Integration of Geospatial Technology and AHP knowledge Based Technique in Preparation of Susceptibility Modelling to Gully Erosion: A Study from Cratonic Part of Eastern India

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Abstract

Gully erosion is conceived as one of the environmental problems resulting mainly from surface run-off and associated geo-physical factors. This erosion augments the process of land degradation. To identify the major factors responsible in this process and their assessment in preparation of gully erosion susceptibility mapping, the geospatial technology has been a huge support for earth scientists for decades. Proper analysis and assessment of satellite images employing multi-criteria decision making models facilitates the estimation of areas of soil erosion and gully formation. The present study, carried out in eastern plateau fringe of India using Remote Sensing (RS) and Geographical Information System (GIS), and Analytical Hierarchy Process (AHP) model to assess zones susceptible to gully erosion. The study reveals around 52% area of Rupai basin experiences moderate to very high gully erosion, and the model is validated performing an accuracy assessment, which is computed as 72.72%. The factors are hold major responsible factors in soil erosion and gully formation are geomorphology, slope, Land Use and Land Cove (LULC), soil and Stream Power Index (SPI). Sites, such as Kutidih, Mahakudar and Kuki experience loss of soil approximately 6.09, 40.96, and 1.40 tonne respectively. The generated gully erosion susceptibility map may help in planning and management of soil and water conservation.

Introduction

Soil is considered to be one of the fundamental parameters in enhancing the regional economy (Das et al. 2020). The 21st century has witnessed rapid population growth with increasing food demand (Ghosh et al. 2021a). This situation severely impacts on soil health. The low level of soil productivity is mainly resulted from excessive use of modern technology and instruments, fertilizer and pesticides. Moreover, extensive mining, industrialization, agricultural practices, sparsely vegetated and deserted lands have direct bearing on upper most portions of soil profile and texture, and ultimately soil erosion starts (Onyando et al. 2005; Zhou et al. 2008). Gully erosion, a destructive form of soil erosion, is caused due to removal of different sediments, sands and rocks *etc.*, from soil or earth surface by the strong surface run-off (Kirkby and Bracken 2009). In recent past, soil erosion turns out to be a global issue owing to loss of soil and agricultural lands and decreasing trend in crop production (Tilahun et al. 2014; Assefa and Hans-Rudolf 2016; Kebede et al. 2020). It was estimated that more than 60% of the world's populations depend on agriculture activities (FAO 2017); whereas in India, the figure is around 62%. Interestingly, they belong to the rural areas where main option of livelihood is agriculture (Census of India 2011). The common environmental problem in semi-arid region is land degradation resulting from soil erosion (Bufalo and Nahon 1992; DeRose et al. 1998; Bennet et al. 2000; Martinez-Casasnovas et al. 2003). Several parts of India have been experiencing the issue of land degradation due to much soil erosion (Vrieling 2006). This serious problem is associated with other events like flooding, desertification, pollution of ground water and loss of soil productivity (Govers et al. 2017; Odunuga et al. 2018; Swamkar et al. 2018). It is found that quality of land use in agricultural watershed degrades owing to soil erosion (Amiri et al. 2019). Globally, the rate of soil formation is 10-40 times less than the soil erosion (Pimentel 2006).

Hence, the event of gully erosion is serious threat to the sustainable man-environment relation along with economic progression (El Maaoui et al. 2012; Ionita et al. 2015; Ibáñez et al. 2016; Rodrigo-Comino and Cerdà 2018), and it is highly associated with poverty and food scarcity in rural agro-ecosystem (Ayele et al. 2015). The rate of sediment erodibility is attributed to lithology, soil, topography, volume and velocity of surface run-off and land use. These are the major factors of gully formation (Patton and Schumm 1975; Imeson and Kwaad 1980; Poesen et al. 2003; Martínez-Casasnovas et al. 2004; Valentin et al. 2005; Zucca et al. 2006; Gómez Gutiérrez et al. 2011; Torri et al. 2012). In the hilly and plateau region, the land erosion is found to be very common along with its associated problems, and the severity of erosion varies from place to place and influences activities of local area development (Fadul et al. 1999). The degraded landforms are much susceptible to soil erosion, and precise mapping helps to take required initiatives to reduce and manage the soil erosion (Kirkby et al. 2009). Thus, it becomes imperative to identify the problems of soil erosion areas to assess the types of land development and trend of erosion for planning and measurement strategies (Dai and Lee 2002; Ayalew et al. 2004; Bijukchhen et al. 2013; Erenner et al. 2016; Pham et al. 2017).

