Rainfall-Runoff Characteristics Of A Rural Settlement, A Case Study Of Ogbogoro, Niger Delta Nigeria

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Abstract: The aim of this study was to ascertain runoff generation processes in tropical climate. The study set two objectives, first to establish a reliable relationship between rainfall and runoff; secondly to determine the role of runoff on increasing surface erosion. The total area studied is about 2,562 acres. Using rainfall data for a period of 12 years 1990-2002, the intensity of rainfall for every year was calculated and in order to determine run off in the area, the rational equation was used and this revealed the total yearly run off in the area. The study revealed that run off in the area is significantly related to rainfall, and that the rate of erosion in the area is increasing. The study also stated that if measures to curtail this is not put in place the people in the area will experience more erosion that could lead to loss of properties, life's and their sources of livelihood. It also revealed that this could lead to a case of total submergence, especially in the face of global climate change. Hence, the study recommends that the development of drainage lines will help in curtailing the rate of erosion in the area even in the face of rising runoff and increased water discharge amidst global climate change.
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Introduction.

Rainfall is known as the main contributor to the generation of surface runoff. Therefore there is a significant and unique relationship between rainfall and surface runoff (Baharudin, 2007). By basic principle of hydrologic cycle, when rain falls, the first drops of water are intercepted by the leaves and stems of the vegetation. This is usually referred to as interception storage. Once they reach the ground surface, the water will infiltrate through the soil until it reaches a stage where the rate of rainfall intensity exceeds the infiltration capacity of the soil. The infiltration capacity of soil may vary depending on the soil texture and structure. For instant, soil composed of a high percentage of sand allows water to infiltrate through it quite rapidly because it has large, well connected pore spaces. Soils dominated by clay have low infiltration rates due to their smaller sized pore spaces. However, there is actually less total pore space in a unit volume of coarse, sandy soil than that of soil composed mostly of clay. As a result, sandy soils fill rapidly and commonly generate runoff sooner than clay soils (Ritter, 2006).

Apart from rainfall characteristics such as intensity, duration and distribution, there are other specific factors which have a direct bearing on the occurrence and volume of runoff. The most common factor is the soil type. Due to the variation of runoff production, different studies have been conducted according to particular soil conditions. For example, runoff production in blanket peat covered catchment would be rather different than urban area catchment. Blanket peat catchments exhibit flashy regimes, but little is known about the exact nature of runoff production processes within such catchments (Holden and Burt, 2003). In the past, many believed that blanket peatlands were able to attenuate floods and to sustain baseflow in streams and rivers during periods of low precipitation. However, recent studies have demonstrated that intact and degraded blanket peats are indeed extremely productive of runoff and have flashy regimes with little base flow contribution (Baharudin and Abustan, 2006). The runoff generation in the area is also associated with the peat soil layering as the deeper layers may be an important overall contributor to runoff (Baharudin et. al., 2007).

Another factor that can affect the runoff production is vegetation. An area which is densely covered with vegetation produces less runoff than bare ground while the amount of rain lost to interception storage on the foliage depends on the kind of vegetation and its growth stage. Vegetation has a significant effect on the infiltration capacity of the soil. A dense vegetation cover shields the soil from the intense raindrop impact which eventually will cause a breakdown of the soil aggregate as well as soil dispersion with the consequence of driving fine soil particles into the upper soil pores.

This results in clogging of the pores, formation of a thin but dense and compacted layer at the surface which highly reduces the infiltration capacity. This particular effect is often referred as to capping, crusting or sealing. In addition, the root system as well as organic matter in the soil increases the soil porosity thus allowing more water to infiltrate.

Large flood events from 1974 to 1998 were selected and the results show that the peak runoff coefficient has decreased from 0.59 to 0.38 throughout the years. The ratios of runoff volume of observed and calculated hydrographs also decreased from 1.25 to 0.91. Based on the fact that the catchment has been experiencing changes from polluted land due to mining and refining activities to steady recovery and growth of vegetation in the area, the findings have positively proven the theory of vegetation effects on runoff characteristics.

