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MORPHOMETRIC AND RUNOFF ANALYSIS INCLUDING SOIL EROSION AND SEDIMENT YIELD ESTIMATION OF UPPER-HELMAND RIVER BASIN AFGHANISTAN

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ABSTRACT

The present study deals with the morphometric and runoff analysis including soil erosion and sediment yield estimation of Upper - Helmand River Basin of Afghanistan. ASTER DEM data has been utilized in Arc-GIS environment for carrying out morphometric analysis to get the various morphometric parameters and their correlation with stream order (U). For the runoff estimation, SCS-CN (Curve Number) method with Arc-GIS and remote sensing has been used for Upper - Helmand river basin, Afghanistan. Due to excessive runoff, top soil surface of watershed can be eroded which may damage the agriculture cycle and as well as reduce the reservoirs capacity. SCS (Soil Conservation Service) curve number method can be effectively used for runoff estimation which is now being used worldwide as it depends upon only few numbers of parameters, such as soil properties, LULC and precipitation. After runoff estimation and its magnitude, soil erosion estimation has been carried out which is a serious problem and greatest destroyer to land cover management and resources of the Upper - Helmand catchment. In the present study for soil erosion, USLE model with Remote Sensing and GIS have been used to estimate the soil erosion risks and sediment yield at the Upper - Helmand catchment outlet (Kajki reservoir).

Keywords: Morphometric Analysis, Arc-GIS, Upper Helmand, ASTER, DEM, USLE (Universal Soil Loss Equation), Sediment Yield, Remote Sensing (RS),. SCS (Soil Conservation Service), CN (Curve Number), LULC (Land Use Land Cover).

I. INTRODUCTION

Mathematical analysis and measurement of the configuration of the earth's surface, its shape and dimensions of landforms is called as morphometric analysis [1]. Watershed morphometric characteristics covers important information regarding the catchment area, its formation and development because all geomorphic and hydrologic processes occur within the watershed [2]. Quantitative description of the drainage system is provided by morphometric analysis of a watershed, which is a significant aspects of the watershed characterization [3]. Characterization of watershed and management requires detail information of topography, drainage network, water divide, channel length, geomorphologic and geological setup measures [4]. To understand the hydrological system of the basin, the ASTER data was utilized, that has given reliable and suitable results [5][6][7

Runoff occurred when the rainfall intensity (I) is more than the infiltration capacity (f_c) of the soil and excess water flows over the land surface to nearby channels [8]. Such a process of runoff is referred as Hortonian runoff who has firstly described it. Two conditions must be satisfied to generate Hortonian flow, first one the rainfall intensity should be more than the rate of losses on the land surface ($I > f_c$) and secondly, the time required for saturation of the surface soil must be lesser then the duration of rainfall [9]. Curve number (CN) is the method which combines the climatic factors and watershed parameters in one entity [10]. Using SCS-CN method, it is observed that in general, good correlation has been found between observed and computed runoff [11]. If conventional hydrological data are insufficient for the purpose of design of water resources system, then remote sensing data are of great use [12]. The runoff Curve Number (CN) can be effectively used in the practical models to calculate surface runoff [13]. The results of SCS-CN model could have been improved if more rain gauge stations are available in a large catchment.

An important item for consideration in the planning and management work of catchment, is the soil erosion. It not only reduces the storage capacity of a reservoir but also affects the resources and productivity of catchment. Erosion implicates the process of the detachment, transport and deposition of soil particles and aggregates [14]. The total amount of detachment (erosion) of soil and then transportation from its source to downstream control point of the catchment is defined as the sediment yield[15]. Therefore, sediment yield rate is the result of soil loss and surface runoff and channel flow. Sediment yield rate basically depends on surface runoff. Therefore, any errors in the prediction of runoff affect the sediment yield.

The original and modified forms of the USLE, is widely used model to assess soil loss from a catchment area [16]. USLE model has involved number of parameters, such as rainfall erosivity factor (R), erodibility factor (K), topographic parameters (LS), vegetative cover (C) and soil conservation practice factor (P). In the present study, Universal Soil Loss Equation (USLE) is being used to assess potential soil erosion from Upper-Helmand catchment and its impact on Kajaki reservoir. Arc-GIS 10.3 software is being used for the generation and development of input digital data for the USLE model to estimate the soil erosion form the catchment and generation of output maps.

II. STUDY AREAS

The Upper - Helmand River basin is located between latitudes 32.254 N to 34.653 N and longitudes 65.092 E to 68.687 E, altitude may varies from 968m to 5036m high with respect to mean sea level, correspondingly with area of 46,793 Km2 (Fig.1). The Upper - Helmand river basin area is embodied by large hills, buried pediments, valleys and alluvial plains. The soil texture is silty clay, sandy, loamy and alluvium. The Upper - Helmand river basin originate in a westerly extension of the Hindu Kush mountain range near Paghman about 40 kilometres west of Kabul and runs southwesterly for about 590 kilometers to the reservoir of Kajaki dam. The river water comes mostly from rainfall at the average elevations of the basin in winter and spring seasons and from melting snows at the high altitude of mountains which escalate to elevations of 5036 meters. Range of Annual precipitations varies between 100 mm to 670 mm and precipitate mostly at higher altitudes during winter and spring [17]. The mountains cause many local variations, though the Upper - Helmand river basin is categorized by a dry continental climate. The temperature of this region is varying from minus (-) 10 °C in winter to plus (+) 34 °C in summer. The fluctuations in temperature are not uniform in character over the whole basin. The catchment is very important in the context of serving inter - sectorial demands including drinking, irrigation and hydropower generation. There is one major reservoir exist in the drainage basin with storage capacity of 1,844 Mm3 at the current spillway elevation [18].

