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# Geo-Environmental Evaluation for Exploring Potential Soil Erosion Areas of Jainti River Basin Using AHP Model, Eastern India

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## Abstract:

**This work aimed to explore soil erosion susceptibility zones of Jainti River basin, which is the 6th order tributary of Ajay River. A total of ten geo-environmental parameters i.e. land use and land cover, geomorphology, slope, drainage density, elevation, lineament, length of overland flow, vegetation cover, soil type and relative relief was selected based on collinearity statistics. Individual factor weights ($F_i$) and their sub-class weights ($V_i$) was calculated based on Analytical Hierarchical Process (AHP) and summed up for producing a map of spatial soil erosion vulnerability. The result reveals that 19.97% (108.97 km$^2$) of the study area, mainly the upper and middle parts of the catchment areas face highly to severe soil erosion problems due to higher elevation, slope and relief, lack of vegetation cover, existence of badland features. The accuracy of the result assessed through ROC (Receiver Operating Characteristic) curve. The Area Under Curve (AUC) is 0.771 resembles to the prediction correctness of 77.1%. It is concluded that this model is very useful for further planning regarding soil erosion problem and replacement of the quality of land in sustainable way.**

**Keywords:** Collinearity; AHP Model; Soil Erosion Susceptibility Map (SESM); Receiver Operating Characteristic (ROC); Area Under Curve (AUC)

## 1.0 Introduction:

Soil erosion caused by water is a quasi-natural environmental phenomenon, has an adverse impact on ecosystem, biological, physical and chemical properties of soil. In these days, soil erosion is one of the serious environmental problems that threatens the world by decreasing the intensity of agricultural production through losing the top soil and nutrients from the soil (Hoyos, 2005; Hlaing et al., 2008; Arekhi et al., 2010; Prasannakumar et al., 2011a, 2011b, and 2012). Soil erosion by water may categorise as one of the serious environmental phenomenon as it lessens the top soil fertility effecting agricultural production and vegetation cover (Shrestha, 1997; Angima et al., 2003). In Asia, a rate of 29.95 t/ha/y of soil erosion denoted indicating a severe risk and a need of management (El-saify, 1994) and Asian rivers contributes enormous production of sediment (about 80%) to the world oceans (Stoddart, 1969). According to information furnished by the Ministry of Agriculture, Govt. of India, in 1980, more or less 53% of India's total geographical area is impacted by environmental degradation due to loss of land quality (CSE, 1982). Therefore, at present, soil degradation and its sustainable management is a burning issue for addressing attentively. The Jainti River basin is the eastern edge of Chhotonagpur plateau of Eastern India with highly rippled and rugged topography, and is classified as highly prone to erosion. Therefore, assessment of soil erosion risk is important for identifying areas exposed to severe erosion and in order to launch proper land management programmes. Such types of assessment in inadequate data situations, geo-environmental and hydro-geomorphologic characteristics pertaining to basin oriented or catchment approach are found to have good predictability (Chorley, 1969; Jha and Kapat, 2009; Jha and Paudel, 2010). So, logical and systematic assimilation of the erosion driven parameters is a significant tool in this context. Application of Remote Sensing (RS) and Geographical Information System (GIS) can make the analysis more appropriate. The field based methods of soil loss quantification and spatial variation are time and cost consuming and lack of sufficient sampling plots may constrain the reliability of actual spatial extent of area under soil erosion. Therefore, monitoring and accurate mapping the spatial pattern of soil loss over a large area is really difficult owing to the time and cost involved in this traditional field based method (Lu et al., 2004; Chen et al., 2010). Soil erosion susceptibility zones can be charted out with the deployment of diverse numerical and geospatial technologies by means of various methods and models. A range of methods and techniques used for the susceptibility appraisal and quantification of soil loss can be found in Dabral et al. (2008), Lal (1994), Ni and Li (2003), Lee (2004), Rahman et al. (2009), Zhang et al. (2009), Kim et al. (2012), Vijith et al. (2012), Khosrokhani and Pradhan (2013), Naqvi et al. (2013), Rozos et al. (2013) and Gayen and Saha (2017). The AHP based techniques were used in many studies in earth system sciences, particularly in landslide and soil erosion susceptibility assessment, site suitability analysis and groundwater studies (Wu et al., 2007; Pourghasemi et al., 2012; Chandio et al., 2012; Althuwaynee et al., 2014; Fattahi et al., 2014; Molina-Navarro et al., 2014; Pazand et al., 2012; Yang et al., 2013).

In the current swot, an attempt has been made to evaluate the erosion susceptibility of river Jainti using the Analytical Hierarchy Process (AHP) and collinearity statistics through the application of Remote Sensing (RS) and Geographical Information System (GIS). The outcome of the work may be beneficial to decision makers for supportive policy formulation for sustaining environment as well as land efficiency.

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**1.1 Geographical Setting of the Study Area:**

Jainti River is a $6^{th}$ order tributary of Ajay River draining through the lateritic eastern part of Chhotonagpur plateau in the Deoghar district of Jharkhand. The length of main water channel is about 49.14 km with a catchment area of 542.69 $km^2$ extends from 24º 5' 56" N to 24º 17' 52" N latitudes and from 86º 23' 19" E to 86º 47' 49" E longitudes (Fig. 1). The river basin comprises of five of $5^{th}$ order, 17 of $4^{th}$ order, 90 of $3^{rd}$ order, 440 of $2^{nd}$ order, 1884 of $1^{st}$ order streams according to Strahler's stream ordering and includes two main sub-watersheds i.e. Dilia and Baghdaru River. The climate of the catchment area varies from sub-tropical to sub-humid experiencing dry hot summer (March to May) and heavy rains in monsoon (June to September)followed by cool dry winters (October to February). Mean annual rainfall is 1239 mm. Mean minimum temperature in winter is 8 °C, while mean maximum temperature in summer is 43 °C. Geomorphologically, the area is a denudational plateau with irregularly distributed denudational dissected hills and valleys. This area belongs to part of the Chhotonagpur plateau with an average elevation of 270 m above mean sea level (MSL) and the direction of slope in general is from north-west to south-east. The watershed consists of moderate to steep slope tracts, isolated flat topped small hills and rugged land surfaces. Overall, the slopes are gradual which lead to development of terraced paddy fields. This basin area consists of granitic gneissic rock of Pleistocene age overlaid by weathered lateritic regolith according to Geological Survey of India report in 1985. The whole study area covered with primary lateritic and denudated laterite. Texturally loamy skeletal fine loamy and soils are major types of soil in this part (Fig. 3j). In the context of land cover, the amount of vegetation is very low as revealed by the land use/land cover classification (about 4.16% of the total area), quantitatively the amount of barren land (14.78%) and fallow lateritic tract (26.16%) is high. This reveals that these areas are open and exposed to erosion by surface runoff and overland flow which can be trigger up with the geo-environmental settings. This erosive nature of catchment area justified and makes a point of interest of this study