Slope and catchment size also influence the generation of surface runoff. Steep slopes in the headwaters of drainage basins tend to generate more runoff than the lowland areas. Overall mountain areas tend to receive more precipitation because they force air to be lifted and cooled. On gentle slopes, water may temporarily pond and later infiltrate, but in mountainsides, water tends to move downward more rapidly.

Wemple and Jones (2003) examined the runoff production on forest roads in a steep, mountain catchment which support the earlier statement. Soils tend to be thinner on steep slopes, limiting storage of water, and where bedrock is exposed, little infiltration can occur. However, in some cases, accumulation of coarse sediment at the base of steep slopes soak up runoff from the cliffs above, turning into subsurface flow (Dasch, 2003). Size of catchment may have an effect to the runoff generation in terms of the runoff efficiency (volume of runoff per unit area). The larger the size of the catchment, the larger is the time of concentration and the smaller the runoff efficiency.

A study to assess the trends of rainfall-runoff characteristics in the Alzette river basin, Luxembourg was conducted by Pfister et. al. (2000). The relationship between atmospheric circulation pattern and stream flow has been emphasized as there has been a marked increase in the contribution of the westerly component of atmospheric circulation to rainfall since 1950. Principal component analysis (PCA) was used to compare the winter maximum daily flow with rainfall characteristics, including predominant atmospheric circulation patterns, rainfall intensity and average duration of rainfall events. By using the PCA method, the impact of zonal circulation, especially of the westerly airflow component, on maximum daily mean flow of the Alzette river has been identified with a strong correlation coefficient of 0.86. Time trends in the streamflow and rainfall characteristics were investigated by computing Kendall's test.

The results of Kendall's tests showed positive trends in westerly airflow rainfall as well as in maximum daily flow are statistically significant and southwesterly airflow rainfall has also contributed to the increment of maximum daily mean flow depending on its interannual fluctuations.

Another study has been conducted by Merz et. al. (2006), regarding the surface generation process at the plot level in relation to rainfall events in a mountainous area of the Himalayas. The study makes use of event analysis with two different perspectives; the precipitation event analysis investigates runoff triggering mechanisms and erosion plot events are studied to investigate surface runoff generation. The results of the study indicated that rainfall events in the catchment can be divided into four major clusters with each cluster having different characteristics and the runoff events in the catchment are closely correlated to the event rainfall intensity parameters and the proposed clusters. The land use characteristics also contributed for the surface flow process whereby the infiltration excess flow is the main process in terms of runoff generation on degraded land while saturation excess overland flow is more relevant for agricultural land.

The essence of this paper is to establish a reliable relationship between rainfall and runoff and obtain estimate for unpaved surface erosion of the catchment.

Materials and Methods

Rainfall data of the study area for a period of twelve years was used for the study, beginning from 1990-2002 this was to determine the pattern of rainfall in the area. Also rainfall intensity of the area was calculated, the essence of this was to identify within the period under study which of the yearly rainfall was more and how did this affect the run off in the area.

To determine run off, which also is a determinant of the extent of surface erosion in the area, the rational equation was used.

Results and Discussion

Yearly rainfall data from 1992 to 2002 was used to ascertain rainfall, rainfall duration and rainfall intensity of the rural catchment as to identify rainfall runoff relationship.

The table shows rainfall data and the calculated rainfall intensity for a period of twelve (12) years. The calculated rain fall intensity record shows that there exist variations in the intensity of rainfall amongst the various years with 2001 having the highest intensity of 78.2mm/h, followed by 1998 having an intensity of 58.6mm/h and the year 1997 was having 55.4mm/h.