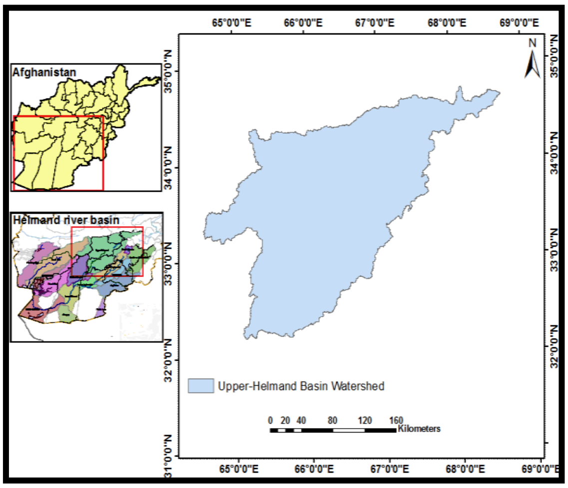

Fig. 1 Study Area of Upper - Helmand river Basin in Afghanistan

III. METHODOLOGY

3.1. Data Acquisition

ASTER DEM data with 30 m resolution is available (http://earthexplorer.usgs.gov/). This data has been analyzed in Arc-GIS 10.3 for carrying out morpohometric analysis. Land use land cover map is downloaded from the United State Geological Survey (USGS) Land Cover Institute (LCI). Soil map, Soil properties such as soil types, structure and texture are obtained from Food and Agriculture Organization (FAO) soil map and 35 years rainfall data is downloaded from global weather. Landsat TM mosaic imagery is downloaded from http://earthexplorer.usgs.gov/.

3.2Morphometric Analysis

The methodology used to calculate various morphometric parameters related to drainage basin is given in the flow chart Fig. 2 and Table 1.

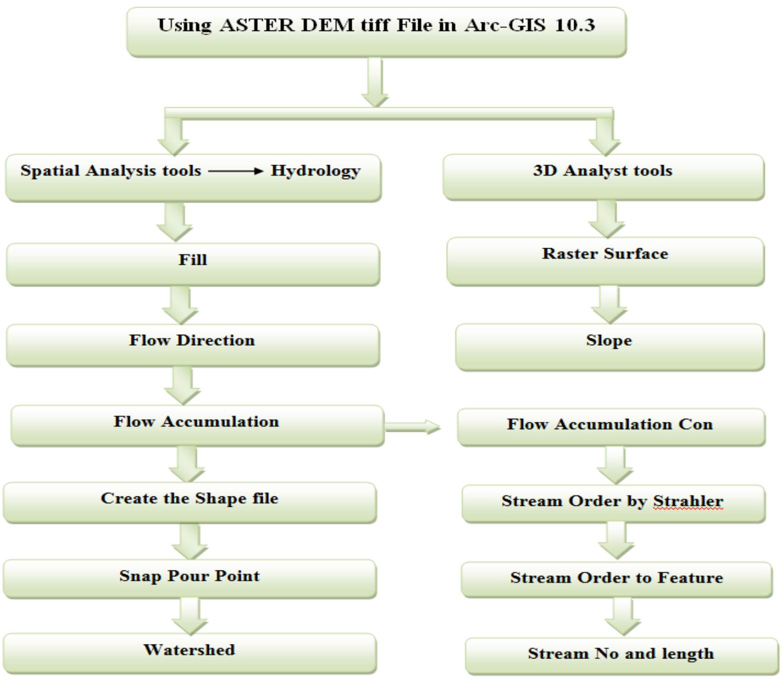

Fig. 2 Flow chart to calculate morphometric parameters related to drainage basin

Table 1 Morphometric parameters with formulae

S. No.	Parameters	Formulae	References
1	Stream order(U)	Hierarchical rank	Strahler (1964)
2	Stream length(Lu)	Length of the stream	Horton (1945)
3	Mean stream length(Lsm)	$L_{sm}= L_u/N_u$ Where Nu is no. of streams	Strahler (1964)
4	Stream length ratio(Rl)	$R_l=L_u/(L_u-1)$	Horton (1945)
5	Bifurcation ratio(Rb)	$R_b=N_u/(N_u+1)$	Schumm(1956)
6	Mean Bifurcation ratio(Rbm)	R_{bm}=Average of all bifurcation ratios	Strahler (1957)
7	Drainage density(Dd)	$D_d=L_u/A$	Horton (1932)
8	Drainage intensity(Di)	$D_i= F_s/D_d$	Faniran (1968)
9	Infiltration Number If	$I_f=F_s$*Dd	Faniran (1968)
10	Drainage texture(T)	$T=N_u/P$	Horton (1945)
11	Texture ratio	$R_t=N_1/P$	Schumm(1965)
12	Stream frequency(Fs)	$F_s=N_u/A$	Horton (1932)
13	Elongation ratio(Re)	$R_e = (2 / L_b) * (A /\pi)^{0.5}$	Schumm(1956)
14	Circularity ratio(Rc)	Rc=4pA/ P2	Miller (1953)
15	Form factor(Ff)	$Ff=A/Lb^2$	Horton (1932)
16	Length of overland flow(Lg)	$Lg= A/(2*L_u)$	Horton 1945
17	Shape factor ratio(Rs)	$R_s=Lb^2/A$	Horton 1956
18	Relative perimeter (Pr)	$P_r= A / P$	Schumm(1956)

3.3. Runoff Estimation

Runoff estimation based on SCS-CN complemented in three stages:

Stage - 1: All data (spatial and non-spatial) are collected from different sources.

Stage – 2: The article with related layers of hydrologic soil group and land use maps are prepared along with overlaid with one another in Arc-Hydro and HEC-GeoHMS Tools. The overlaid endings are allocated by curve number.

Stage – 3: This is the final stage in which the runoff is estimated based on rainfall occurred in study area. All the three stages are shown in Fig. 3.

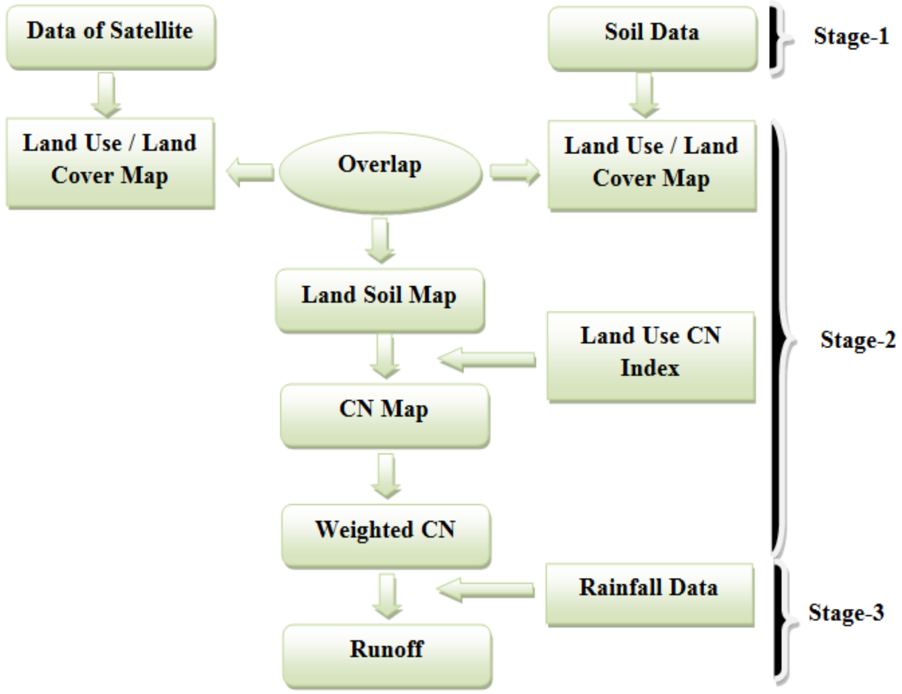

Fig. 3 Flow chart for Runoff Estimation based on SCS-CN

3.4. Soil Erosion

USLE model is widely used for the assessment of soil loss from the catchment in USA. This model predict the average annual soil loss (A), which is the result of five different factors that influence the soil loss and is given below Equation (1) :

