Modeling Surface Runoff Path and Soil Erosion in Catchment Area of Hanp River of District Kabeerdham, CG, INDIA, Using GIS

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Abstract- Modeling of runoff path and soil erosion potential estimation is significantly important for its economic and environmental impacts. A very precise model can give a very good understanding of soil erosion complexities in study area. The amount of soil erosion is associated with many natural climatic conditions. To measure such conditions Universal soil loss equation (USLE) has been used in the study area. In present study five controlling factors i.e. rainfall erosivity factor (R), Length slope factor (LS), soil erodability factor (K), vegetation cover factor (C) and erosion control factor (P) has been calculated for the measurement of soil erosion.

GIS (Geographical Information System) is very useful tool for processing with the available datasets. The present study has been made for a total area of 1175 Sq KM in and around Kabeerdham District, this includes Kawardha, Pandariya and Bodla administrative blocks. Hanp and Phonk are main rivers in which Hanp is longest river. Runoff network and erosion potential zones were identified under this study.

The Observations showed that most of area is of low erosion potential zone with having low slope gradient and some hilly area is showed higher erosion potential caused by higher slope inclination. Study describes that GIS is a efficient tool in modelling of surface runoff path and for estimation of soil erosion potentials.

Index Terms- Geology, GIS, Hydrogeology, Runoff and USLE.

I. INTRODUCTION

The surface water run-off path complex drainage network, the type of soil and infiltration ratio on precipitation occurrences affect the hydrological run-off of water. The study has been done for an area of 1175.5 square KM. The study area is having tropical climate, where weathering is dominant process of land sculpturing, drainage consist an important element of the surface geodynamics. The Kabeerdham district is bounded by hills in the western part. The general slope direction is towards south-east. The main objective of the present study is to model run-off path and soil erosion potentials using USLE based algorithm. The Universal soil loss equation (USLE) is an empirical formula which calculates 'Annual soil erosion potential'. It requires various Factors such

as Topographic factor, Rainfall erosivity factor, Soil Erodability factor, Cover management factor and Support practice factor. Many authors have been reported that soil erosion potentials can be analyze using USLE method.[1], [2], [3], [4], [5].

First pioneer of this field R. E. HORTON [6] had introduced modern approach of quantitative analysis of morphology of drainage basins. It was suggested that a geometric relationship existed between the numbers of stream segments in successive stream orders by the Horton's law of stream lengths. [6] The law of basin areas indicated that the mean basin area of successive ordered streams formed a linear relationship when graphed.

Run-off modeling requires surface slope information for the calculation of topographic factor which affect the rate of runoff on the surface. Calculation of surface run-off also requires study of entire basin. The basin morphology is measure of fluvial process operations in the basin. The Morphometric techniques through statistics, remotes sensing and GIS are becoming more and more useful to a geomorphologist to analyze the land as an open system[6]. Morphological analysis of the drainage basin has importance in the Geomorphological studies. A river channel adjusts its size to accommodate the channel forming flows. The adjustment of the stream channel area reflected in its Morphometry. Study of Geology, Geomorphology and Environment of area helps in administrative decision.

II. EXPERIMENTAL DETAILS, MATERIAL AND METHODS:

Date used in the study: The data used in the present study are CartoSAT-1 Stereo images, CARTOSAT-1 DEM of 30 Meter resolution(Source-NRSC), Soil Texture map and Google satellite images.

Software used in the study: ArcGIS 10.3 Desktop.

Method and Concept: Surface run-off/Overflow is a function of infiltration and surface flow of water in response of

precipitation occurrences. With available information of natural precipitation and topographic slope gradient it is possible to calculate the surface run-off path. For calculation of the path ArcGIS 10.3 software was used. In the ArcGIS software, ArcModels were constructed to extract the 'Triangulated Irregular Network' (TIN), Digital Terrain Model (DEM) and Drainages.

The Cartosat-1 is having stereo imaging and 2.5 meter Grid Resolution which is used for generation of surface digital elevation model.

Flow path extraction: Arc models were constructed for the processing on DEM for generation of Flow direction, Flow accumulation, slope, pour points and drainage lines. Extracted drainage network represent the major path of the water flow in the surface.

Soil Erosion Potential: The soil erosion potential of any area depends upon the various agents / factors. For calculation of soil erosion potential zones in study area USLE method has been used. Preparation of USLE based map conclude calculation of various Factors such as Topographic factor, Rainfall erosive factor, Soil Erodability factor, Cover management factor and Support practice factor using empirical formulas.

The Universal Soil Loss Equation (USLE) computes the average soil loss per unit area. USLE are defined as:

$$A = R \times K \times LS \times C \times P$$

Where: A = Average annual soil erosion potential, R = Rainfall erosivity (R) factor, K = Soil erodability (K) factor, L and S = Topographic (LS) factor, C = Cover Management (C) Factor, P = Support Practice (P) Factor.