Table 1. Yearly Rainfall Amount (Mm), Duration And Intensity (1990-2002)

Year	Rainfall Amount	Duration (hours)	Intensity (mm/h)
1990	2509.7	1164.9	38.1
1991	2148.3	1027.2	34.0
1992	1962.2	947.9	34.5
1993	2511.5	1030.8	38.6
1994	2374.2	1306.6	34.7
1995	2567.3	1425	25.1
1996	2339.7	1294.4	35.5
1997	2329.4	1355.9	55.4
1998	2153.5	1163.3	58.6
1999	2186.2	1131.6	53.6
2000	1794.1	824.7	39.7
2001	2153.5	1281.8	78.2
2002	2186.2	1052.1	37.0

Source: extracted from Weli (2004).

Run Off Determination In The Area.

Using the Rational equation:

$Q = KiA$

where Q = peak rate of runoff in cubic feet or cubic meters per second

K = runoff coefficient (see American Society of Civil Engineers, *Manuals and Reports of Engineering Practice* No. 37, 1970).

i = intensity of rainfall in inches or centimeters per hour

A = watershed area in acres or hectares

Table 2: Yearly Run Off In The Area.

Year	Intensity	Area in acres	Run off coefficient	Discharge (run off)
1990	38.1	2,562	0.50	48,806.1
1991	34.0	2,562	0.50	43554
1992	34.5	2,562	0.50	44195.5
1993	38.6	2,562	0.50	49446.6
1994	34.7	2,562	0.50	44450.7
1995	25.1	2,562	0.50	32153.1
1996	35.5	2,562	0.50	45475.5
1997	55.4	2,562	0.50	70967.4
1998	58.6	2,562	0.50	75066.6
1999	53.6	2,562	0.50	68661.6
2000	39.7	2,562	0.50	50855.7
2001	78.2	2,562	0.50	100174.2
2002	37.0	2,562	0.50	47397

Source: researchers field work computation (2011).

From the table above, it is evident that the highest run off in the area was in the year 2001 with a run off value of 100174.2 m^3 and 1998 following with a run off value of 75066.6 m^3. From the table, 1995 had the lowest run off with a value of 32153.1 m^3

Applying the Pearson product moment correlation statistical technique, to test for relationship,

$$r_{xy} = \frac{\frac{\Sigma(x-x)(y-y)}{n}}{\sigma x \times \sigma y}$$

where σx = 13489.5

σy = 221.7

n = 12

$\Sigma(x-x)(y-y)$ = 19172377.01

r_{xy} = 0.53

Testing for the significance, using the students "t" statistic

$$t = \frac{r\sqrt{n-2}}{\sqrt{1-r2}}$$

$\underline{0.53\sqrt{12-2}}$

$1-(0.53)^2$

$= \frac{0.53 \times 3.16}{1-0.2809}$

$= \frac{1.6748}{0.7191}$

$= 2.32$

df = n-2 = 10

since the calculated "t" statistic value of 2.32 at 95% significant level and 10 degree of freedom is greater that the critical value of 2.23, it then implies that a relationship exist between rainfall and run off in the area, though not significant.

Coefficient of determination

$r^2 \times 100\%$

$= 0.53^2 \times 100\%$

$= 28.09\%$

This explains that 28.09% variation in runoff is explainable by rainfall in the area.

Conclusion and Recommendation

In line with aim of the study which was to ascertain the extent of runoff in the area arising from rainfall and how this has affected the rate of surface erosion in the area, been a forested catchment.

The study revealed that run off in the area is related to rainfall, though not significant, and that the rate of erosion which is dependent on the extent of discharge in the area is increasing having an upward turn of rainfall in the area from the period of 1995 to 2001 (see table 2 above).

Having known this and noting that the area is a coastal community whose distance from a major river in the region is less than 1km indicates that if measures to curtail this is not put in place the people in the area will experience more erosion that could lead to loss of properties, life's and their sources of livelihood and in most cases total submergence, especially in the face of global climate change.

Hence, the study recommends that the development of drainage lines will help in curtailing the rate of erosion in the area even in the face of rising runoff and increased water discharge. Also policies regulating the use of substances that increases the carbon content of the atmosphere should be implemented and pursued to the latter as a means of reducing excessive rainfalls arising from increased temperature.

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