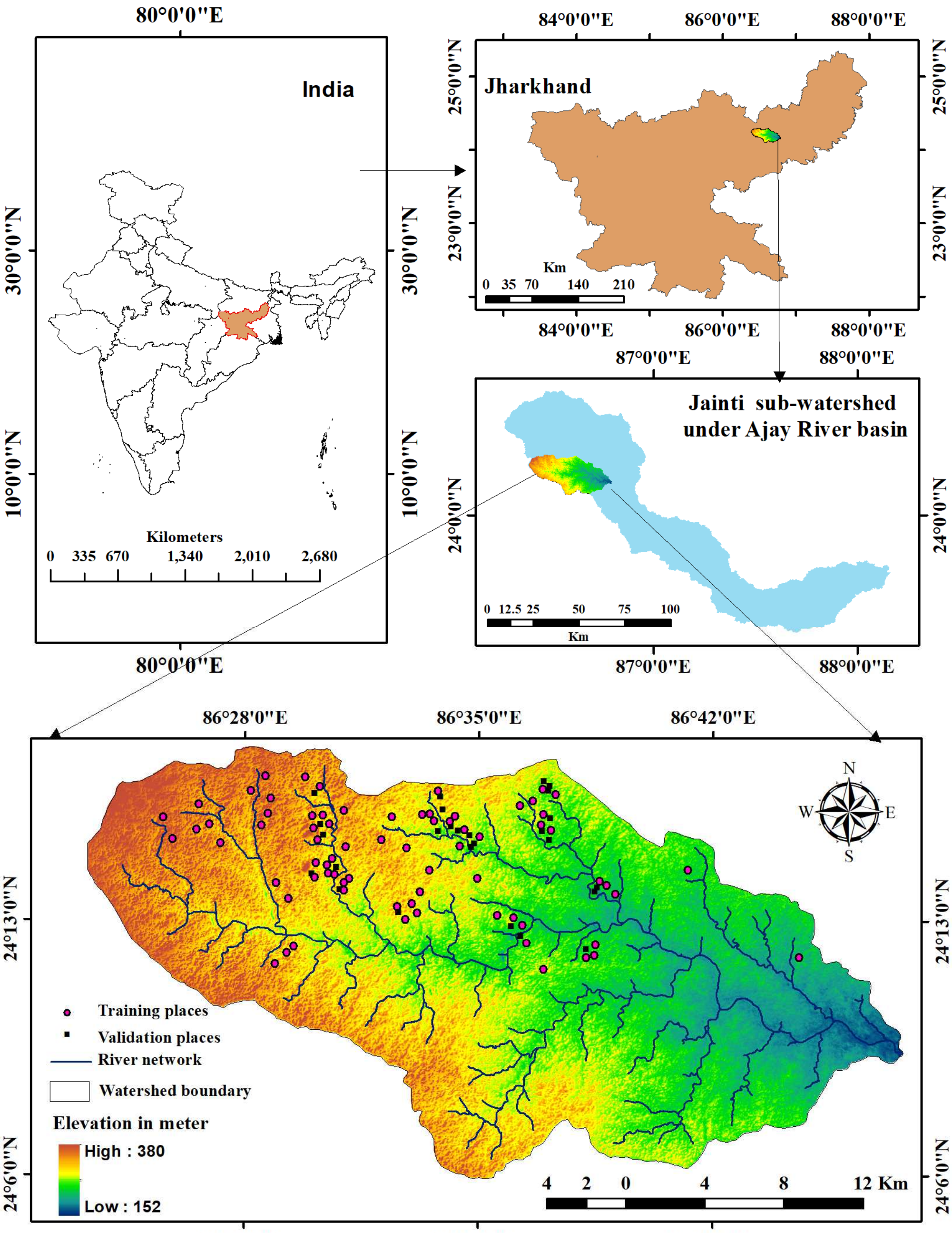


**Figure 1:** Location of the Jainti River basin

## 2.0 Materials and Methods:

### 2.1 Data Used and Analysis:

**Table 1:** Sources and types of different data layers

| Data | Sources | Type and time/period |
|---|---|---|
| Drainage network | Survey of India (SOI), Topographical sheets no. 72L/7, 72L/8, 72L/11, 72L/12, 72L/15 and 72L/16 | Scale 1:50000; published in 1979-1984. |
| Digital elevation model | ASTER GDEM version. 2 http://gdem.ersdac.jspacesystems.or.jp/ | October, 2011; Spatial resolution 30m |
| Satellite images | Landsat8 OLI/TIRS https://landsat.usgs.gov/ | 12th June 2016, spatial resolution 30 m. Path/row- 140/43 |
| Geomorphology | http://bhuvan5.nrsc.gov.in/bhuvan/wms | Scale 1:50000; December, 2011 |
| Rainfall data | www.imd.gov.in/ | From year of 1982 to year 2016 |
| Soil type | State Agriculture Management and Extension Training Institute (SAMETI, Jharkhand) | Scale 1:250000 |

**Table 2:** Formulas and methods used in the study for calculation of the different parameters

| Parameter | Formula/ Method | References |
|---|---|---|
| Drainage density ($D_d$) | $D_d = \sum L\mu / A$ where $\sum L\mu$ is the total length of stream segments of all orders<br>$A$ = area of the basin/grid in km$^2$ | Horton (1932) |
| Relative relief ($R_r$) | $R_r = (RMax - RMin)$, where $RMax$ = relief maximum; $RMin$ =relief minimum | Smith (1935) |
| Length of overland flow $(L_o)$ | $L_o = 1/2D_d$ ,where $D_d$ = drainage density of the basin/grid | Horton (1945) |
| NDVI | $NIR - R / NIR + R$ ,where<br>$NIR$ = digital number of Near Infrared band and $R$ = digital number of Red band | Carlson & Ripley (1997) |

Soil erosion susceptibility assessment of an area be influenced by various aspects such as climate, topography, geology, land use/land cover, slope distribution etc. (Rahman and Saha, 2008). Centred on geo-environmental scenario the investigations have been started after collection of the required datasets (Table 1). Selection of parameters in the study has been done through field survey, literature review and expert's judgement. Based on dominance over the catchment and collinearity analysis, ten geo-environmental aspects employed in the present analysis. Table 2 shows the formulas used in the study. For assessing the ground fact and application of the study, the statistical analyses have been conducted using the statistical software SPSS 22 and MS Excel 2007.