Topographic (LS) factor: The L and S Factor represent the effects of slope length (L), and slope steepness (S) on the erosion of a slope. The combination of the two factors is commonly called the "topographic factor". The influence of terrain on erosion is represented by length slope factor which reflects the fact that erosion increases with slope angle and slope length. Cartosat-1 DEM (30 m) resolution is used to calculate LS factor. Steeper the slope more will be the loss of soil. Length factor (L) and slope factor (S) according to smith were calculated, and it is shown in Figure 2 as Topographic factor (LS). [7]

The LS factor was calculated using following expression:

$$LS = (\sqrt{(L/22)(0.065+0.045) S} + 0.0065 * S^2)/1$$

Where, L = slope length (m) fixed to 30 meters and S = slope steepness (radians).

Support Practice (P) Factor: It is the ratio of soil loss with specific support practice to the corresponding loss with up and slope tillage. The factor is an expression of the effect of specific conservation practice in soil such as contouring strip cropping, terracing and subsurface drainage. These practices affect erosion by modifying the flow pattern, grade or direction of the surface runoff and by reducing the amount and rate of runoff The P value for the study area ranging from 0.1 to 1.0. The landuse and Landcover (LULC) map of the study area is used for the calculation of the P – factor by assigning values of P-factor to each of LULC class. [7] Table 2.

Cover Management (C) Factor: It is the ratio of soil loss from an area with specified cover and management tot that from an identical area in tilled continuous fellow. Vegetation cover and management data is determined with the help of LULC map obtained from LANDSAT imagery. Table 2 shows C factor value obtained from past researches and C factor map is shown in Figure 2 (C-Factor Map). The value of C factor in study area varies from 0.0 to 0.4.

Rainfall erosivity (R) factor: R factor is an erosion index in MJ.mm/(ha.hr.year) [5]. R factor is determined for selected rain gauge station of study area from following equation:

$$R = P \times 0.5$$

Where, P=Mean annual rainfall in mm and R = rainfall erosivity factor in MJ/ha.mm/h. Mean annual rainfall data of area is obtained from CGWB website. The rainfall erosivity value is higher on the location where rainfall intensity is high and vice versa [7]. R-factor map is shown in Figure 2 (R-Factor).

Soil erodability (K) factor: It is depends upon organic matter, soil texture and soil structure. The total volume of potassium dichromate used to oxidize the organic matter in the soil and the volume of organic matter present in the oven dried sample is determined. Soil erodability (K) of the study area was calculated using the relationship between soil texture class and organic matter content proposed by stone and hillborn [8] and also Wischmeier et al. [1]. Soil texture class and K-factor values relation is given in the Table 3 for this study area. K-Factor map is shown in the Figure 2 (K-factor).

USLE Calculation: USLE analysis includes R factor, K factor, LS factor, C factor and P factor values. The average annual soil erosion potential (A) is computed by multiplying the developed raster data from each USLE Analysis as follows:

$$(A = R \times K \times L \times S \times C \times P)$$

A is the resultant USLE output in tons/hectate/year.

The output of USLE has been classified in various erosion classes by categorizing USLE values. **Error! Reference**

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Entire process was encapsulated using ArcGIS models and Python script for its automation. Python script has been used for the categorization of the USLE result in various desirable numbers of classes according to the potential zones.

III.   RESULTS OR FINDING:

R factor is ranging from 600 to 700 units. It is showing that the area is significantly affected by moderate rainfall. The average rainfall occurrence is around 1000 mm to 13500 mm in this study area source: CGWB (Central Ground Water Board).

Soil Erodability (K) is found variable, and it is ranging from 1.0 to 0.24, most of the higher value are in the low land areas. Soil type is changing from hilly area to low land areas, and hence the variation observed in soil erodability class.

Topographic Factor (LS) is observed in between 1 to 7 and hence some of its region is steeply sloping and some of its area is gently sloping.

Landcover management factor (C) observation in area shows variation in between 0 to 0.4 which is showing terrain is mostly agriculture.

Support practice factor is observed in the study area and it is ranging in between 0.1 to 1.0 which shows that in some places support practices have been presented and hence erosion activity is affected.

Average annual soil erosion potential (A) has been calculated, which is observed in between 0 to 130. A is the resultant USLE output in ton/ha/year. The average erosion potential (or Soil loss) of the study area is **0.1819 ton/ha/year**. The range of USLE is showing that some hilly area and some river or drainage/stream associated location are highly erosive. USLE based various erosion classes are categorized in **Error! Reference source not found.**. USLE results showed that area is significantly under natural erosion process and losing soil.

