Global Scientific JOURNALS

GSJ: Volume 11, Issue 4, April 2023, Online: ISSN 2320-9186
www.globalscientificjournal.com

DETERMINATION OF RUNOFF AND SOIL EROSION EFFECT ON ORAHI RIVER CATCHMENT RIVERS STATE NIGERIA USING RS AND GIS TOOLS

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Abstract: A Catchment is an area delineating all the land that contributes water to a common point resulting from rainfall and flooding events. The need for management, conservation and monitoring of a catchment is vital. Remote Sensing and Geographic Information System (GIS) are analytical tools for analysing spatial distributed information. In this study satellite images of LandSat ETM+ image have been used. Extreme runoff and soil erosion are two severe problems of catchment development and conservation. This study, determines the use of SCS Curve Number (CN) to estimate the runoff and USLE equations are used to measure the soil loss from the study Rivers Orashi catchment. This study was carried out on River Orashi catchment, the Orashi region within Rivers State, Nigeria having an area of 251.65 Sq.km. The geographical location lies in longitudes 060 27'30" and 060 29'30" East and latitudes 050 04'30" and 050 07'00" north. It is in the coastal zone of Nigeria's Niger Delta region (Eteh and Okechukwu, 2021). The daily rainfall data of 5 rain gauge stations (2000-2020) was collected and used to predict the daily runoff from the catchment using SCS-CN method and GIS. The analysis shows that for the study period 1990-2020, minimum and maximum values of (a) yearly computed average rainfall are 90.3 mm and 2293.6 mm and (b) yearly computed average runoff are 56.26 mm and 2293.6 mm respectively. All five parameters of USLE equation for soil loss as follows. R, K, LS, C, and P were estimated. Catchment analysis for erosion shows that the region is experiencing very severe soil erosion and flooding conditions whereas some areas are subjected to water logging, moderate soil erosion and flooding conditions. The average computed annual soil loss from study watersheds is 28.34 ton /ha/year.

Keywords: GIS, Catchment, SCS-CN, USLE

1.0 Introduction.

A watershed is the area covering all the land that contributes runoff water to a common point. Every watershed has different characteristics like size, shape, slope, geology, soil, geomorphology, land use, vegetation. Nigeria has limited information on runoff. The soil conservation service curve number (SCS-CN method) also known as hydrologic soil group method was adopted in this study, this method is a versatile and popular for quick runoff estimation and is relatively easy to use with minimum data and it gives adequate results (Chatterjee et al 2001; Gupta & Panigrahy 2008).

Soil as the topmost layer of the earth's crust houses and sustains life of both plants and animals . Therefore, soil is very important to farmers, who depend on soil to provide abundant, healthy crops each year. Soil erosion is one of the biggest global environmental hazards causing severe land degradation. Population explosion, deforestation, unsustainable agricultural cultivation, and overgrazing are among the main factors causing soil erosion hazards (Reusing et al., 2000). Universal Soil Loss Equation (USLE) are the most popular empirically based models used globally for erosion prediction and control and has been tested in many agricultural watersheds in the world. Remote sensing and GIS techniques have become valuable tools specially when assessing erosion at larger scales due to the amount of data needed and the greater area coverage. For this reason use of these techniques has been widely adopted.

2. Study Area

The Orashi River catchment under investigation is on the North-West region of Rivers State cutting across Ogba/Egbema/Ndoni Local Government Area (L.G.A), Ahoada West L.G.A in Rivers State, Nigeria (Eteh & Okechukwu, 2021). The area is a rapidly growing urban area in the South-South geopolitical region of Nigeria. The major communities surrounding it are Biseni and Zarama in Bayelsa State and Jonkrama 1,2,3,4, Akinima, Oruama, Mbiama, Ushie, Idu, Kriegini, Omoku, Obrikom, Ndoni in Rivers State. The area is accessible by road and river. The Orashi River has a length of 205km. The important tributaries of Orashi River are Omoku, Okposi, Engenni, Bonima, Ubu and Epie rivers (Eteh & Okechukwu, 2021). It occupies an area of 25, 165 Hectares, which is 251.65 square kilometres (Federal Ministry of Environment, 2021)

The study area covers that part of the Orashi river basin that is between Omoku, Idu, Joinkrama and Akinima towns as sub catchments which lies along the banks of this river.This zone is located within longitudes 0060 27'30" and 0060 29'30" East and latitudes 050 04'30" and 050 07'0" north of the equator in the coastal zone of Niger Delta (Eteh & Okechukwu, 2021) as shown in figure 1.1