$$A = R\ K\ LS\ C\ P \qquad (1)$$

Where A is annual average soil loss (ton/ha/year), R is rainfall erosivity factor (MJ/ha.mm/h), K is soil erodibility factor (MJ mm/ha/ h/ y), L is the slope length factor, S is the slope steepness factor, C is the cover management factor and P is conservation practice factor all the above factors calculation procedure is described belo.

3.4.1.Rainfall Erosivity Factor (R)

The rainfall erosivity factor (R) is obtained from the rainfall intensity data. In the Upper-Helmand watershed, the rain gauge stations do not have rainfall intensity data. Hence, R is found from mean annual rainfall (P) [19] and is given below by Equation (2):

$$R = 0.5 * P \qquad (2)$$

The annual and monthly precipitation data are downloaded from site http://globalweather.tamu.edu/ which covers 42 stations for 35 years. R values are estimated and interpolated over the whole watershed using geostrategic model (Kriging). The R values are varying from 82 to 362 and are shown in Fig. 4.

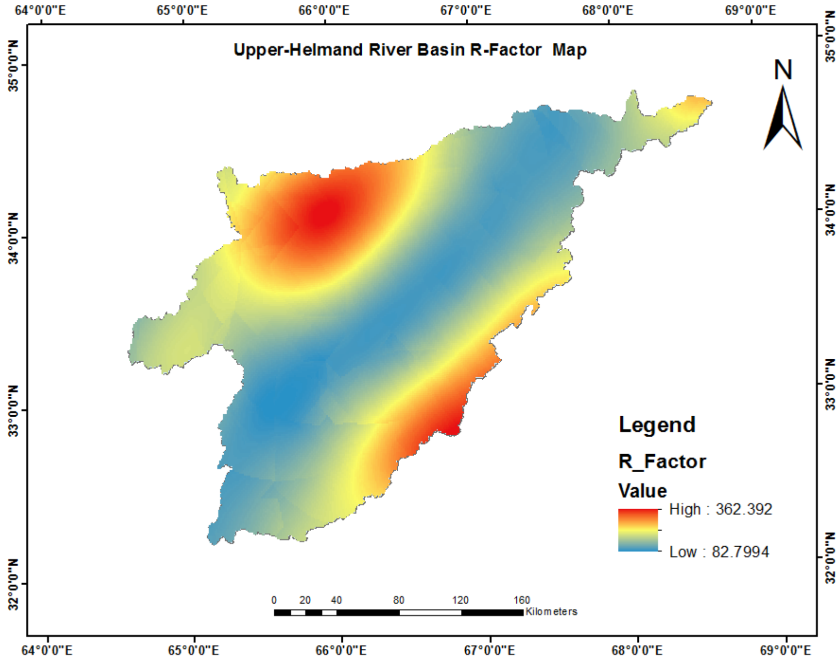

Fig.4 R-Factor Map Upper-Helmand Catchment

3.4.2.Soil Erodibility Factor (K)

The estimation of soil eordibility factor (K) is based on physical properties of soil (texture and organic matter content[20], and is given in below Equation (3).

$$K = f_{csand} \times fcl\text{-}si \times forg \times fhisand \times 0.1317 \quad (3)$$

Where $f_{csand}$is a factor of soil which has high coarse sand and gives low soil erodibility through Eq.(4).

$$(4) \quad f_{csand} = \left(0.2 + 0.3 \cdot \exp\left[-0.256 \cdot m_s \cdot \left(1 - \frac{m_{silt}}{100}\right)\right]\right)$$

$f_{cl\text{-}si}$ is a factor of soil which has high clay to silt ratio and gives low soil erodibility as obtained from Eq.(5).

$$(5) \quad f_{cl-si} = \left(\frac{m_{silt}}{m_c + m_{silt}}\right)^{0.3}$$

f_{org} is a factor of soil which has organic carbon content and reduce the erodibility of soil and is given by Eq (6).

$$(6) \quad f_{orgc} = \left(1 - \frac{0.0256 \cdot orgC}{orgC + \exp[3.72 - 2.95 \cdot orgC]}\right)$$

f_{hisand} is a factor of soil which has high content of sand and reduce the erodibility of soil and is given by Eq(7):

$$f_{hisand} = \left(1 - \frac{0.7 \cdot \left(1 - \frac{m_s}{100}\right)}{\left(1 - \frac{m_s}{100}\right) + \exp\left[-5.51 + 22.9 \cdot \left(1 - \frac{m_s}{100}\right)\right]}\right) \quad (7)$$

In Equation (5) to Equation (7) m_s, m_{silt}, $m_c$and $orcC$ are the percentage of sand, silt, clay and organic content of top soil respectively. The above factors are calculated and given in Table.2 from the soil texture of Upper-Helmand catchment based on FAO soil classification. Accordingly, the soil erodibilty factor K is calculated using equation (3) and is given in Table 2 and also shown in Fig. 5 for Upper-Helmand river basin.

Table.2 Soil texture of Upper-Helmand catchment bass on FAO Soil Classification.