Higher category code in table 1 shows higher erosion rate and lower values shows lower erosion rate. Using these map engineers can plan soil and water conservation structure in the higher erosion prone areas.

Table 1 USLE based erosion potential measurements of study area.

Potential Range (ton)	Area (In Hectare)	Tons/Hectare/Year
0 to 10	830046900	0.01369863
10 to 20	110330500	0.02739726
20 to 40	85525100	0.082191781
40 to 60	36891400	0.136986301
60 to 80	21016500	0.191780822
80 to 120	24032300	0.273972603
> 120	67667600	0.547945205

Table 2 Landuse & Landcover class based C-Factor and P-factor Values from empirical studies (source: Devatha et al [5]).

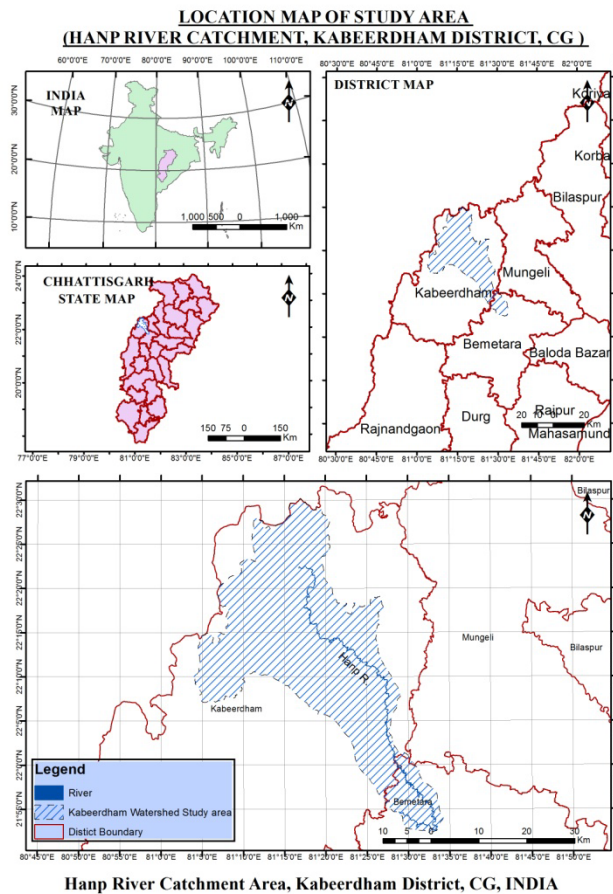| Landuse class codes	C factor values	P factor values
AGCR	0.34	0.4
BUMN	0.2	1
BURH	0.2	1
BURU	0.2	1
BURV	0.2	1
BUUC	0.2	1
BUUP	0.2	1
FRDE	0.001	0.1
WBCN	0	0.5
WBLP	0	0.5
WBRS	0	0.5
WBRT	0	0.5
WBSA	0	0.5
WLBR	0.4	1
WLSD	0.001	0.1
WLSP	0.4	1
WLWL	0.4	1

Figure 1 Location map of Hanp River Catchment Area with district boundaries.

Table 3 Soil Texture based K Factor (source: stone and hillborn [8] and Wischmeier et al. [1].)

| Textural Class	K Factor		
	tonnes/hectare (tons/acre)		
	Average OMC*	Less than 2% OMC	More than 2% OMC
Clay	0.49 (0.22)	0.54 (0.24)	0.47 (0.21)
Clay loam	0.67 (0.30)	0.74 (0.33)	0.63 (0.28)
Coarse sandy loam	0.16 (0.07)	–	0.16 (0.07)
Fine sand	0.18 (0.08)	0.20 (0.09)	0.13 (0.06)
Fine sandy loam	0.40 (0.18)	0.49 (0.22)	0.38 (0.17)
Heavy clay	0.38 (0.17)	0.43 (0.19)	0.34 (0.15)
Loam	0.67 (0.30)	0.76 (0.34)	0.58 (0.26)
Loamy fine sand	0.25 (0.11)	0.34 (0.15)	0.20 (0.09)
Loamy sand	0.09 (0.04)	0.11 (0.05)	0.09 (0.04)
Loamy very fine sand	0.87 (0.39)	0.99 (0.44)	0.56 (0.25)
Sand	0.04 (0.02)	0.07 (0.03)	0.02 (0.01)
Sandy clay loam	0.45 (0.20)	–	0.45 (0.20)
Sandy loam	0.29 (0.13)	0.31 (0.14)	0.27 (0.12)
Silt loam	0.85 (0.38)	0.92 (0.41)	0.83 (0.37)
Silty clay	0.58 (0.26)	0.61 (0.27)	0.58 (0.26)
Silty clay loam	0.72 (0.32)	0.79 (0.35)	0.67 (0.30)
Very fine sand	0.96 (0.43)	1.03 (0.46)	0.83 (0.37)
Very fine sandy loam	0.79 (0.35)	0.92 (0.41)	0.74 (0.33)