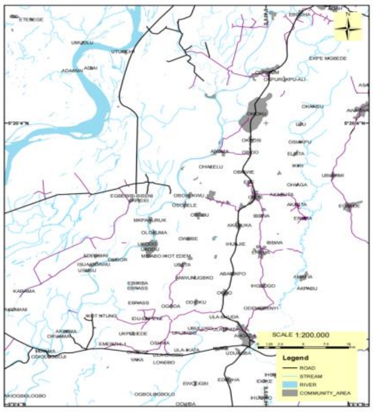


Figure 1.2: Showing the map of the Orashi River Basin. Source: Author, 2022.

3. Methodology

3.1. Soil Conservation Service (SCS) Method

In the early 1950s, the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) (then named the Soil Conservation Service (SCS)) developed a method for estimating runoff from rainfall. The SCS curve number method Is based on the water balance equation and two fundamental hypotheses which are stated as,

ISSN 2320-9186

1) Ratio of the actual direct runoff to the potential runoff is equal to the ratio of the actual infiltration to the potential infiltration,
2) The amount of initial abstraction is some fraction of the potential infiltration (Handbook of hydrology, 1972).

$$P/(P - 1a) = F/S \qquad (1)$$

$$F = P - Ia - Q \qquad (2)$$

Substituting equation (2) in equation (1) and by solving;

$$Q = (P - 1a)2 / (P - 1a) + S \qquad (3)$$

Where, Q = Actual runoff (mm),
P = rainfall (mm),
Ia = initial abstraction, which represents all the losses before the runoff begins and is given by the empirical equation.

$$Ia = 0.2\ S \qquad (4)$$

Substituting equation (4) in equation (3); the resulting equation (3) becomes

$$Q = (P - 1a)2 / (P + 0.8S)$$
$$\text{for } P > 1a(0.2S) \qquad (5)$$

S = the potential infiltration after the runoff begins given by following equation.

$$S = ((25400/(CN)) - 254 \qquad (6)$$

Where, CN is Curve Number.
The Curve Number is a dimensionless parameter indicating the runoff response characteristic of a drainage basin. In the Curve Number Method, this parameter is related to land use, land treatment, hydrological condition, hydrological soil group, and antecedent soil moisture condition in the drainage basin or catchment area.
However, SCS method is originally designed for use in catchment area of 15km^2, it has been modified for application to larger catchment area by weighing curve numbers with respect to watershed/catchment land cover area (Vishvam, Lodha, & Prakash, 2015).
The equation of weighted curve number is expressed as.

$$CN_W = \frac{\sum(CN_i * A_i)}{A} \qquad (7)$$

Where CNw is the weighted curve number; CNi is the curve number from 1 to any number N; Ai is the area with curve number CNi ; and A the total area of the watershed or catchment.

3.2. Data Set

The data set used in this study are both sourced remotely and insitu in the field. Rainfall data for the year of 1990-2020 (30 years) data were collected from the Nigeria Meteorological Agency (NIMET, 2020)).
Various thematic maps such as Land Use map, Soil map, Slope map and SPOT satellite image of year 2020 was collected from www.dopa-explorer.jrc.ec.europa.eu, 2020 Figure-2(a) & (b) .

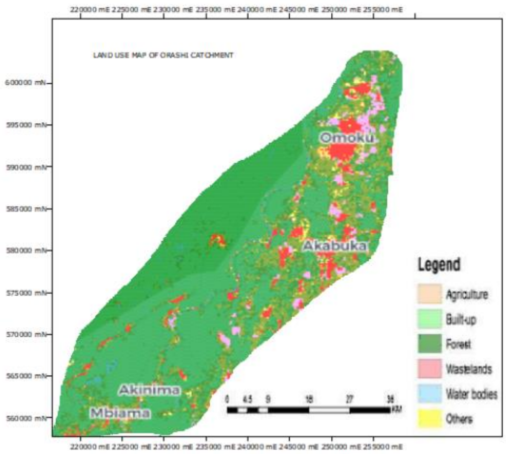
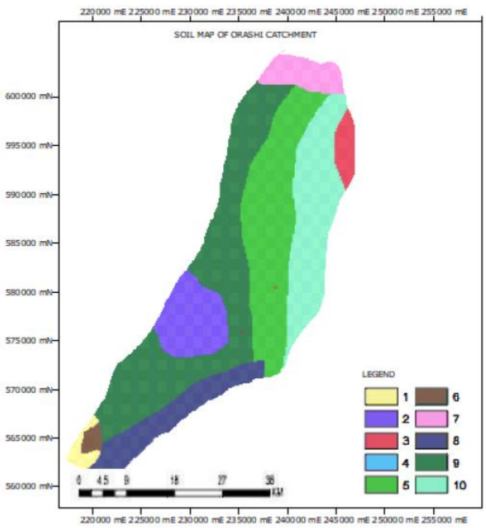