### 2.2 Application of Analytical Hierarchy Process (AHP):

The present study involves identifying and mapping of the erosion threatened areas using Analytical Hierarchical Process (AHP). AHP is a semi-quantitative approach where decisions are taken through hierarchical analysis of associated variables by assigning numerical score through pairwise comparison which represents the importance of every individual factor (Saaty, 1977; Saaty and Vargas, 2001; Maity and Mandal, 2017). At first, this approach includes decomposition of the decision making problem into a hierarchy of criteria and alternatives. Then preference values are assigned to each factor according to importance scale of AHP (Table 4) to determine the relative importance in connection with the goal (Saaty, 1977; Saaty and Vargas, 2001). After that, the comparison matrix of the criteria can be set up as following (Equation. 1)

$$A = \begin{matrix} a_{11} & a_{12} & a_{13} & a_{1n} \\ a_{21} & a_{22} & a_{23} & a_{2n} \\ \ldots & \ldots & a_{ij} & \ldots\ldots\ldots \\ a_{n1} & a_{n2} & a_{n3} & a_{nn} \end{matrix} \quad (1)$$

where

$$a_{ij} = \frac{Wi}{Wj} = \frac{\text{weight for attribute i}}{\text{weight for attribute j}}$$

The next procedure is to assign priority weights for every factor through computation of normalised eigenvector, which is very popular method for calculating preferences from inconsistent pairwise comparison matrices (Saaty, 1990). The weights are derived by summing up the values in each column of pairwise comparison matrix and each cell value is divided by the summed values of the same factors column. The average value of each row is the primary eigenvector of the matrix. As this matrix was randomly prepared, for this reason, some degrees of inconsistency may occur (Saaty, 1980; Saaty, 1994). The consistency ratio is calculated on the basis of Equation (2):

$$CR = CI / RI \quad (2)$$

where CI is the Consistency Index and RI is the Random Index (Table 3). Inclusion or exclusion of a variable in the investigation depends on the value of consistency ratio. The value of CR should remain lower than or equal to 0.1 (Saaty, 1980). CI reflects the consistency of one's judgement. CI can be calculated by following Equation (3):

$$CI = \lambda Max - n / n - 1 \quad (3)$$

where n is the order of the matrix, λMax is the largest eigenvalue.

In this analysis considering the identification of soil erosion areas as a decision goal, importance of ten geo-environmental criteria i.e. land use / land cover, geomorphology, slope, drainage density, elevation, lineament, length of overland flow, soil type, vegetation cover and relative relief and sub-criteria (each class of the factors) has been analysed using this AHP methodology. Preference values of importance assigned to the factors and their sub-classes based on their distribution over the catchment and experts decision to build the comparison matrices. CR of each parameter was calculated for inclusion or exclusion in or from the study.

**2.3 Collinearity Diagnostics:**

In this study, primarily ten geo-environmental parameters such as slope, land use / land cover, relative relief, geomorphology, elevation, drainage density, length of overland flow, soil type, vegetation cover, and lineaments have been selected for predicting the result on the basis of collinearity statistics. In this context, it is important to say that amount of precipitation is very important driver of soil erosion, but there is no such significant spatial variation in rainfall amount in the study area. Multicollinearity or collinearity is a statistical method in which two or more explanatory variables in a multiple regression model are incorporated. This means that one can be predicted from the others with a degree of accuracy. The existence of multicollinearity estimates the impact of one variable on the dependent variable, while other factors tend to be less precise if the explanatory variables are uncorrelated with each other. Collinearity can be detected in different methods such as large changes in the estimated regression coefficient when an explanatory variable is added or removed. In this study, we have used a formal detection-tolerance or the Variance Inflation Factor (VIF) for multicollinearity (Equation 4 and 5).

$$Tolerance = 1 - R_j^2 \quad (4)$$

$$VIF = 1 / tolerance \quad (5)$$

where $R_j^2$ is the coefficient of determination of a regression of predictor (j) on all other predictors. A tolerance of less than 0.20 or 0.10 and/or a VIF of 5 or 10 and above indicates a multicollinearity problem (Asteriou et al., 2016; Saha, 2017). In the present analysis, Table 5 shows the tolerance and VIF of each factor within the limits indicating absence of collinearity problem. Considering the soil erosion susceptibility result as dependent variable and each of geo-environmental parameters as independent variable collinearity statistics calculated and examined for exclusion or inclusion of the factors from the analysis. It should be mentioned in this context that within this catchment there is no broad variation in rainfall distribution (Table 5). Therefore, this parameter is considered constant factor for erosion occurrence in this basin area as lateritic soil and high rainfall both trigger up the erosion process with presence of associate geo-environmental elements.

**Table 3:** Random inconsistency indices for n = 10 (Saaty, 1980)

| **n (**order of matrix) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| **RI** (Random Inconsistency value) | 0.00 | 0.00 | 0.58 | 0.9 | 1.12 | 1.24 | 1.32 | 1.41 | 1.46 | 1.49 |

**Table 4:** Scale of preference between two parameters in AHP (Saaty, 2001)

| **Scales** | **Degree of preference** | **Explanation** |
|---|---|---|
| 1 | Equally | Two activities contribute equally to the objective |
| 3 | Moderately | Experience and judgment slightly to moderately favour one activity over another |
| 5 | Strongly | Experience and judgment strongly or essentially favour one activity over another |
| 7 | Very strongly | An activity is strongly favoured over another and its dominance is showed in practice |
| 9 | Extremely | The evidence of favouring one activity over another is of the highest degree possible of an affirmation |
| 2, 4, 6, 8 | Intermediate values | Used to represent compromises between the preferences in weights 1, 3, 5, 7, and 9 |
| Reciprocals | Opposites | Used for inverse comparison |

**Table 5:** Collinearity statistics of the included parameters of the study area

| Model | | Collinearity Statistics | |
|---|---|---|---|
| | | Tolerance | VIF |
| 1 | (Constant) | | |
| | Elevation | 0.437 | 2.288 |
| | Drainage density | 0.531 | 1.883 |
| | Slope | 0.493 | 2.028 |
| | Relative relief | 0.425 | 2.351 |
| | NDVI | 0.601 | 1.664 |
| | Length of overland flow | 0.457 | 2.19 |
| | Lineament | 0.916 | 1.092 |
| | Geomorphology | 0.612 | 1.635 |
| | Land use/land cover | 0.505 | 1.978 |
| | Soil type | 0.439 | 2.012 |

**Table 6:** Annual average rainfall in mm. of last 35 years (1982-2106) recorded in the surrounding meteorological stations according to Indian Meteorological Department (IMD)

| Meteorological Stations | Geographical Location | Average Annual Rainfall in mm |
|---|---|---|
| Deoghar | 86°42'2.821"E / 24°28'56.213"N | 1252.71 |
| Dumka | 87°17'59.85"E / 24°23'40.214"N | 1294.25 |
| Giridh | 86°17'46.47"E / 24°11'45.782"N | 1247.75 |
| Dhanbad | 86°25'47.34"E / 23°47'29.439"N | 1319.57 |
| Bokaro | 86°8'50.654"E / 23°39'42.311"N | 1339.49 |

**2.4 Receiver Operating Characteristic (ROC):**

In statistics, Receiver Operating Characteristic curve, is a graphical plot that elucidates the analytical capability of a binary classifier system as its discrimination inception is varied. In the present analysis a total of 101 different patches mapped through ground investigation. These locations are categorised into two subsets i.e. training sub-set (74.25% of the data set) and validation sub-set (25.75% of the data set) through random partitioning method to construct the ROC curve. This is a widely used method for modelling and validating the accuracy of particular model (Jebur et al., 2014). Due to small size of patches were converted to point features in GIS. ROC curve plotted based on binary responses of these patches i.e. soil erosion presence and soil erosion absence, in terms of susceptibility. For this, a value of ‘1’ was assigned to the soil erosion points and a value of ‘0’ was assigned to the non-soil erosion points.