*OMC- Organic Material Content in Percentage.
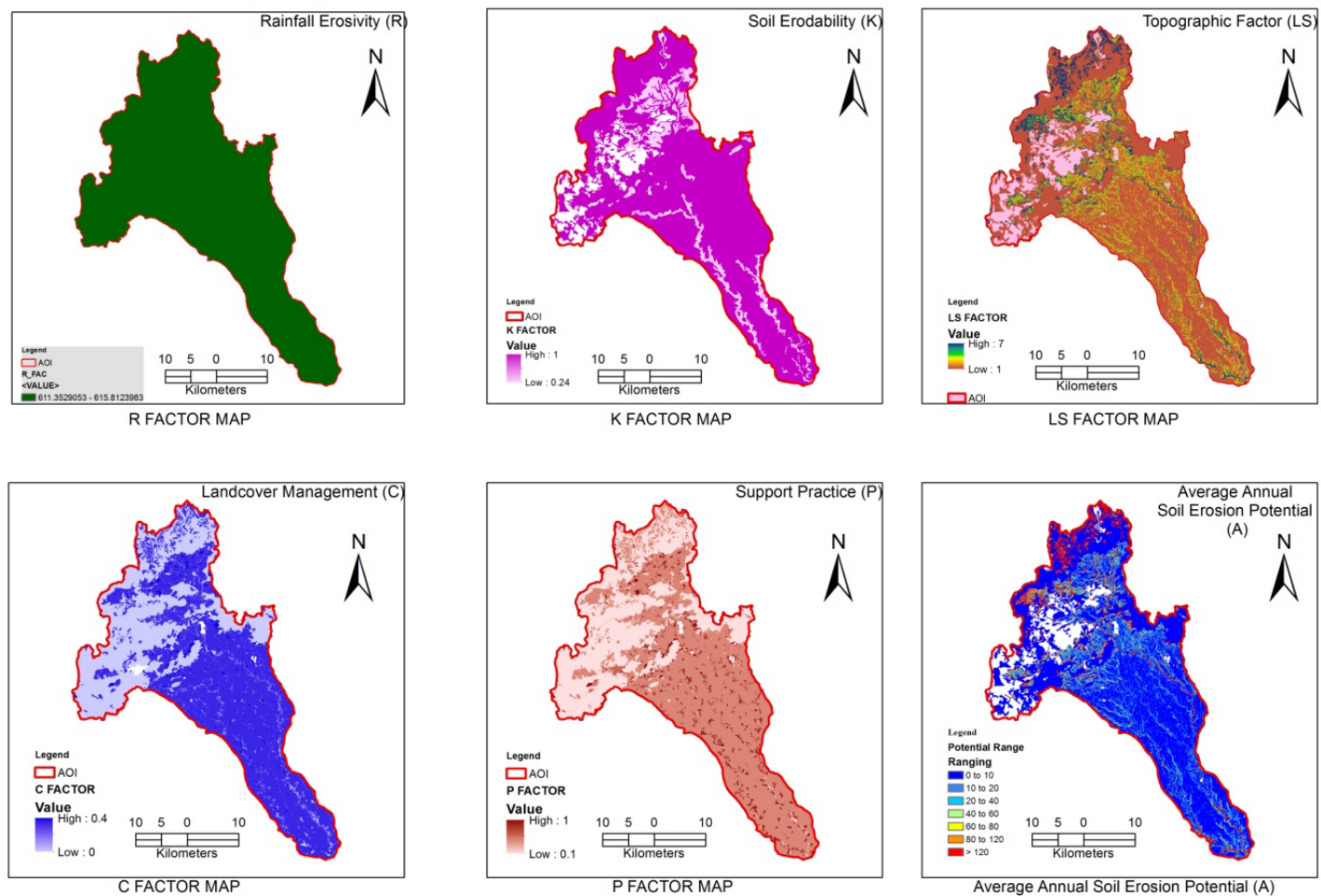
Figure 2 Universal Soil Loss Equation output maps of studied area.

IV. CONCLUSION:

GIS and Remote Sensing techniques are efficient tool in modeling surface runoff path and soil erosion potential classes/zones. Study proves that GIS technology is implementable in local terrain of Kabeerdham District for Modeling Runoff path and Soil Erosion in Catchment Area. The complexities presented in terrain makes it difficult for in point of its feasibility for manual survey for calculation of soil erosion potential and runoff. Adapted methodology follows USLE calculation is proving its capacity for modeling soil erosion potential areas and run-off path for surface water flow.

V. ACKNOWLEDGMENT

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