Figure 2(a): Soil Map or Orasshi Catchment
So



3.3. Antecedent Soil Moisture Condition (AMC)

Antecedent Moisture Condition (AMC) refers to the water content present in the soil at a given time. This condition is an important factor for determine final CN value.

SCS developed three antecedent soil-moisture conditions (I, II, III,) according to soil conditions and rainfall limits for dormant and growing seasons.

In this study average condition (AMC-II) is taken for determine CN value for the study area.

3.4. Hydrologic Soil Group Condition (HSG)

SCS developed soil classification system that consists of four groups, which are identified as A, B, C, and D according to their minimum infiltration rate.

CN values were determined from HSG and AMC of the Orashi river catchment area. Runoff curve numbers for (AMC II)for hydrologic soil cover are shown in Table 1.

Table 1. Runoff curve numbers (AMC II) for hydrologic soil covers.

Land use	Hydrologic Soil Group			
	A	B	C	D
Agriculture (without Kharif)	72	81	88	91
Double Crop	62	71	88	91
Plantation	45	53	67	72
Commercial	89	92	94	95
Industrial	81	88	91	93
Urban	89	92	94	95
Village	72	82	87	91
Land with scrub	36	60	73	79
Land without scrub	45	66	77	83
Scrub forest	33	47	64	67
Canal	100	100	100	100
River	97	97	97	97
Reservoir	100	100	100	100
Prosophis	61	70	74	78
Quarry	71	87	89	91

Sourec: (Ref-TR 55, 1986).

3.5. Weighted Area Curve Number

Different layers of land use/Land Cover, Soil, Hydrologic Soil Group (HSG) were added in Attribute table using union tool in ArcGIS 10.1.

The result obtained from union attribute was used to compute Weighted area curve Number of the study area. Calculated value of CN is 88.14 (taking CN=88) in Table 2.

Table 2. Calculation of Weighted Curve Number for AMC II.

Land use	Soil type	CN	Area in km2	(%)of Area	(%)of Area*CN	(WCN)
Agriculture	C	88	883.26	74.54	6559.23	88.14
	D	91	47.89	4.04	367.73	
Buit up	C	94	119.51	10.08	947.99	
	D	95	2.31	0.194	18.50	
Waste land	C	77	49.90	4.211	324.27	
	D	83	1.60	0.135	11.23	
Forest	C	77	3.2	0.2695	20.75	
	D	83	0.140	0.011	0.977	
Water bodies	C	100	34.96	2.95	294.98	
	D	100	1.72	0.15	14.54	
Others	C	74	38.53	3.25	240.59	
	D	78	1.99	0.17	13.11	

Source: Vishvam, et al, 2015

3.6. Calculation of Runoff

In Present study, Calculation of Runoff was done using equation (5) for which Potential maximum Retention (S) is 34.64 and Initial abstraction Ia is 6.93.

The following procedure was used to calculate the surface runoff:

1). Deciding Antecedent Moisture Condition (AMC-II) as considered.

2). Preparation of land use/land cover (Figure 2-a) & soil map (Figure 2-b) using satellite images.

3). Preparation of the hydrological soil group layer from available soil map.

4). Integrating HSG and LU/LC maps in GIS environment and estimate CN (Table-2).

5). Calculate potential maximum retention (S) using equation (6) &

ISSN 2320-9186

Initial Abstraction (Ia) using Equation (4)
6). Calculation of daily, monthly & annually runoff using Equation (5)
This study, an average rainfall and average runoff for the period of 2000-2020) shows an increase over the Orashi River Catchment as shown in Figure 3

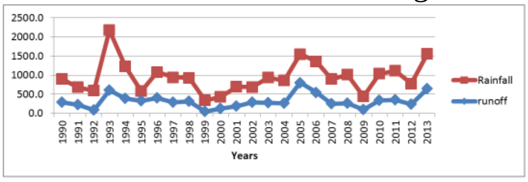


Figure 3. Average annual rainfall vs Annual runoff.