**2.5 Weighted Linear Sum Combination (WLCM) and Soil Erosion Susceptible Zones (SESZ):**

For necessary measures and steps against soil erosion, it is needed to demarcate the erosion prone areas according to degree of susceptibility. Therefore, after preparation of thematic layers of each parameter and assigning the individual factor weights ($F_i$) and their sub-class weights ($V_i$), spatial integration of all thematic layers has been done using the raster calculator tool of ArcGis 10.3.1 software. For giving weights, spatial occurrence of every parameter in the study area has been observed carefully. Following the AHP method weights are assigned to all the spatial factors. A CR value of <0.1 indicates an acceptable level of consistency in pair-wise comparison to recognise the weights applied. Table 8 shows the CR value of this study 0.027, justify the good level of consistency in pair-wise comparison. Similarly Table 7 depicts all the CR values of sub-classes are <0.1 signifies the recognition of assigned weights for them. Finally, using the obtained weights, a Weighted Linear Combination Model (WLCM) has been adopted for getting the soil erosion susceptibility zones (SESZ) of Jainti River basin in RS-GIS environment. The WLCM elaborated through the following equation (equation 6):

$$SESZ = \sum_{i=1}^{n} (V_i \times F_i) \quad (6)$$

where $V_i$ is the rating classes or weighted classes of each predisposing factor and $F_i$ is the weights for each predisposing factor of soil erosion.

**Table 7:** Pairwise comparison matrix, weights and consistency ratio of factors sub-classes ($V_i$)

| Parameter | Subclasses | Pair-wise comparison matrix | | | | | | | | | Weight |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | |
| Slope in degrees | <4 | 1.0 | 0.33 | 0.20 | | | | | | | 0.109 |
| | 4-8 | 3.0 | 1.0 | 0.50 | | | | | | | 0.309 |
| | 8-25.19 | 5.0 | 2.0 | 1.0 | | | | | | | 0.582 |
| Consistency ratio: 0.004 | | | | | | | | | | | |
| Relative relief in m/km$^2$ | 25-35 | 1.0 | 0.50 | 0.25 | 0.17 | | | | | | 0.074 |
| | 35-45 | 2.0 | 1.0 | 0.50 | 0.25 | | | | | | 0.138 |
| | 45-55 | 4.0 | 2.0 | 1.0 | 0.25 | | | | | | 0.275 |
| | 55-123 | 6.0 | 4.0 | 2.0 | 1.0 | | | | | | 0.513 |
| Consistency ratio: 0.004 | | | | | | | | | | | |
| Land use/ land cover | Dense vegetation | 1.0 | 0.50 | 0.50 | 0.33 | 0.33 | .25 | .2 | .17 | .14 | 0.026 |
| | Sand deposition | 2.0 | 1.0 | .50 | .33 | .33 | .25 | .25 | .20 | .17 | 0.033 |
| | Built-up area | 2.0 | 2.0 | 1.0 | .50 | .50 | .33 | .33 | .20 | .20 | 0.044 |
| | Scattered vegetation | 3.0 | 3.0 | 2.0 | 1.0 | .50 | .50 | .33 | .25 | .20 | 0.062 |
| | Agricultural land | 3.0 | 3.0 | 2.0 | 2.0 | 1.0 | .50 | .50 | .25 | .20 | 0.075 |
| | Agricultural fallow | 4.0 | 4.0 | 3.0 | 2.0 | 2.0 | 1.0 | .50 | .33 | .25 | 0.103 |
| | Water body | 5.0 | 4.0 | 3.0 | 3.0 | 2.0 | 2.0 | 1.0 | .50 | .33 | 0.137 |
| | Fallow land | 6.0 | 5.0 | 5.0 | 4.0 | 4.0 | 3.0 | 2.0 | 1.0 | .50 | 0.218 |
| | Barren land | 7.0 | 6.0 | 5.0 | 5.0 | 5.0 | 4.0 | 3.0 | 2.0 | 1.0 | 0.304 |
| Consistency ratio: 0.03 | | | | | | | | | | | |
| Drainage density in Km/km$^2$ | <1.5 | 1.0 | 0.50 | 0.25 | 0.17 | | | | | | 0.076 |
| | 1.5-3 | 2.0 | 1.0 | 0.50 | 0.33 | | | | | | 0.152 |
| | 3-3.5 | 4.0 | 2.0 | 1.0 | 0.50 | | | | | | 0.283 |
| | 3.5-5.35 | 6.0 | 3.0 | 2.0 | 1.0 | | | | | | 0.490 |
| Consistency ratio: 0.04 | | | | | | | | | | | |
| Elevation in m | 154-200 | 1.0 | 1.0 | 0.50 | 0.25 | 0.14 | | | | | 0.066 |
| | 200-230 | 1.0 | 1.0 | 0.50 | 0.25 | 0.17 | | | | | 0.069 |
| | 230-260 | 2.0 | 2.0 | 1.0 | 0.50 | 0.25 | | | | | 0.129 |
| | 260-290 | 4.0 | 4.0 | 2.0 | 1.0 | 0.50 | | | | | 0.259 |
| | 290-380 | 7.0 | 6.0 | 4.0 | 2.0 | 1.0 | | | | | 0.477 |
| Consistency ratio: 0.002 | | | | | | | | | | | |
| Geomorphology | Badlands | 1.0 | 2.0 | 5.0 | 2.0 | 3.0 | 4.0 | | | | 0.328 |
| | Denudational dissected hill | 0.50 | 1.0 | 5.0 | 3.0 | 4.0 | 5.0 | | | | 0.305 |
| | Structural hill | 0.20 | 0.20 | 1.0 | 0.33 | 0.50 | 0.25 | | | | 0.044 |
| | Karst origin | 0.50 | 0.33 | 3.0 | 1.0 | 3.0 | 2.0 | | | | 0.152 |
| | River | 0.33 | 0.25 | 2.0 | 0.33 | 1.0 | 0.50 | | | | 0.070 |
| | Plateau | 0.25 | 0.20 | 4.0 | 0.50 | 2.0 | 1.0 | | | | 0.101 |
| Consistency ratio: 0.054 | | | | | | | | | | | |
| NDVI | -0.20-0.13 | 1.0 | 2.0 | 3.0 | 5.0 | | | | | | 0.483 |
| | 0.13-0.15 | 0.50 | 1.0 | 2.0 | 3.0 | | | | | | 0.272 |
| | 0.15-0.18 | 0.33 | 0.50 | 1.0 | 2.0 | | | | | | 0.157 |
| | 0.18-0.45 | 0.20 | 0.33 | 0.50 | 1.0 | | | | | | 0.088 |
| Consistency ratio: 0.005 | | | | | | | | | | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Length of overland flow | <1 | 1.0 | 0.50 | 0.20 | | | | | | | 0.128 |
| | 1-1.5 | 2.0 | 1.0 | 0.50 | | | | | | | 0.276 |
| | 1.5-2.67 | 5.0 | 2.0 | 1.0 | | | | | | | 0.595 |
| Consistency ratio: 0.006 | | | | | | | | | | | |
| Lineament density/$km^2$ | <1 | 1.0 | 0.50 | 0.20 | | | | | | | 0.122 |
| | 1-2 | 2.0 | 1.0 | 0.33 | | | | | | | 0.230 |
| | 2-3.5 | 5.0 | 3.0 | 1.0 | | | | | | | 0.648 |
| Consistency ratio: 0.004 | | | | | | | | | | | |
| Individual factors | Slope | 1.0 | 2.0 | 2.0 | 2.0 | 2.0 | 3.0 | 5.0 | 5.0 | 5.0 | 0.232 |
| | Relative relief | 0.50 | 1.0 | 2.0 | 3.0 | 3.0 | 4.0 | 4.0 | 4.0 | 5.0 | 0.217 |
| | Land use/ Land cover | 0.50 | 0.50 | 1.0 | 2.0 | 2.0 | 3.0 | 4.0 | 5.0 | 5.0 | 0.162 |
| | Elevation | 0.50 | 0.33 | 0.50 | 1.0 | 1.0 | 2.0 | 2.0 | 3.0 | 4.0 | 0.099 |
| | Drainage density | 0.50 | 0.33 | 0.50 | 1.0 | 1.0 | 2.0 | 3.0 | 3.0 | 4.0 | 0.105 |
| | Geo-morphology | 0.33 | 0.25 | 0.33 | 0.50 | 0.50 | 1.0 | 2.0 | 3.0 | 4.0 | 0.072 |
| | NDVI | 0.20 | 0.25 | 0.25 | 0.50 | 0.33 | 0.50 | 1.0 | 2.0 | 3.0 | 0.049 |
| | Length of overland flow | 0.20 | 0.25 | 0.20 | 0.33 | 0.33 | 0.33 | 0.5 | 1.0 | 2.0 | 0.036 |
| | Lineament | 0.20 | 0.20 | 0.20 | 0.25 | 0.25 | 0.25 | .33 | .5 | 1.0 | 0.027 |
| Consistency ratio: 0.033 | | | | | | | | | | | |
| Soil type | Fine loamy soil | 1.0 | 0.25 | | | | | | | | 0.20 |
| | Loamy skeletal soil | 4.00 | 1.0 | | | | | | | | 0.80 |
| Consistency ratio: 0.000 | | | | | | | | | | | |