Susceptibility mapping of soil erosion is often performed to perceive the events like landslide or gully erosion. The basic goal of this technique is to demarcate the risk prone areas and to identify the influential geo-environmental factors. To understand the sensitivity of a region, the qualitative theories and statistical measurements techniques are widely employed by experts along with Geographical Information System (GIS). Worldwide Several researchers have adopted Universal Soil Loss Equation (USLE)/ Revised Universal Soil Loss Equation (RUSLE) model to estimate the terrain susceptibility on the basis of rate of soil erosion (Besler 1987; de Neergaard et al. 2008; Vijith and Dodge-Wan 2018). Several times, researchers face problems related to insufficient data on gulling and landslides; therefore, it becomes difficult to generate maps and point out the locations of landslides or gullies during field visits. In such case, various models, such as artificial neural network, multi criteria evaluation, weighting and ranking based method, were applied by different scholars to assess the degree of soil erosion risk (Dandapat et al. 2020). In some cases, these models have their own limitations to quantify the impacts of different environmental factors with soil erosion interaction owing to complex nature of soil erosion process (Kheir et al. 2006).

But model like Analytical Hierarchy Process (AHP), a popularized, efficient, simple and consistent, well defined and predictive test model using experts' opinions and statistical measurements, is generally adopted to overcome shortcomings (Ghosh et al. 2020a, 2021; Karmakar et al. 2021). Numerous scholars across the world used the AHP model to estimate the susceptibility to landslide or soil erosion in different regions, and found suitable results in predicting the vulnerability based on selected parameters (Neaupane and Piantanakulchai 2006; Yalcin 2008; Nekhay et al. 2009; Althwaynee et al. 2012; Youssef et al. 2012; Kayastha et al. 2013; Pourghasemi et al. 2013; Rahaman and Aruchamy 2017; Arabameri et al. 2018). Therefore, it is important to have a model with more integrated approach to analyse different environmental factors more systematically in quantifying the severity of soil erosion process (Ghosh et al. 2020a, 2021). In recent times, AHP model coupled with Remote Sensing (RS) and GIS has drawn attention significantly among various scholars (Rozos et al. 2011; Li et al. 2015; Das et al. 2018, 2020). Several researchers have carried out many studies on identification of vulnerable areas to soil erosion integrating AHP model with geospatial technology (Nasiri 2013; Pradeep et al. 2014; Abbasi et al. 2017; Thomas et al. 2018).

The present study is conducted on the Rupai river basin, situated in the extended part of *Chotanagpur Granite Gneiss Complex* (CGGC) of Purulia district in the state of West Bengal, India. The entire basin is mainly composed of hard rock of granite gneiss, granite and biotite granite (Fig. 9). The study area receives

sufficient precipitation seasonal basis (Ghosh et al. 2020a, b, c), but surface run-off is high due to high degree of slope and low porous lithology (Ghosh 2020a, b, 2021). This situation enhances the degree of soil erosion in the form of gully formation mainly in monsoon period. It is important to map the areas susceptible to soil erosion and gully formation and its spatial distribution of varying magnitude. And to do the same, this study includes AHP model with RS & GIS to assess the event. Besides this, an attempt has also been made here to estimate the loss of soil from the studied segments.