Soil unit symbol	sand % topsoil	silt % topsoil	clay % topsoil	OC % topsoil	F_{csand}	F_{cl-si}	F_{org}	F_{hisand}	K_{USLE}	K
I	58.9	16.2	24.9	0.97	0.200	0.756	0.925	0.994	0.139	0.0183
JC	39.6	39.9	20.6	0.65	0.201	0.883	0.975	1.000	0.173	0.0227

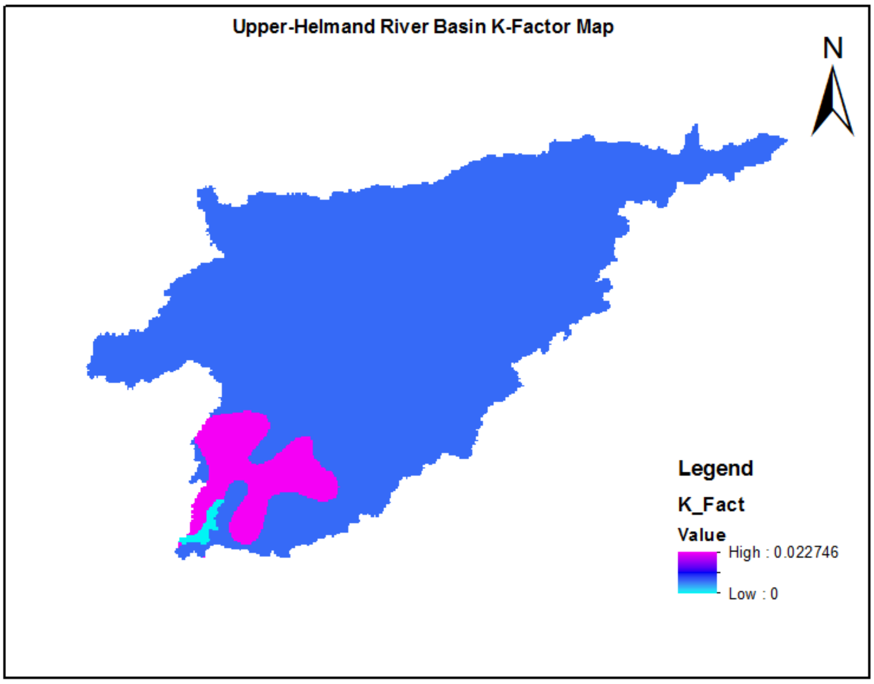

Fig.5 K-Factor Map of Upper-Helmand Watershed

3.4.3.Topographic Factor (LS)

An Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER) Digital Elevation Model (DEM) (Fig.6) of 30 m resolution images have been prepared and is used to calculate topographic factor (LS). LS is factor combining the product of L (length of slope) and S (steepness of slope). L factor is computed for each pixel of the grid using Eq. (8), (Demet and Govers 1996):

$$L_{ij-in} = \frac{\left[\left(A_{ij-in} + D^2\right)^{m+1} - \left(A_{ij-in}\right)^{m+1}\right]}{\left(D^{m+2}\right)\times\left(x_{ij}{}^{m}\right)\times\left(22.13\right)^{m}} \quad (8)$$

In eq.(8), Lij-in is slope length for grid cell (i,j), Aij-in is contributing area at the inlet of the grid cell with coordinates (i,j) (m2), D is grid cell size in metre, m is length exponent of the USLE L-factor, xij is equal to (sinαi,j + cosαi,j).The exponent ‘m’ in Eq.9 was used according to the algorithm proposed of McCool et al (1989) and is expressed below:

$$m = \frac{\beta}{\beta+1} \quad (9)$$

Where β varies according to slope gradient [20]. Further β value is obtained by following equation:

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(10) $$\beta = \left(\frac{\sin\theta}{0.0896}\right) / \left[3(\sin\theta)^{0.8} + 0.56\right]$$

The slope steepness factor is derived using the Eq.11(a)andEq.11(b) as proposed by (McCool et at., 1987) for slope length >4m.

$S = 10.8 \sin\theta + 0.03$ (for slope gradient < 9%) (11a)

$S = 16.8 \sin\theta + 0.5$ (for slope gradient ≥ 9%) (11b)

Where S is dimensionless slope steepness factor and θ is slope angle in degree. The variation of topographic factor (LS) is shown in Fig.7, which varies between 0 and 11.91.

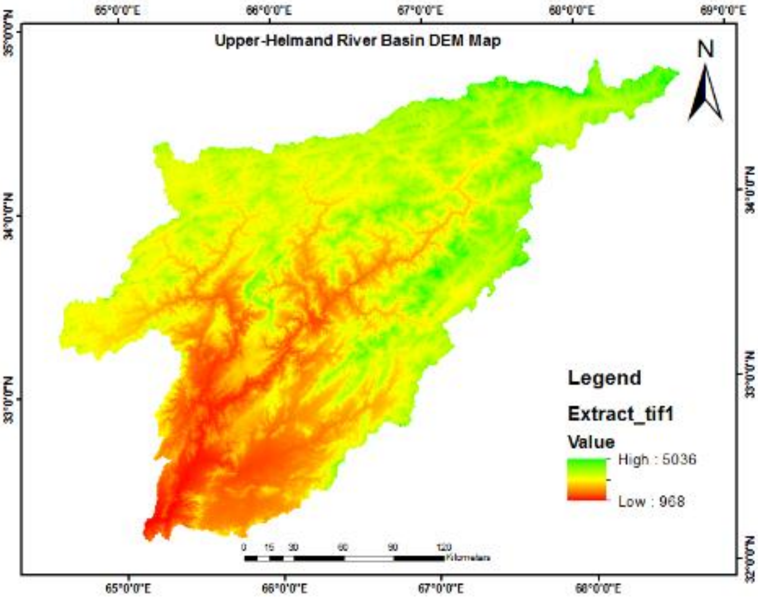

Fig.6 DEM Map

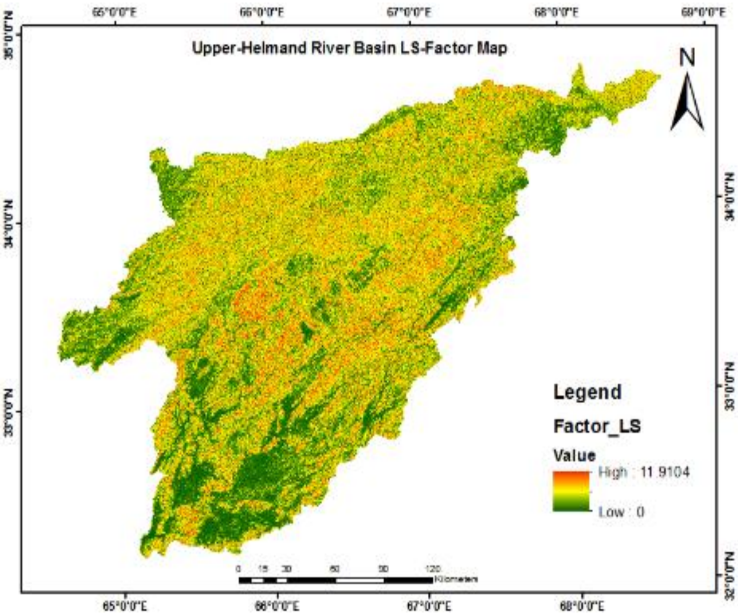

Fig.7 LS-Factor Map

3.4.4. Cover Management Factor (C_m)

For cover management factor (C_m), imagery is extracted from Landsat TM and was used to find out the Cm-factor values based on LULC and shown in Fig.8. Fig. 8 clearly shows that Cm is equal to 0.4 for most of the catchment area.

