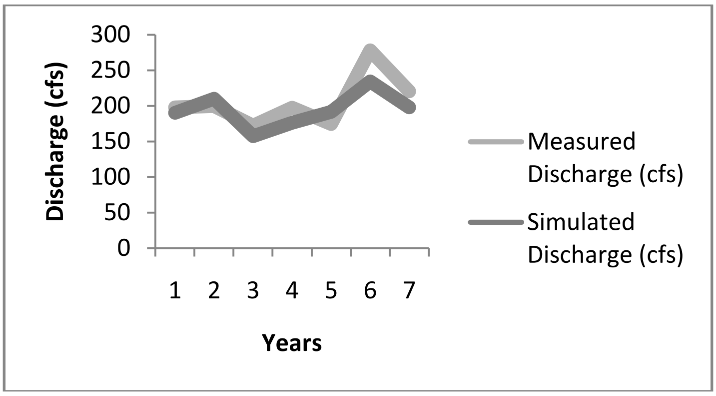

Figure 4.6: Showing Relationship between Measured Discharge and Simulated Discharge

4. Conclusions and Recommendation

5.1 Conclusions

The following conclusions were made based on the findings in the study of runoff computation of River Omi:

i. The computed runoff (which is a function of the rainfall, land use, infiltration rate, soil type) plotted against months shows the month with high runoff. Also, the areas which will experience high runoff (prone to flood).
ii. Mathematical model was developed for measuring discharge on this project and it can be seen clearly the relationship between this two parameters.
iii. Mathematical model developed in this study simulate discharge effectively and with of 5%-30% between simulated discharged and the measure discharged.
iv. Design of hydraulic structures such as drainage system, bridges etc. should make use of the value of peak runoff.

5.2 Recommendations

The following recommendations are drawn with regard to this concluded project;

1. Proper runoff investigation will encourage adequate measures and controls of environmental disasters like flooding, erosion and water management.
2. We recommend that periodic accounts and checking of environmental features of any catchment area in study is required (elevation, slope, and other hydrological parameters).
3. There is need for other methods of computing runoff to be used in other to determine the accuracy to compare (Curve Number Method) adopted in this project.
4. Consideration of effect(s) of runoff during construction of hydrological structures by using SCS method should be encouraged because it put hydrological features and information of the environment into consideration, and the simplicity of the method.

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