Geographical Settings of Rupai River Basin

Rupai, an important left bank tributary of Subarnarekha river in CGGC, flows in western part of Purulia district. It originates from Jhalda-I community development block of Purulia with a length of 136.46 km occupying an area of 141.48 km², and meets with Subarnarekha river at Jhalda-II community development block of Purulia. The study area lies in between 85° 53' E to 86° 02' 30" E and 23° 15' 30" N to 23°23' N longitudes and latitudes respectively (Fig. 1). Regionally the area is a part CGGC of eastern Indian peninsular shield and belongs to the north of Singhbhum craton (Duloi 2016). The presence of china clay in the district is largely associated with Precambrian granitic rocks and meta-sediments of the CGGC. The district is characterized by undulating rolling topography with moderate to gentle slope (Ghosh 2020a, 2021; Karmakar 2021). The lithology of the district is mainly dominated by Archean granite gneiss followed by sandstone and shale of Permo-Carboniferous, Pre-Cambrian granites and quartzite, semi-consolidated sediments of Quaternary and deposition of recent alluvium sediments of recent time (Duloi 2016). Purulia experiences sub-tropical hot and dry climate (Chakrabarty 2011; Government of India 2018; Ghosh et al. 2020a), and enjoys annual rainfall and temperature ranging from 1100 to 1500 mm and 7° to 46° C respectively (Government of West Bengal 2007, 2014;). The vegetation of the study area is mainly deciduous in nature, and major forest covers are *Shorea Robasta*, *Vachellia*, *Butea Monosperma*, *Madhuca Longifolia*, *Aegle Marmelos*, etc., which are sparsely distributed (Mandal et al. 2018; Ghosh et al. 2020a, b). In the study area, a number of residual hills are found and soil is mainly skeletal in nature and more likely to be infertile (Ghosh et al. 2020b, c). Basically, the soil of the study of interest is lateritic nature as it belongs to *Rarh* Bengal (red soil area, mainly Purulia, Paschim Medinipur, Bankura, Paschim Bardhaman district of West Bengal). These areas are characterized by dense network of rills and gullies forming badland topography (Ghosh et al. 2021b)

Figure 1 is near here

Materials And Methods

Sources of Database

The field study is carried out in the month of October 2021 in Rupai river basin. Collection of primary data involves measurements of gullies. Total station survey (Geomax ZT-20) is done to make long and cross profiles. Handheld Global Positioning System (GPS) of Garmin eTrex-20 is used to precisely locate the sites of investigation. A total number of eleven sites are visited after carefully observing different temporal images of the basin from Google Earth Pro software. During the field study, it is found that three sites are more susceptible to gully erosion. Hence, all the measurements are done in those sites only. To have the proper knowledge regarding soil erosion and gully formation, it is important to obtain other relevant data which only can be obtained from secondary sources. Understanding and assessment of soil erosion and gully formation requires basic information on a number of factors (Valentin et al. 2005; Conforti et al. 2011; Arabamari et al. 2018). Parameters in the process of gully erosion are not same for all regions (Arabamari et al. 2018), and needs attention in the selection of parameters emphasizing on local influential factors. In this present study, a number total number of ten factors, such as geomorphology, slope, land use and land cover (LULC), soil, Stream Power Index (SPI), curvature, lithology, elevation, drainage density and Topographical Wetness Index (TWI) have been taken into account to perform the study of Gully Erosion Susceptibility Mapping (GESM). Data required on these factors are obtained from several national and international sources, such as Digital Elevation Model (DEM) of Shuttle Radar Topography Mission (SRTM) downloaded from <http://earthexpolrer.usgs.gov> (spatial resolution of 1-arc second) acquired on 23rd September 2014; Landsat-8 Operational Land Imager (OLI) satellite image downloaded from <https://earthexplorer.usgs.gov> (30 m spatial resolution) obtained on 2nd April 2019; geomorphological map on a 1:250000 scale of Geological Survey of India (GSI); soil map on a 1:250000 scale of National Bureau of Soil Survey and Land Use Planning (NBSS&LUP) of India to make individual thematic layer of all selected parameters. In order to process, analyse and prepare the different thematic maps, ArcGIS 10.3.1 and Erdas Imagine 2014 RS and GIS software are used.

Thematic Layers and Its Preparation

While preparing the thematic layers, maps are properly geo-coded following the Universal Transverse Mercator (UTM) projection, world geodetic survey (WGS-84) and 45 N zone. The delineation of Rupai drainage basin and preparation of drainage density layer is mapped from SRTM-DEM in ArcGIS software adopting hydrology tool of spatial analyst. To produce elevation, slope, curvature, SPI and TWI thematic layers, the SRTM-DEM is also considered and processed and analysed in ArcGIS software using surface tool of spatial analyst. On the contrary, the thematic layers of geomorphology, lithology and soil of the study of interest are reproduced extracting them from the maps of GSI and NBSS&LUP employing editor tool of ArcGIS software. The LULC map is prepared classifying the OLI image in different LULC types in Erdas Imagine software adopting maximum likelihood algorithm of supervised classification.