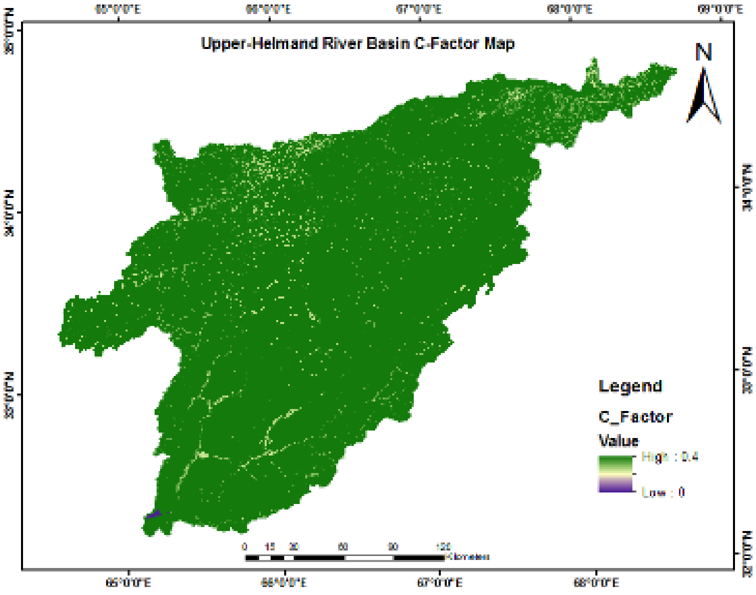

Fig. 8 C-Factor Map

3.4.5. Conservation Practice Factor (P)

In the present, there are no erosion control practices adopted in the catchment area, hence the P-factor value is taken as 1.0 in USLE model.

3.5. Sediment Yield Determination

The sediment yield equation is expressed as follows:

$$Y = SDR \times A_g \qquad (12)$$

Where, Y is sediment yield at catchment outlet, SDR is sediment delivery ratio and Ag is gross soil erosion from the catchment.Williams and Berndt (1972) correlated SDR with slope of main channel (SLP) and the corresponding relation is given as follows:

$$SDR = 0.627 * SLP^{0.403} \quad (13)$$

Eq. 13 gives a reasonable good value for the determination of sediment delivery ratio despite using few parameters of catchment (Williams and Berndt 1972). The estimation of SLP requires only two parameters of the catchment - the length of channel and elevation of channel.

3.6. Sediment Trap Efficiency

For the estimation of sediment trap efficiency, the Brune's Curve (1953) has been adopted, which is a common and popular method. Brune collected the data from 44 normal pounded reservoirs in USA and developed an envelope curve plotted against η_{trap} versus capacity inflow ratio (C/I) and shown in Fig. 7 and then he drawn a median curve, which can be used for the determination of trap efficiency (η_{trap}).

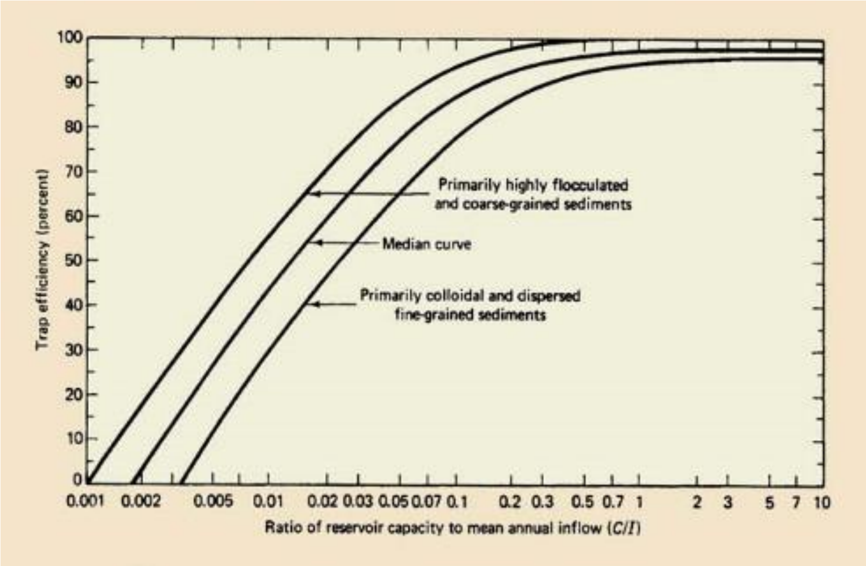

Fig. 9 Sediment traps efficiency as per Brune (1953)

IV. RESULT AND DISCUSSION

4.1 Morphometric Analysis

The present study highlights the analysis of morphometric parameters of Upper - Helmand river, which is located in Afghanistan. In this study, ArcGIS 10.3 along with ASTER Global Digital Elevation Model (GDEM) and Geographical Information System (GIS) have been used to evaluate Linear Aspects, Areal Aspects and Relief Aspect and are given in Table 3 and Table 4.