**Table 8:** Individual Factor weights ($F_i$) and their comparison matrix

| Data layers | Pairwise comparison matrix | | | | | | | | | | Weight |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| SLP | 1.00 | 2.00 | 2.00 | 3.00 | 3.00 | 3.00 | 3.00 | 4.00 | 4.00 | 5.00 | 0.227 |
| RR | 0.50 | 1.00 | 2.00 | 3.00 | 3.00 | 3.00 | 4.00 | 4.00 | 4.00 | 5.00 | 0.202 |
| LULC | 0.50 | 0.50 | 1.00 | 1.00 | 2.00 | 2.00 | 3.00 | 3.00 | 3.00 | 4.00 | 0.125 |
| ELEV | 0.33 | 0.33 | 1.00 | 1.00 | 2.00 | 3.00 | 3.00 | 3.00 | 4.00 | 5.00 | 0.131 |
| DD | 0.33 | 0.33 | 0.50 | 0.50 | 1.00 | 1.00 | 2.00 | 2.00 | 3.00 | 4.00 | 0.081 |
| SOIL | 0.33 | 0.33 | 0.50 | 0.33 | 1.00 | 1.00 | 1.00 | 2.00 | 2.00 | 3.00 | 0.068 |
| GEOM | 0.33 | 0.25 | 0.33 | 0.33 | 0.50 | 1.00 | 1.00 | 1.00 | 2.00 | 3.00 | 0.056 |
| NDVI | 0.25 | 0.25 | 0.33 | 0.33 | 0.50 | 0.50 | 1.00 | 1.00 | 1.00 | 2.00 | 0.044 |
| LOF | 0.25 | 0.25 | 0.33 | 0.25 | 0.33 | 0.50 | 0.50 | 1.00 | 1.00 | 2.00 | 0.039 |
| LIN | 0.20 | 0.20 | 0.25 | 0.20 | 0.25 | 0.33 | 0.33 | 0.50 | 0.50 | 1.00 | 0.026 |
| Consistency ratio: 0.027 | | | | | | | | | | | |
| Note: SLP= slope; RR=relative relief; LULC= land use/land cover; ELEV= elevation; DD= drainage density; SOIL=soil; GEOM= geomorphology; NDVI= Normalized Difference Vegetation Index; LOF= length of overland flow; LIN= lineament density. | | | | | | | | | | | |