AHP Model and Its Application

The application of Multi-Criterion Decision Analysis (MCDA) is used successfully in various disciplines for years (Schmoldt 2011; Guaita-Martínez et al. 2019; Ghosh et al. 2020a; Salabun 2020; Karmakar et al. 2021). The AHP model, developed by T. Saaty in 1980 (Ghosh et al. 2020a; Karmakar et al. 2021), is one of the popular and widely accepted methods in MCDA because of its multidimensional application in several fields in case of decision making (Akadiri and Olomolaiye 2012; Waris et al. 2019; Ghosh et al. 2020a; Karmakar et al. 2021), and the model can simplify the complexity of problems based on best possible opinions of experts (Punniyamoorthy et al. 2012; Celik 2019; Ghosh et al. 2020a; Karmakar et al. 2021). The selected ten factors, which are mutually related to each other, responsible for gully erosion are analysed adopting AHP model to assign weight to each factor and their sub-classes depending upon the role of each factor in the process of gully erosion. To quantify weight numerically of any factor based on its relative importance in a whole event is most significant

quality of AHP model (Waris et al. 2019; Ghosh et al. 2020a; Karmakar et al. 2021). The Consistency Index (CI), an important aspect of AHP, facilitates to validate the judgement score assigned by decision makers (Saaty and Vargas 1982; Ghosh et al. 2020a). There are four steps involved to run the AHP model, such as assigning weight, pair-wise comparison matrix, weight normalization and consistency assessment (Benjmel et al. 2020; Ghosh et al. 2020a). The selected ten parameters are first arranged in hierarchical order considering priorities to assign weight based on nine point scale (Table 1) devised by Saaty in 1980, and each point of the scale defines some specific importance (Saaty 1990). The process of weight assignment is conducted based on literature review and proper field investigation (Ghosh et al. 2020a; Karmakar et al. 2021). In second step to compare all the factors with each other, a pair-wise comparison matrix (W) is done (equation 1). To obtain the normalization of weight (W_{ij}) from matrix table (Table 2), the equation 2 is employed following the eigen vector technique of Saaty (Neissi et al. 2020; Ghosh et al. 2020a; Karmakar et al. 2021), and p represents geometric mean of i^{th} factor.

1

$$W = \begin{bmatrix} f_{13} & f_{14} \dots & f_{1n} \\ f_{23} & f_{24} \dots & f_{2n} \\ f_{n1} & f_{n2} \dots & f_{nn} \end{bmatrix}$$

2

To verify the judgement coherence, the Consistency Ratio (CR) is developed (equation 3), and it is derived dividing CI from Random Consistency Index (RCI). In order to allow the judgement value, the CR value required to be less than 0.1, else new comparison matrix needs to be computed assigning fresh judgement values to all factors till the CR value does not reach to less than 0.1 (Ghosh et al. 2020; Karmakar et al. 2021). The mathematical expression used in calculating CI is denoted by equation 4. Here, n depicts number of factors taken into consideration, and λ_{max} describes principal eigen value (Saaty 1990).

$$CR = \frac{CI}{RCI}$$

3

$$CI = \frac{(\lambda_{max} - n)}{n - 1} \quad (4)$$

Computation of Gully Erosion Susceptibility Zone Index and Accuracy Assessment

The computation of Gully Erosion Susceptibility Zone Index (GESZI) is performed taking in to account all the thematic layers of ten factors and this done by map algebra tool of in ArcGIS software using weighted linear combination method. Following equation (5) is adopted to calculate GESZI. Here, f_w refers weight of each factor and f_r denotes rank of sub-classes. The final output of Gully Erosion Susceptible Zone (GESZ) is generated from ArcGIS software involving all the parameters. The value of GESZI is dimensionless and derived GESZI values are categorized into five distinct classes, namely: very low, low, moderate, high and very high following natural break classification system of ArcGIS software. To validate the map of GESZ, the overall all accuracy assessment is carried out in conformity of the studies areas. Finally, a flow chart is prepared to portray the details of methodology (Fig. 2).