Table 3 Linear aspect of the Upper - Helmand River Basin

Stream order	Streams Number (Nu)	Bifurcation ratio(Rb)	Mean Bifurcation ratio	Length of streams(Km)	Mean stream length (Km)	Stream Length ratio of Basin	Mean length ratio(Rl) of Basin
1	14719		4.23	14825.64	1.01	0.46	0.46
2	1926	7.64		6793.02	3.53	0.52	
3	432	4.46		3557.88	8.24	0.39	
4	94	4.60		1375.66	14.63	0.57	
5	24	3.92		783.56	32.65	0.65	
6	6	4.00		506.41	84.40	0.84	
7	2	3.00		426.89	213.45	0.23	
8	1	2.00		99.89	99.89	0.00	
Total	17204			28368.94			

Table 4 Areal and Relief Parameters

SN	Parameter	Value
1	Mean bifurcation ratio (Rbm)	4.23
2	Perimeter (P) in Km	1762
3	Basin area in Km2	46793
4	Basin Length in Km(Schumm 1956)	589.65
5	Texture Ratio (T)	8.354
6	Drainage density (Dd)	0.61
7	Length of overland flow (Lg)	0.820
8	Stream frequency (Fs)	0.37
9	Infiltration Number (If)	0.226
10	Elongation ratio (Re)	0.41
11	Circularity ratio (Rc)	0.19
12	Form factor (Ff)	0.14
13	Relief (R)	4068

4.2. Runoff Estimation

The Arc-GIS 10.3 software divided the Upper -Helmand river basin into 40 small sub-watersheds and created Curve Number (CN) for each small sub basin. As per the growing five days' rainfall, during October, November, December and January, the curve number falls in Antecedent Soil Moisture Condition AMC-III. Accordingly, the runoff is estimated for 35 years (1979 to 2014) and are given in Table 5, which shows the runoff in million-hectare meter (Mhm) corresponding to rainfall in each year.

The rainfall and corresponding runoff for all 35 years is shown in Fig. 18 in the form of bar chart.

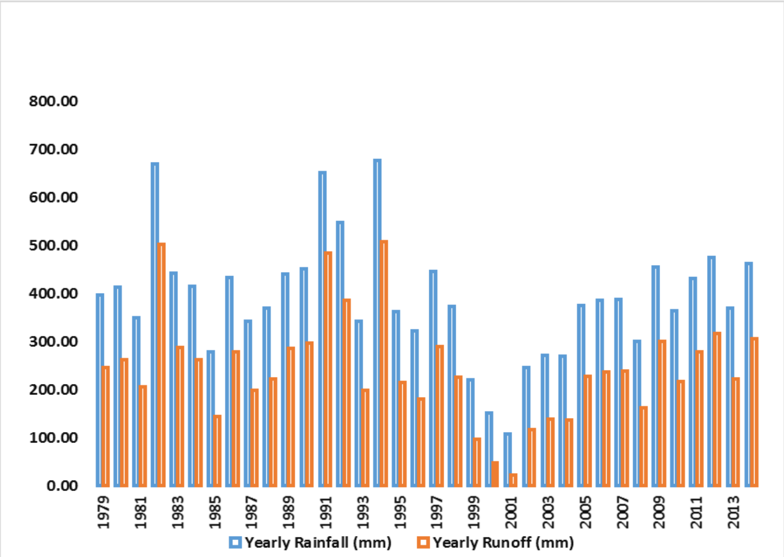

Fig. 10 Bar chart of Rainfall and Runoff

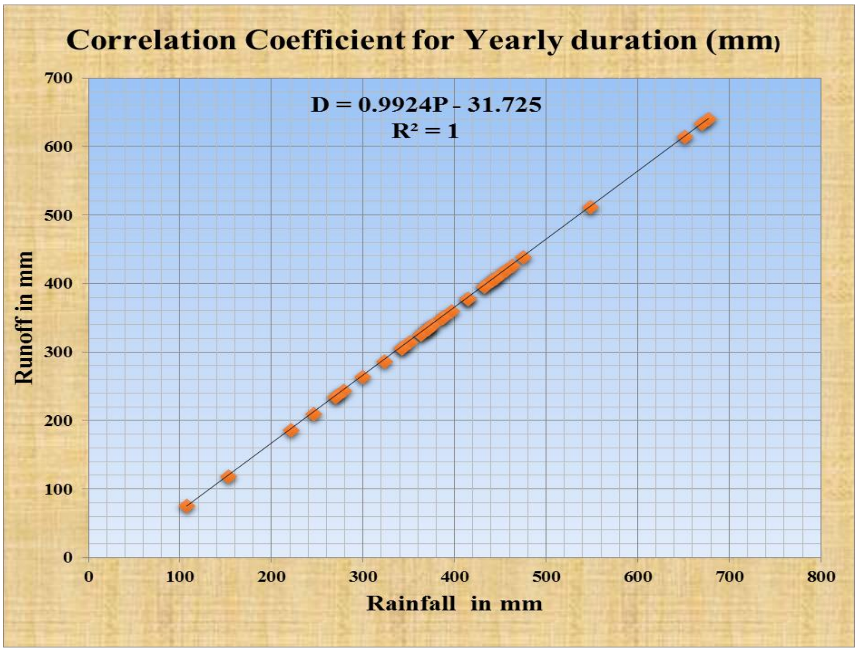

Fig. 11 Rainfall (P) versus Runoff (D)

Table. 5 Runoff estimation of 35 years for Upper - Helmand river basin

Year	Annul Precipitation (mm)	CN (AMC-III)	PMR S	Runoff (mm)	Area (Km2)	Runoff (Mm3)	Runoff (Mhm)
1979	396.72	89.10	31.037	361.727	46793	16,926.30	1.693
1980	414.57	89.100	31.073	379.483	46793	17,757.15	1.776
1981	350.94	89.100	31.073	316.224	46793	14,797.09	1.480
1982	670.82	89.100	31.073	634.924	46793	29,709.98	2.971
1983	442.79	89.100	31.073	407.569	46793	19,071.36	1.907
1984	415.06	89.100	31.073	379.964	46793	17,779.64	1.778
1985	279.36	89.100	31.073	245.248	46793	11,475.91	1.148
1986	433.77	89.100	31.073	398.586	46793	18,651.03	1.865
1987	343.68	89.100	31.073	309.010	46793	14,459.52	1.446
1988	370.71	89.100	31.073	335.865	46793	15,716.15	1.572
1989	441.61	89.100	31.073	406.389	46793	19,016.15	1.902
1990	451.83	89.100	31.073	416.569	46793	19,492.52	1.949
1991	651.98	89.100	31.073	616.122	46793	28,830.19	2.883
1992	548.90	89.100	31.073	513.295	46793	24,018.60	2.402
1993	342.68	89.100	31.073	308.024	46793	14,413.37	1.441
1994	677.51	89.100	31.073	641.600	46793	30,022.39	3.002
1995	362.93	89.100	31.073	328.130	46793	15,354.17	1.535
1996	323.16	89.100	31.073	288.649	46793	13,506.75	1.351