Table 3. Average Rainfall-Runoff of Orashi River Catchment.

Year	Rainfall(mm)	Runoff (mm)
1990	898.7	288.1
1991	676.7	223.6
1992	594.9	91.9
1993	2170.2	603.5
1994	1220	390.4
1995	582.62	332.01
1996	1078.9	407.7
1997	939.7	294
1998	928.33	315.71
1999	336.28	49.49
2000	431.7	126.3
2001	691.9	185.2
2002	687.5	291.8
2003	934.9	281.2
2004	854.8	261.2
2005	1547.96	800.19
2006	1357.3	548.6
2007	899	252.2
2008	1012	261.1
2009	437.38	99.25
2010	1036.6	340.2
2011	1106.1	350.1
2012	775.08	242.06
2013	1555	639.7

Source:

4. Methodology for Soil Erosion

4.1. Universal Soil Loss Equation

The Universal Soil Loss Equation (USLE) is an Empirical model for predicting the annual soil loss caused by rainfall which was developed by Wischmeier and Smith (1965). The Universal Soil Loss Equation (USLE) widely applied at watershed scale to predict the long term average annual rate of erosion on a field slope based on rainfall pattern, soil type, and topography.Crop system and management practices (Williams and Berndt,1972, 1977). The universal Soil Loss Equation is defined as,

A=R*K*LS*C*P (8)

Where,

A= Annual computed Soil Loss (ton/ha/year)
R=Rainfall Erosivity factor
K=Soil Erodibility factor
LS= Slope-length factor
C= Crop management factor
P= Supporting Practice management factor

The calculation of Soil Erosion using USLE was based on Sub catchment level. Orashi river catchment has four sub catchments as shown in Figure 4.

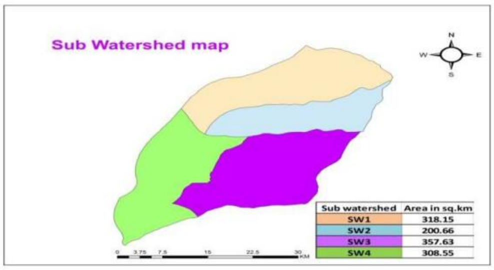


Fig. 4. Sub Catchment map, Source:

4.2. Rainfall Erosivity Factor (R-Factor)

Soil erosion is closely related to rainfall through the combined effect of detachment by raindrops striking the soil surface and by the runoff. According to USLE method, soil loss from the cultivated field is directly proportional to a rain storm parameter, if other factors remain constant. Rain-erosivity (R) is calculated as a product of storm kinetic energy (E) and the maximum 30 minutes rain fall intensity. This relationship helps to quantify the impact of rain drop over a piece of land and the rate of runoff associated with the effect of rain event. However, this study doesn't have adequate meteorological data. The R factor was determined using equation (9) (Chaudhry & Nayak, 2003).

Ra=79+0.363*Xa (9)

Where,
Ra = Annual R factor,
Xa= Average Annual Rainfall in mm.

This study utilises the rainfall data broadcast from the meteorological department of the federal aviation authority in Port Harcourt. The average annual rainfall erosivity (Ra) was calculated using rainfall data obtained for the years (2000-2020).

Table 4. Average Annual Rainfall Erosivity factor.

Station Name	Average Annual Rainfall (1990-2013)		
	Rainfall in mm	R-factor	(R_a=79+0.363*X_a)
Halol	1062.55	464.71	
Wadala Tank	677.18	324.82	
Vadodara	1020.48	449.43	
Waghodia	867.70	393.97	
Pilol	869.28	394.55	

Source:

In present study R factor is used by Sub watershed approach. As Orashi river catchment was divided into 4 sub catchments. So the calculated value for sub watershed is given below in table 5.

Table 5. Calculated R- factor.

Sub watershed	Rainguage Stations	Calculated R-factor
SW1	Halol, Wadala tank	627.12
SW2	Halol, Wadala tank, Waghodia	920.85
SW3	Waghodia, Vadodara, Pilol	974.92
SW4	Vadodara	449.43

Source:

4.3. Soil Erosivity (K) Factor

Soil Erosivity factor represents the soil susceptibility to deformation and transport of soil particles under an amount of runoff for specific rainfall. The K factor is rated mainly scale from 0 to 1, where 0 is for least susceptibility soil for erosion and 1 is for High susceptibility soil for erosion by water.

Table 6. K- factor values for different textures.