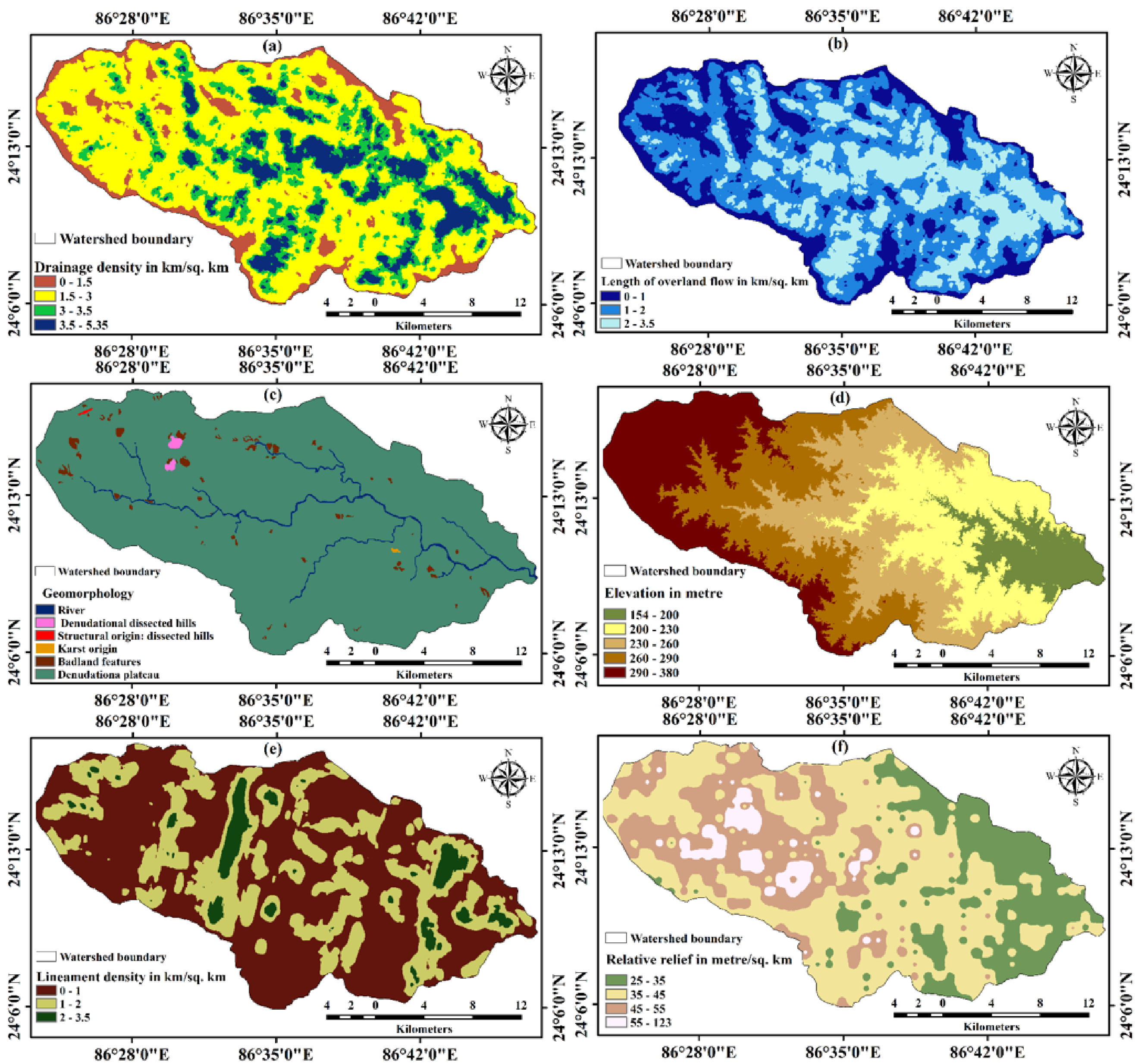


**Figure 3:** Geo-environmental parameters used in the study for the generation of soil erosion susceptibility map of Jainti River basin: a) drainage density, b) length of overland flow, c) geomorphology, d) elevation, e) lineament density, f) relative relief

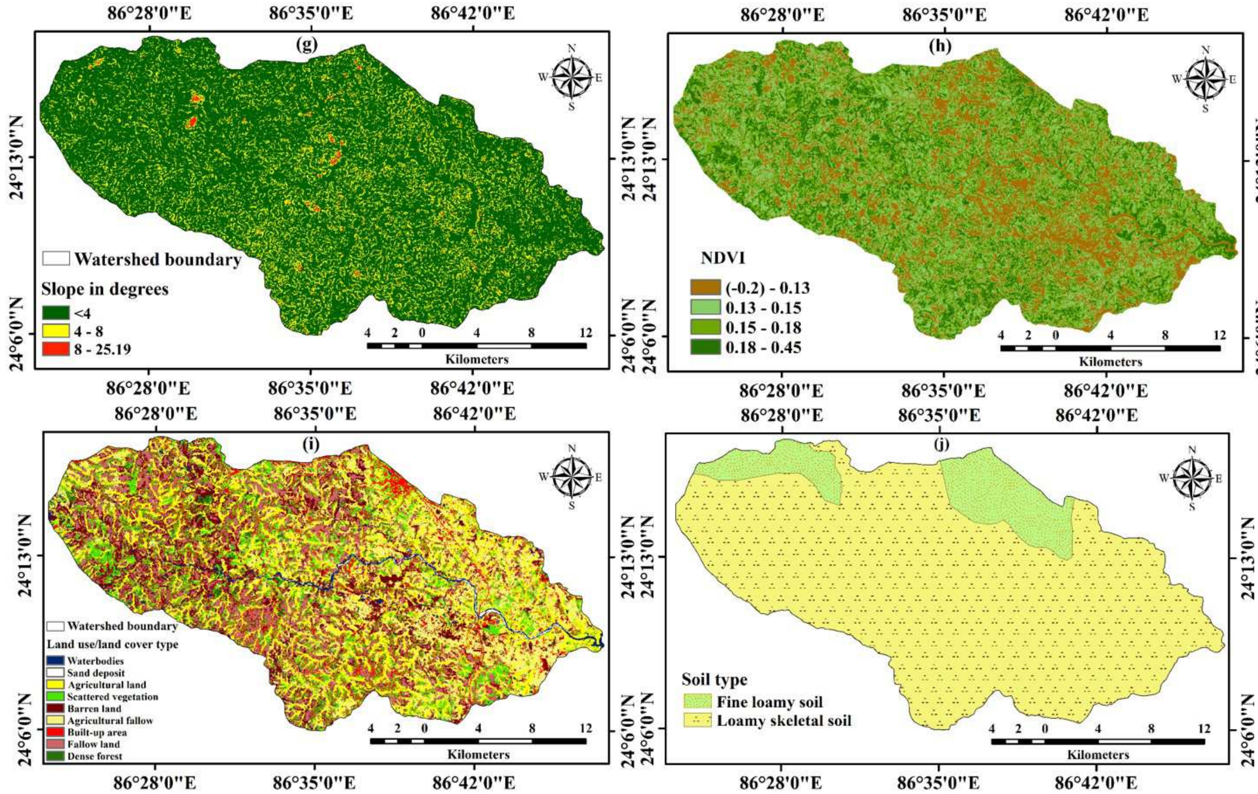


**Figure 3 Cont.:** Geo-environmental parameters used in the study for the generation of soil erosion susceptibility map of Jainti river basin: - g) slope, h) NDVI, i) land use/land cover, j) soil type

## 2.6 Extraction and Evaluation of the Geo-Environmental Parameters:

### 2.6.1 Elevation, Relative Relief and Slope:

Relief map derived from a Digital Elevation Model (DEM) of 30 m resolution (Bhunia et al., 2012). The present area shows a maximum height of 380 m in the upper catchment and minimum height of 154 m (Fig.3d) that means that the relative relief of the total basin is 226 m which denotes a moderate degree of slope, in general, of the whole basin area. But this broad consideration is not enough to describe the various relief characteristics in microscale and therefore a relative relief per $km^2$ (Fig. 3f), and a slope map (Fig. 3g) has been generated. Higher relative relief in a unit area shows a maximum difference in elevation which presents a highly undulated topography (Smith, 1935). In respect to total area, 5.08% shows very high relative relief and 23.73% is under moderately higher class, mainly in middle and upper section of the basin. Comparing to this, lower part has a less difference in altitude. Slope is a very important aspect of relief character. Out of the total area 81.54% has a gentle slope (<4º), 17.93% is under moderate (4º - 8º) and only 0.53% (8º – 25.19º) is under steep slope, respectively. The spatial distribution of slope is highly uneven, which created a rugged land surface in the study area. Generally, areas with combination of higher elevation, high relative relief and slope are more susceptible to soil erosion with the presence of erosive agents.