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1997	445.79	89.100	31.073	410.551	46793	19,210.92	1.921
1999	221.55	89.100	31.073	188.182	46793	8,805.62	0.881
2000	152.71	89.100	31.073	120.855	46793	5,655.18	0.566
2001	107.80	89.100	31.073	77.790	46793	3,640.02	0.364
2002	245.82	89.100	31.073	212.100	46793	9,924.80	0.992
2003	272.38	89.100	31.073	238.338	46793	11,152.54	1.115
2004	270.45	89.100	31.073	236.431	46793	11,063.33	1.106
2005	376.03	89.100	31.073	341.155	46793	15,963.67	1.596
2006	386.15	89.100	31.073	351.216	46793	16,434.47	1.643
2007	387.91	89.100	31.073	352.964	46793	16,516.26	1.652
2008	300.11	89.100	31.073	265.796	46793	12,437.38	1.244
2009	456.31	89.100	31.073	421.031	46793	19,701.29	1.970
2010	363.78	89.100	31.073	328.980	46793	15,393.96	1.539
2011	432.69	89.100	31.073	397.516	46793	18,600.98	1.860
2012	475.44	89.100	31.073	440.079	46793	20,592.61	2.059
2013	370.79	89.100	31.073	335.941	46793	15,719.69	1.572
2014	463.52	89.100	31.073	428.209	46793	20,037.18	2.004

4.3. Soil Ersion

The soil erosion rates, as derived from the Raster multiplication of the USLE factors are shown in Fig.12, which vary from 0 to 31.98 ton/ha/year. These erosion rates have further been classified into three classes - slight, moderate and high soil erosion and are given in Table -7. It is cleared from this Table – 7 that the soil erosion risk is low in 80.92% of the study area with a soil loss of 4.66 ton/ha/year, while 17.59% of the area is under moderate erosion with soil loss of 15.31 tons/ha/year. Hardly 1.49% of the area is under high erosion with soil loss of 26.62 ton/ha/year. The average quantity of actual soil loss over the whole watershed,as estimated by USLE model is 6.22 ton/ha/year. Accordingly, the total soil erosion estimated by USLE model is estimated as 29.1 Mton/year over the whole basin. After dividing by the specific gravity of the sediment (1.5tons/m3), the soil erosion from the Upper - Helmand catchment will be 19.4 Mm3/year

Erosion Class	**Range (tons/ha/year)**	**Land Use Class**	**Area Cover Km2**	**Cover Area%**
1	0-10	Slight	37865.9	80.92
2	10-20	Moderate	8,229.7	17.59
3	20-31.98	High	697.7	1.49

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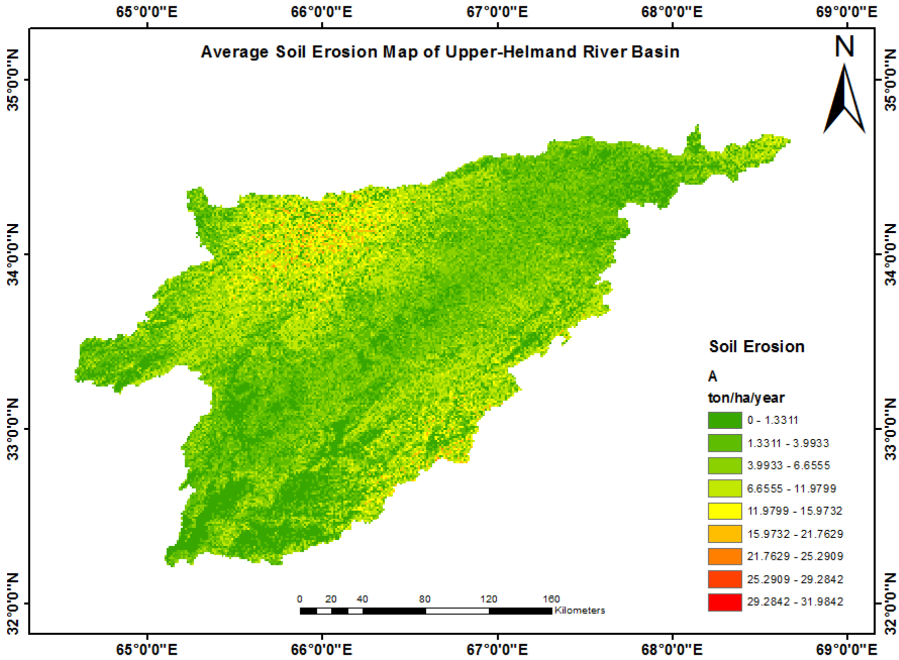

Fig. 12 Soil Erosion Map OF Upper - Helmand Catchment

4.4. Sedimentation Yield of Kajaki Reservoir

The gross erosion from the catchment is estimated as 19.4 Mm3/year and the sediment delivery ratio for the watershed is computed as 54%. Therefore, the net sediment yields of Kajki reservoir will be 10.47 Mm3/year. The average trap efficiency of the reservoir is 0.87 as obtained from Fig. 7. This result in the net sediment trapped in the reservoir 8.92 M m3/year. The reservoir storage capacity at the crest of spillway was 1844Mm3 in 1953 (Perkins, & Culbertson, 1970). At the same spillway elevation of 1033.5 m, the total storage capacity at present is 1282 Mm3. Thus, the total reduction in reservoir during last 63 years will be 562 Mm3, which results in average reduction in storage capacity as 8.92 Mm3/year. All the details regarding sediments of Upper - Helmand river basin is given in Table - 8 and Table - 9 for 35 years.

Table 8 Soil Erosion and Sediment yield from Upper - Helmand Catchment of 35 years