Textural class	Organic matter Content (%)		
	0.5	2	4
Fine sand	0.16	0.14	0.1
Very fine sand	0.42	0.36	0.28
Loamy sand	0.12	0.1	0.08
Loamy Very fine sand	0.44	0.38	0.3
Sandy loam	0.27	0.24	0.19
Very fine sandy loam	0.47	0.41	0.33
Silt loam	0.48	0.42	0.33
Clay loam	0.28	0.25	0.21
Silt clay loam	0.37	0.32	0.26
Silty Clay	0.25	0.23	0.19

Source: Stewert et.al-1975.

In Present study consists of soil texture classes namely as 1) Course loamy 2) Fine sand 3) Fine loamy. From above texture of classes, organic matter content normally varies from (1.5 to 2.6 %- taken 2 %). K values for different soil textures has defined by the stewert et.al (1975) which is given in table 6.

Table 7. Calculated average value of K-factor for different sub watershed

Sr.no	Sub watershed	Calculated K-factor
1	SW1	0.26
2	SW2	0.25
3	SW3	0.28
4	SW4	0.26

4.4. Slope Length & Steepness (LS) Factor

The slope length and slope steepness can be used in a single index, which expresses the ratio of soil loss as defined by Wischmeier (1978).

LS = (X/22.1) m * (0.065 + 0.045 S + 0.0065 S)2 (10)

X = slope length (m or km);
S = slope gradient (%)
Slope value was derived from Digital Elevation Model (DEM) of Orahi river watershed. The values of X and S were derived from DEM. To calculate the slope length (X) value, Flow Accumulation was derived from the DEM after conducting Fill and Flow Direction processes by using Arc Hydro tool in ArcGIS 9.3.

Slope Length (X) = (Flow accumulation * Cell value)(11)
By substituting X value, LS equation will be:
LS = (Flow accumulation*Cell value /22.1) m (0.065 + 0.045 S + 0.0065 S^2) (12)
Moreover slope (%) also directly derived from the DEM using ArcGIS 9.3.

Table 8. M value.

Slope (%)	1 < Slope (%)	1<Slope(%) ≤3	3 < Slope (%)< 5	Slope (%) ≥ 5
m - value	0.2	0.3	0.4	0.5

The value of m varies from 0.2 –0.5 depending of the slope as shown in table 8 (Wischmeier and Smith, 1978) which is used for above LS calculation. The result of the analysis is shown in figure (5).LS factor is calculated using Raster Calculator in Arc GIS software. Step by step procedure will describe below.

4.5. Procedure for LS factor Using ArcGIS 9.3

1) In ArcGIS 9.3 check in extension that Arc Hydro tool is marked or not. Mark Arc Hydro tool is used for calculation of LS factor.
2) Click on Terrain Preprocessing then click on DEM manipulation click on Fill sinks. It will fill automatically. After fill successfully a new map is generated.
3) Now, Slope map is created using DEM.
4) Calculate Using Raster calculator plot the below equation.
Again click on Terrain Preprocessing then click on Flow Direction. It will automatically give flow direction and a new map is generated.
Again click on Terrain Preprocessing then click on Flow Accumulation. It will accumulate flow and a new map is generated.

LS=(("Fac"*25/22.1)^0.2)*(0.065+0.045*"Slope" +0.0065*("Slope"*"Slope")) (13)

After following above procedure to calculate LS factor using Arc Hydro tool in Arc GIS the final result shows the value of LS factor in given Table 9.

Table 9. Calculated LS factor values.

Sr.no	Sub watershed	Calculated LS factor
1	SW1	3.43
2	SW2	3.41
3	SW3	0.12
4	SW4	0.29

4.6. Crop Management (C) Factor

The crop management factor is used to reflect the effect of cropping and management purpose on erosion rates. It represents the ratio of soil loss under a given crop to that of the Base soil (Morgan, 1994).
It is considered the second major factor (after topography) controlling soil erosion. An increase in cover factor indicates a decrease in exposed soil, and thus an increase potential soil loss.
The C factor is calculated depending upon different land use types as per below Table 10 (Wischmeier and Smith 1978).

Table 10. C- factor values for different land use/ land cover.