### 2.6.2 Drainage Characteristics:

Jainti River basin is a sub-watershed of Ajay River basin. Jainti River basin consists of 1844 $1^{st}$ order streams, 448 $2^{nd}$ order streams, 90 $3^{rd}$ order streams, 17 $4^{th}$ order streams, 5 (five) $5^{th}$ order streams and one $6^{th}$ order streams and creates a dendritic pattern of drainage. Based on drainage density, the area is categorised into four classes (Fig. 3a). In the lower and middle parts of the basin, the number and density of the drainage is high (3.5 – 5.35 km/ $km^2$). Length of overland flow is also high in the same regions.

**2.6.3 Land Use/Land Cover:**

Mainly fallow and cleaned up areas are exposed to erosion hazard. In this study, land use/land cover map (Fig. 3i) has been prepared based on maximum likelihood method of supervised image classification from Landsat imagery of 30 m resolution. An accuracy assessment method viz. Cohen's Kappa index has been used to assess the accuracy of the classification. The result of this assessment shows 89% accuracy which signifies that the classification is near to accurate. The amount of vegetation cover is very low (near to 5%). Though, agricultural is the dominant land use (39.45%) in this basin area, but these are remained fallow throughout the year excepting rainy/monsoon season. Beside this, the area is largely dominated by fallow exposed lateritic lands (26.16%) and barren lands (14.78%) which are very prone to erosion.

**2.6.4 Geomorphology and Soil Type:**

Geomorphologically, the area is a denudational plateau in broad. Two denudational dissected small hills, structurally originated one dissected small hill, are present in the upper part of the basin (Fig. 3c). Badlands are special characteristics of this basin which are of high potentiality of soil erosion. Characteristics of soil surface contributes in governing the infiltration rate, surface run-off, soil erosion and gully expansion .The soil type of the study area derived by digitizing the soil map from State Agriculture Management and Extension Training Institute and these are fine loamy soil and loamy skeletal soil (fig 3j).

**2.6.5 Lineament:**

Cracks and lineaments are co-factor of erosion and have a positive role to soil detachment. Lineament density map reveals that in middle portion of the upper catchment area, concentration of lineament is high, which is about 2 km to 3.5 km/km$^2$ (Fig. 3e) which accelerates the erosion probability.

**2.6.6 Normalized Difference Vegetation Index:**

Normalized Difference Vegetation Index (NDVI) represents the vegetation and its healthiness. Higher index value denotes live vegetation, while lower indicates open places and water logged areas (Fig. 3h). In this study, live vegetation areas are less than the open place areas. Lack of vegetation cover accelerates the erosion risk in this river basin.

## 3.0 Results and Discussion:

The work deals with the objective of identification and delineation of the soil erosion susceptible areas in the basin using the spatial analyst tool of ArcGis. The analyses have been accompanied with the methodology of AHP and collinearity statistics including ten geo-environmental parameters to assess the role of these for making the area erosion prone. The works start with assigning weights to the individual ($F_i$) parameters (Table 8) considering their occurrence in the area. Slope shows a maximum weight (0.227) followed by relative relief (0.202), land use/land cover (0.125), elevation (0.131), drainage density (0.081), geomorphology (0.056), soil type (0.068), NDVI (0.044), length of overland flow (0.039) and lineament density (0.026). Soil erosion is directly allied with slope steepness, similarly relative relief which symbolises as maximum difference in altitude within a minimum unit, weighted and ranked in second position, following the slope. A soil type with varying texture is one of the most important factor for governing erosion rates in the areas with diversified soil zones. Fine loamy and loamy skeletal soil are main soil in this area. However, by overlaying the soil map with soil erosion susceptibility map, it shows that under the fine loamy soil, very low susceptible area is 40.35%, low is 35.46%, moderate is 10.75, high is 9.45% and very low area is 3.98% while under the loamy skeletal area, very low susceptible area is 32%, low is 35.17%, moderate is 13.41%, high is 13.18% and very high area is 5.44%. Loamy skeletal soil areas denotes more susceptible areas due to coarse texture particles.

Spatial irregularity of erosion hazard also largely varied depending upon land use/land cover categories i.e. generally barren lands are more subjective to erosion then agricultural land or fallow, while fallow tracts are more exposed to hit by the erosional agents than agriculture or vegetation covered areas. Consecutively other drainage density, elevation, geomorphology etc. are weighted according to amount and consistency over the catchment. It is often seen that in some cases a particular class of factors is more significant to drive the erosion process rather than a broad factor. So it is necessary to consider each sub-class in the analysis in order to perfection of the result.

So the second step involves in the study, is to assigning weights (Table 7) to the sub-classes ($V_i$) through AHP according to their degree of importance towards soil erosion. Result of potential soil erosion index denotes a value ranging from 0.080 to 0.425 calculated through WLCM approach (Weighted Linear Sum Combination Method). Higher index value represents higher erosion prone areas and lower values indicate areas with lower risk of soil loss. The soil erosion susceptibility map (Fig. 4) has been classified into five severity classes such as very low (0.08-0.15), low (0.15-0.18), moderate (0.18-0.22), high (0.21-0.26), severe (0.26-0.43) potentiality, using the natural breaks classification method in GIS environment. Highly and severely erosion susceptible areas acquire 14.83% (80.48 $km^2$) and 5.14% (27.89 $km^2$) of the respectively. Very low risk zone covers 22.64% (122.87 $km^2$), low risk area covers 33.23% (180.34 $km^2$) and moderately potentiality zone showing an area about 24.16% (131.11 $km^2$) of the basin. It has been seen that mainly the upper and middle parts of the basin are of severe to high potentiality of erosion. Comparing to this, risk of soil loss is relatively low in the lower catchment of this basin.

Considering the places with high to severe and very low to moderate risk, the occurrence of each representative parameter has been analysed by selecting some random places from different soil erosion susceptibility classes in GIS environment. Generally, higher the slope leads to quick detachment of soil and high value of relative relief is an indicator of maximum difference in altitude in a minimum area. In case of land use/land cover open and fallow places are more erosive. The result reveals that highly to severely erosion susceptible areas occur mainly where degree of slope and relative relief is high with the presence of fallow and barren land.