$$GESZI = \sum_i^n (f_w \times f_r) \quad (5)$$

Table 1 is near here

Table 2 is near here

Table 3 is near here

Figure 2 is near here

Description of Factors of Soil Erosion and Gully Formation

Geomorphology

Geomorphology is the study of landforms including its evolution, classification and several geomorphic processes acting upon them (Summerfield 1991; Huggett 2007; Karmakar 2021). Understanding of geomorphology helps to assess the landscape more precisely (Murmu et al. 2019; Karmakar et al. 2021). Geomorphologically the Rupai basin area can be divided into six sub-classes based on existing landforms (Fig. 3). The north, west and south western portions of the river basin are characterized by pediplain (36.64%) followed by dissected hills and valleys (30.36%) and pediment (24.26%). The rest of the landforms do not significantly dominate in the river basin. Among the sub-classes of geomorphology, the dissected hills and valleys obtain highest weight (0.286) followed by residual hill (0.238) and pediment (0.19), while valley fill secures lowest weight of 0.048 due to its lower level of elevation compared to other landforms of in the study area (Table 3). Dandapat et al. (2020) observed almost same situation in case of Dulung river basin of west Bengal.

Figure 3 is near here

Slope

In the process of soil erosion in the form of rills and gullies, slope plays a crucial role. Slope simply may defined as the variation of elevation on topography in a certain space (Yeh et al. 2016; Guru et al. 2017; Ghosh et al. 2020a, b). There is an inverse relation of degree of slope with infiltration rate and directly proportional to surface run-off (Siva et al. 2017; Karmakar et al. 2021). Higher degree of slope augments the soil erosion in the form of rill and gully (Conforti et al. 2011). The study area exhibits undulating topography with varying degree of slopes. The general geological slope of the basin is west to east and south-east ward (Fig. 4). Most of the basin area (71.87%) is experienced low degree of slope (i.e. less than 3 degree) and extended predominantly north, west and south-west portion of the basin. The moderate degree of slope (3-9 degree) covers an area of 15.58%. An area of 12.55% belongs to high to very high degree of slope. Higher degree of slope is found mainly at eastern and south-eastern portions. There are some residual hills situated in the basin, namely: Lagamburu, Jajahatu and Gajaburu (Jhalda-I), and Bansa and Shikra (Jhalda-II), which are also seen in the same directions. The weight value for sub-categories ranges in between 0.18 to 0.21 (Table 3). Different studies revealed that higher degree of slope increases the surface run-off with higher velocities and results in disintegration of soil particles and its transportation (Conforti et al. 2011; Zabihi et al. 2017; Yang et al. 2021; Dandapat et al. 2020). This situation gets worsened in absence of vegetation cover (Yang et al. 2021).

Figure 4 is near here

Land Use and Land Cover

The LULC plays a significant role in the process of gully erosion (Conforti et al. 2011; Yang et al. 2021). A number of variables, such as run-off rate, infiltration, surface water, soil moisture and water holding capacity etc., are influenced by LULC (Singh et al. 2018; Ghosh et al. 2020a; Karmakar et al. 2021). The presence of vegetation cover significantly decreases the erosive action of surface run-off and gully erosion susceptibility (Conforti et al. 2011). The study area mostly possesses fallow land (36.45%) followed by vegetation cover (33.48%). Hilly surface with dense forest is computed to be 18.67%. The lowest proportion of basin (1.34%) is covered by built up are and others (Table 3). Vegetation cover and hilly surface with dense forest dominate eastern and south-eastern portion of the river basin, while fallow land and agricultural fallow land are observed in western and middle portion of the basin (Fig. 5). The higher weight value is obtained by fallow land, agricultural fallow land and built up area (Table 3). It is mentioned by several researchers that fallow lands (Conforti et al. 2011), agricultural fallow lands (Dandapat et al. 2020) and range area (Arabameri et al. 2018). It is evident that open spaces with steepness are more susceptible to gully erosion.

Figure 5 is near here

Soil

The physical properties of soil highly influence the rate of surface run-off, infiltration capacity, resistivity to soil erosion as well initiation of gully formation. Soil texture is a function of sub-surface flow and piping, and the formation of gullies starts when the top of the pipes falls down (Igwe et al. 2020). The study of interest mainly forms four consecutively four distinct soil group from west to east (Fig. 6). Fine soil mainly dominates (40.49%), while gravelly loamy extends around 4.19%. The rest of the proportion is covered by fine loamy to fine loamy - coarse loamy (Table 3). Fine soil is mainly susceptible to erosion (Dandapat et al. 2020) and it is also reflected by the weight value of sub-classes of soil (Table 3).