Land use	Sub Land use	C-factor
Agriculture	Current Fallow	0.6
	Kharif + Rabi (Double cropped)	0.6
	Kharif Crop	0.5
	Plantations	0.5
Buit up	Commercial	0.2
	Industrial	0.2
	Towns/cities (Urban)	0.2
	Villages (Rural)	0.2
Forest	Scrub Forest	0.02
Others	Prosophis	0.15
	Quarry	0.15
Waste land	Land with Scrub	0.95
	Land without Scrub	0.8
Water bodies	Canal	0
	Lakes / Ponds	0
	Reservoirs	0
	River	0

In present study, for Orahi river watershed C factor is calculated depending upon different land use types. Each land use/ land cover has a value varies from 0 to 0.95 as per below in Table 11.

Table 11. Average values of C- factor for Sub watershed.

Sr.no	Sub watershed	Calculated C-factor
1	SW1	0.30
2	SW2	0.31
3	SW3	0.34
4	SW4	0.31

4.7. Conservation Practice (P) Factor

Conservation practice factor (P) in USLE expresses the effect of conservation practices that reduce the amount and rate of runoff, which reduces soil erosion.
It is the ratio of soil loss with a support practice on crop lands to the

ISSN 2320-9186

corresponding loss with up & down slope (Renard et.al., 1997).

Table 12. Conservation Practice (P) factor on different slope gradient.

Sr.no	Sub watershed	Calculated P-factor
1	SW1	0.58
2	SW2	0.58
3	SW3	0.60
4	SW4	0.60

4.8. Procedure for Using USLE

1) Determine the R factor using available Rain-guage station data which covers watershed (Table 5).

2) Based on the soil texture, determine the K value (Table 7).

If there is more than one soil type in a field is present and the soil textures are not very different, use the soil type that represents the majority of the field.

3) Divide the field into sections of uniform slope gradient and length. Assign an LS value to each section using Arc Hydro tool in Arc GIS interface (Table 9).

4) Choose the crop type factor and tillage method factor for the crop to be grown. Multiply these two factors together to obtain the C factor (Table 11).

5) Select the P factor based on the support practice used (Table 13).

6) Multiply above all 5 factors to calculate Annual soil erosion (Ton/ha/year) (Table 14).

Table 14. Annual Soil Erosion for different sub watershed.

Sub watershed	R-factor	K-factor	LS-Factor	C-factor	P-factor	Annual
SW1	627.12	0.26	3.43	0.3	0.58	97.31
SW2	920.85	0.25	3.14	0.31	0.58	129.97
SW3	974.92	0.28	0.12	0.34	0.6	6.68
SW4	449.43	0.26	0.29	0.31	0.6	6.30
			Total Annual Soil Erosion			240.27

4.9. Soil Erosion Calculation

In this study, A Quantitative assessment of Orahi river watershed is taken place using USLE. All five parameters of Universal Soil Loss Equation (USLE) are calculated for each four sub watershed. After calculation of all five parameters of USLE, annual soil erosion of Orahi river watershed is 240.27 ton /ha/year as shown in Table-14.

As per the different class group category given by the Rambabu & Narayan for erosion by water in India is given in Table 15.

Table 15. Different classes of soil erosion by water in India(Ref-Rambabu& Narayan)

Sr.no	Soil erosion class group	Soil erosion range(ton/ha/year)
1	Slight	0-5
2	Moderate	5-10
3	High	10-20
4	Very High	20-40
5	Severe	40-80
6	Very Severe	>80

5. Conclusion

Orahi river watershed consists of different Land uses/covers. About 79 % of the area is cover by Agricultural land, 10 % area is built up, 3 % area is cover by water bodies and remaining 8 % area is wastelands, quarries etc.

The computed values of minimum and maximum (a) Yearly average rainfall are 336.28 mm and 2170.2 mm respectively and (b) Yearly average runoff are 49.49 mm and 800.19 mm respectively.

The soil losses estimated using Universal Soil Loss Equation (USLE) has been carried out for Orahi River Watershed. After calculation of the five parameters of USLE for the all four sub watersheds, it is found that two sub watersheds coded as SW1 & SW2 are subjected to very severe conditions of erosion (given in Table-16) and needs some watershed treatment to control the high rate of erosion.

Table 16. Classes of soil erosion & prioritization Orahi watershed.

Sub watershed	Annual Soil Erosion	Class group	Priority
SW1	97.31	Very Severe	2
SW2	129.97	Very Severe	1
SW3	6.68	Moderate	3
SW4	6.3	Moderate	4

The other two sub watersheds coded as SW3 & SW4 are subjected to moderate conditions of erosion. The annual computed soil loss from the whole Orahi river watershed is 240.27 ton /ha/year.

ISSN 2320-9186

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