Year	Rainfall (mm)	R	K	LS	C	A tons/ha /year	A x 106 ton	Reservoir Capacity in x 106 m3	Annual Inflows in x 106 m3	(C/I)	Te	SDR	Net Sediment ton x106	Net Sediment x 106 m3
1979	371.14	185.57	0.0205	4.32	0.3872	6.37	29.80	1844.00	11340.05	0.16	0.91	0.54	14.65	9.76
1980	391.47	195.74	0.0205	4.32	0.3872	6.72	31.44	1844.00	12087.65	0.15	0.90	0.54	15.28	10.19
1981	326.90	163.45	0.0205	4.32	0.3872	5.61	26.25	1844.00	9451.49	0.20	0.93	0.54	13.18	8.79
1982	640.02	320.01	0.0205	4.32	0.3872	10.98	51.40	1844.00	23244.90	0.08	0.85	0.54	23.59	15.73
1983	435.77	217.89	0.0205	4.32	0.3872	7.48	34.99	1844.00	13280.49	0.14	0.88	0.54	16.63	11.09
1984	388.05	194.02	0.0205	4.32	0.3872	6.66	31.16	1844.00	12107.97	0.15	0.90	0.54	15.14	10.10
1985	256.67	128.33	0.0205	4.32	0.3872	4.40	20.61	1844.00	6609.23	0.28	0.94	0.54	10.46	6.97
1986	417.26	208.63	0.0205	4.32	0.3872	7.16	33.51	1844.00	12897.69	0.14	0.87	0.54	15.74	10.49
1987	313.74	156.87	0.0205	4.32	0.3872	5.38	25.19	1844.00	9156.21	0.20	0.92	0.54	12.52	8.34
1988	347.23	173.62	0.0205	4.32	0.3872	5.96	27.88	1844.00	10261.44	0.18	0.91	0.54	13.70	9.13
1989	395.61	197.81	0.0205	4.32	0.3872	6.79	31.77	1844.00	13230.14	0.14	0.88	0.54	15.10	10.06
1990	426.92	213.46	0.0205	4.32	0.3872	7.33	34.28	1844.00	13665.17	0.13	0.88	0.54	16.29	10.86
1991	636.68	318.34	0.0205	4.32	0.3872	10.93	51.13	1844.00	22406.25	0.08	0.85	0.54	23.47	15.64
1992	514.39	257.19	0.0205	4.32	0.3872	8.83	41.31	1844.00	17859.16	0.10	0.87	0.54	19.41	12.94
1993	310.25	155.13	0.0205	4.32	0.3872	5.32	24.91	1844.00	9115.93	0.20	0.94	0.54	12.65	8.43
1994	329.71	164.86	0.0205	4.32	0.3872	5.66	26.48	1844.00	23543.15	0.08	0.85	0.54	12.15	8.10
1995	336.23	168.11	0.0205	4.32	0.3872	5.77	27.00	1844.00	9941.43	0.19	0.91	0.54	13.27	8.85
1996	314.76	157.38	0.0205	4.32	0.3872	5.40	25.28	1844.00	8329.85	0.22	0.93	0.54	12.69	8.46
1997	408.75	204.37	0.0205	4.32	0.3872	7.01	32.82	1844.00	13407.84	0.14	0.87	0.54	15.42	10.28
1998	357.44	178.72	0.0205	4.32	0.3872	6.13	28.70	1844.00	10376.36	0.18	0.90	0.54	13.95	9.30
1999	201.87	100.94	0.0205	4.32	0.3872	3.46	16.21	1844.00	4459.59	0.41	0.96	0.54	8.40	5.60
2000	144.10	72.05	0.0205	4.32	0.3872	2.47	11.57	1844.00	2184.08	0.84	0.97	0.54	6.06	4.04
2001	93.66	46.83	0.0205	4.32	0.3872	1.61	7.52	1844.00	981.04	1.88	0.98	0.54	3.98	2.65
2002	217.04	108.52	0.0205	4.32	0.3872	3.72	17.43	1844.00	5341.83	0.35	0.96	0.54	9.03	6.02
2003	245.03	122.51	0.0205	4.32	0.3872	4.20	19.68	1844.00	6341.25	0.29	0.94	0.54	9.99	6.66
2004	254.13	127.07	0.0205	4.32	0.3872	4.36	20.41	1844.00	6267.65	0.29	0.94	0.54	10.36	6.91
2005	371.66	185.83	0.0205	4.32	0.3872	6.38	29.85	1844.00	10480.99	0.18	0.91	0.54	14.67	9.78
2006	359.78	179.89	0.0205	4.32	0.3872	6.17	28.89	1844.00	10900.13	0.17	0.91	0.54	14.20	9.46
2007	357.64	178.82	0.0205	4.32	0.3872	6.14	28.72	1844.00	10973.15	0.17	0.91	0.54	14.11	9.41
2008	291.61	145.81	0.0205	4.32	0.3872	5.00	23.42	1844.00	7416.24	0.25	0.94	0.54	11.89	7.92
2009	417.32	208.66	0.0205	4.32	0.3872	7.16	33.51	1844.00	13856.27	0.13	0.87	0.54	15.74	10.50
2010	343.64	171.82	0.0205	4.32	0.3872	5.90	27.60	1844.00	9976.54	0.18	0.91	0.54	13.56	9.04
2011	435.03	217.52	0.0205	4.32	0.3872	7.47	34.93	1844.00	12852.19	0.14	0.87	0.54	16.41	10.94
2012	488.98	244.49	0.0205	4.32	0.3872	8.39	39.27	1844.00	14675.00	0.13	0.88	0.54	18.66	12.44
2013	370.97	185.49	0.0205	4.32	0.3872	6.37	29.79	1844.00	10264.58	0.18	0.91	0.54	14.64	9.76
2014	532.05	266.02	0.0205	4.32	0.3872	9.13	42.72	1844.00	14164.27	0.13	0.87	0.54	20.07	13.38

R = Rainfall Erosivity Factor

K = Soil Erodibility Factor

LS = Topographic Factor

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SDR = Sediment Delivery Ratio

CP = Crop Management and Soil Conservation Practice Factor A = Average Soil Loss

C/I = Reservoir Capacity Inflow Ratio

Te = Trap Efficiency

V. CONCLUSION

5.1. Morphometric Analysis

- ✓The maximum order of the Upper - Helmand is found as eight with the basin length as 590 km. Area covered by Upper - Helmand River Basin is 46793 km2 and Perimeter is 1762 km.
- ✓Bifurcation ratio of Upper – Helmand river basin is 4.230 which indicate normal category basins and good structural control within the drainage.
- ✓The Circulatory ratio of the basin is 0.19 which indicates elongated shape of basin with highly permeable soil Strata with low runoff.
- ✓Drainage Density is obtained as 0.61 which indicates moderate drainage texture and the basin area is large and of low permeable sub-soil.
- ✓The Elongation ratio is found as 0.41 for the Upper - Helmand river basin which shows as an elongated basin and low runoff.

5.2. Runoff Estimation

- ✓ As per the growing five days' rainfall, a composite curve number of whole catchment is estimated as AMC III with its numerical value as 89.10.
- ✓ The present drainage basin is un-gauged, for which runoff rainfall relationship has been developed (Eq. 14) using SCS-CN method along with Arc-GIS 10.3.

5.3 Soil Erosion and Sediment Yield

- ✓ In the present study, USLE model, GIS and RS have been used to estimate soil erosion.
- ✓ The quantity of average annual soil erosion is estimated as 19.4 Mm3/year and the sediment trapped in the Kajaki reservoir is as 8.92 Mm3 /year which is validated by a sedimentation survey carried out by Whitney in 2006.

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