Figure 6 is near here

Stream Power Index

It is a measure to understand the erosive power of surface water flow considering the simple assumption that the discharge is proportional to the specified catchment area. This measure is important because river incision and slope toe erosion are directly influenced by the power of running water (Conforti et al. 2011). Around 78% of the basin area comes under the category of -0.04 to 0.0, where -0.21 to -0.04 and 0.0 to -0.02 sub-classes share around 9% area by each of them. The lowest value (0.67%) belongs to 0.05 to 0.18 (Table 3). Broadly, the basin is divided into, west and certain portion of east (Fig. 7). The areas with high SPI may experience greater possibility of erosion (Conforti et al. 2011; Arabameri et al. 2018).

Figure 7 is near here

Curvature

The bend of topographic surface from a horizontal plain is termed as curvature. Based on the shape of bends of topographic surface, the convex profile is referred when it is curved upward and concave while it is curved downward (Conforti et al. 2011; Karmakar et al. 2021). A significant proportion of the basin (47.82%) is flat followed by concavity of topography (36.64%). The share of convex curvature is observed to be 17.54% (Table 3), and it is found west and south-western directions due to presence residual hills and pediments (Fig. 8). The study of curvature helps to realize gully initiation and development. The presence of higher amount of concave curvature expedites the process of gully erosion (Conforti et al. 2011; Zabihi et al. 2017).

Figure 8 is near here

Lithology

The occurrence of gully significantly depends on lithological properties. The geological map gives impression of underlying lithology (Igwe et al. 2020). The river basin owns different types of rocks of different geological formations from Proterozoic to Quaternary (Karmakar et al. 2021). The dominating rocks are found here (72.10%) granite gneiss followed by biotite gneiss and granite. Unclassified soil and alluvium account for 2.50% (Table 3). The map of the basin shows that granite and gneiss spread from west and north to east direction (Fig. 9). Unconsolidated and well exposed materials are suitable for gully formation (Conforti et al. 2011). The presence of unclassified soil and alluvium of quaternary and recent deposits are highly susceptible to gully erosion.

[Figure 9 is near here](#)

Elevation

The river basin is situated at *CGGS*, a hard rock plateau region, and elevation map depicts moderately spacing contour due to presence of several residual hills (Fig. 10). The highest share of the basin (35.43%) belongs to the range of elevation of 228 to 268 m followed by 181 to 228 m (31.71%), while around 16% area comes under 326 to 645 m elevation. The study reveals that moderate to high elevated areas are more prone to erosion (Table 3). Several other works also pointed out in this regard (Arabameri et al. 2018; Yang et al. 2021).

[Figure 10 is near here](#)

Drainage Density

Within a unit of area, the total length of streams is known as drainage density. It is also referred as closeness of stream spacing and influenced by a number of variables, such as slope, lithology, soil, vegetation cover, rainfall etc., (Ghosh et al. 2020a; Karmakar et al. 2021). This indicator influences soil, rill and gully erosion (Dandapat et al. 2020). The higher drainage density is observed towards higher elevated and sloping areas (Fig. 11) and ranges from 0.47 to 0.89 (31.30%) and 0.89 to 1.31 (29.85%) followed by 1.31 to 1.74 (Table 3). The weight value enhances with increasing drainage density (Dandapat et al. 2020; Yang et al. 2021).

[Figure 11 is near here](#)

Topographic Wetness Index

This is a measure to perceive the topographical control over hydrological process (Igwe et al. 2020). It is calculated taking into account the possibility of storing of water in a certain area of the basin with the probability of moving of water following the gravity (Karmakar et al. 2021). The higher value of TWI indicates greater risk of susceptibility of soil erosion and subsequent formation of related landforms. It is also documented by Conforti et al. (2010), Arabameri et al. (2018) and Igwe et al. (2020). The lower basin area (14.82%) lies in between the range of 11.76 to 22.28. The study finds relatively low importance of TWI (Table 3). Areas belonging to east to west experience lower TWI (Fig. 12).

[Figure 12 is near here](#)

Gully Erosion Susceptibility Zone

The integration of geospatial techniques and AHP model employing all the ten selected factors facilitates to generate the GESZM of Rupai river basin. The GESZ is classified in five distinct classes adopting natural break classification system of ArcGIS software (Table 4). The area falls under low to moderate group of GESZ is 51.71% based on dimensionless value of GESZ. Very low GESZ is found to be 19.72%. On the contrary, the values of high and very high GESZ are 19.88% and 8.68% respectively. High to very high GESZ is observed scattered way in some portion of middle of the basin and west to south-west margin (Fig. 13).