**3.1 Validation of Model:**

Validating the predicted results of a model is very significant in a study. The zonation of susceptibility map produced using natural breaks method for this study was used largely in the existing literatures. A positive relation between the predicting model and ground reality is very much necessary for the research study (Ayalew et al., 2005). At present, ROC (Receiver Operating Characteristic) is a widely used methodology for diagnostic test of result of predicting model. Success rate of the soil erosion susceptibility mapping has been validated using ROC curve. A total number of 101 patches have been identified through field investigation (Fig. 1) and GPS survey. A total of 75 training dataset and 26 validations (fig.1) dataset have been considered to construct and plot the ROC curve through statistical operation. ROC curve drawn based on binary responses of these data sets (absence or presence of soil erosion). The derived result indicates the true positivity success rate (TPR) of this assessment. Area under the curve explains the accuracy of the susceptibility mapping through AHP model. The area under curve (AUC) is 0.771 or 77.1% which indicates a fair to good performance of this model (fig. 5). This result of accuracy assessment qualifies that prediction accuracy of this AHP model is good in this study area. Finally, it will be concluded that this model is truly explained the soil erosion susceptibility based on these selected parameters of this basin.

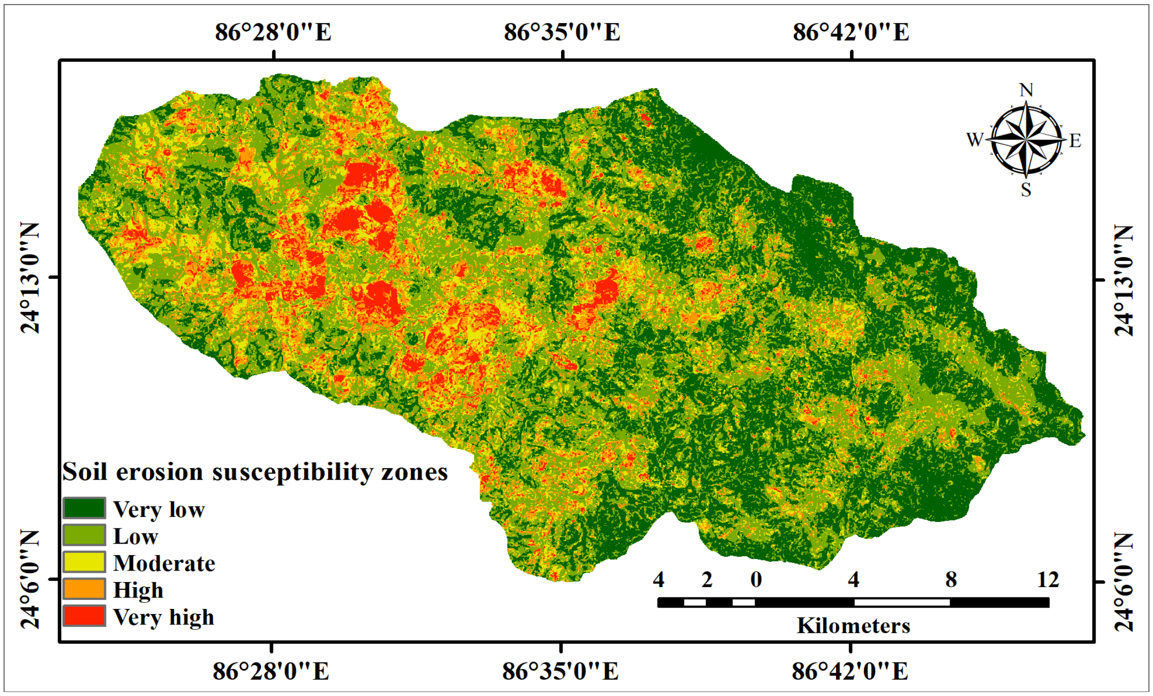


**Fig. 4:** Soil erosion susceptibility classes of the Jainti River basin

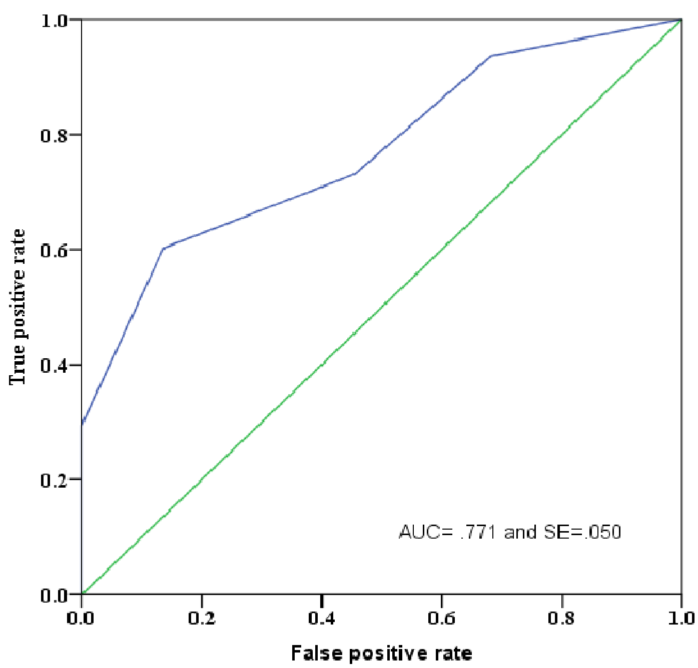


**Fig. 5:** Success rate curve of the AHP model

## 4.0 Conclusions:

The Jainti river basin is a fringe area of Chhotonagpur plateau falls under the Deoghar district of Jharkhand. This work has been carried out to identify the erosion prone areas with the help of AHP method including nine geo-environmental parameters, which are more or less responsible for soil degradation in an area. This work also evaluates the contribution of Geographical Information System and Remote Sensing and application of AHP in susceptibility assessment. The result shows that Analytical Hierarchical Process is very useful one among the various Multi-criteria decision approaches for vulnerability assessment. This area is characterised by highly undulated topography with lateritic fine loamy and loamy skeletal type of soil. Very hot and dry summer and very cold winter with heavy rain in monsoon accelerate the soil erosion hazard in this catchment. Major places of the area remain exposed throughout the year. So during monsoon heavy rainfall directly hits the exposed places leads to huge soil loss and forest degradation every year. An overlay analysis describes that high degree of erosion potentiality zones occurs mainly where the slope steepness is high, land part is exposed i.e. fallow lateritic tract, relative relief with higher elevation in the loamy skeletal soil areas. Mainly central part of the upper catchment where elevation and slope amount is high and in small hill slope areas the erosion risk is severe. As the study identified and quantified that at present almost 19.97% of the area falls under high risk for soil erosion, it will helps the authorities for further planning in the field of soil conservation and scientific land management.

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