[Table 4 is near here](#)

[Figure 13 is near here](#)

Accuracy Assessment of Gully Erosion Susceptibility Zone Map

To know reliability of the derived GESZ based on GESZ map, the accuracy assessment is a prerequisite condition towards the validation of the model. In order to do the same, a total number of eleven sites are visited to investigate the ground truth reality based on available literatures and observation of Google Earth Pro software for selection of suitable sites across the entire basin (Fig. 14). The Keyhole Markup Language (KML) file is prepared in Google Earth Pro and overlaid on GESZ map. The overlaid sites of investigated are now distributed on GESZ map, and found the frequency of site numbers locating in different classes of GESZ. The total sites of investigation with susceptibility to gully erosion moderate to very high is now summed up and divided from total number of sites. The derived result is multiplied by hundred. Finally, the level of accuracy assessment is computed to be 72.72% (Table 5), which is very high and advocates for the derived GESZ map.

[Table 4 is near here](#)

[Figure 14 is near here](#)

Estimation of Gully Erosion

The total loss of soil from the three studied gullies is estimated using the simple calculation. These three gully sites of the river basin are namely: Kutidih (23° 20' 32.92" N and 85° 56' 21.17" E), Mahakudar (23° 20' 27.39" N and 85° 56' 28.43" E), and Kuki (23° 18' 36.55" N and 85° 55' 45.65" E). Total length, average width and depth of gullies (m) are computed to obtain the total volume of all gullies (Plate 1). The bulk density of laterite soil for *Rarh* Bengal is calculated by Ghosh et al. (2021b) as 2.205 gm cm⁻³ up to 1.45 m depth. Now, the volume of gully is multiplied by average bulk density of laterite. The estimated value of the weight of eroded materials from gullies of Kutidih, Mahakudar and Kuki are calculated to be 6.09 tonne, 40.96 tonne and 1.40 tonne respectively.

[Plate 1 is near here](#)

Conclusion

Assessment of susceptibility to gully erosion involves a huge time and labour when geol-physical investigation is carried out for a large watershed or basin. In this research work, integrating geospatial technology with AHP model helps to assess the zones of gully erosion. Moreover, the field visits also enhances the reliability of the investigation and preparation of mapping. This study reveals that geomorphology, slope, LULC, soil and SPI are the most influential factors in the process of soil erosion and gully formation. Around 52% of the basin area is susceptible to gully erosion. Some sites have also been experiencing a huge soil loss in the form of severe gully erosion. Seasonal field visits around the year with precise investigation, the study may yield more suitable results.

Declarations

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Authors' contributions

PM conducted field work, collected secondary data, analysed it and partially drafted the first manuscript. MM formulated the idea of the work, conducted field, partially drafted and critically revised the manuscript. SM conducted field and partially drafted the manuscript. BG helped in analysing data and revision of manuscript.

Ethical approval

Not applicable

Consent to participate

Not applicable

Consent to publish

Not applicable

Competing Interest

The authors declare no competing of interest.

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Data availability

Not applicable

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Tables

Table 1 Saaty's nine-point Scale and random consistency index

Intensity of importance on an absolute scale	1	2	3	4	5	6	7	8	9
Definition	Equal	Weak	Moderate	Moderate Plus	Strong	Strong Plus	Very Strong	Very Very Strong	Extreme
Number of factors	1	2	3	4	5	6	7	8	9
RCI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

Table 2 Pair-wise comparison matrix of ten influencing factors and their normalized weight

Factors	Geomorphology	Slope	LULC	Soil	Stream power index	Profile curvature	Lithology	Elevation	Drainage density	TWI	Geometric mean	Normalize weight
Geomorphology	9/9	9/8	9/7	9/7	9/6	9/5	9/4	9/3	9/3	9/2	1.85	0.167
Slope	8/9	8/8	8/7	8/7	8/6	8/5	8/4	8/3	8/3	8/2	1.64	0.148
LULC	7/9	7/8	7/7	7/7	7/6	7/5	7/4	7/3	7/3	7/2	1.44	0.130
Soil	7/9	7/8	7/7	7/7	7/6	7/5	7/4	7/3	7/3	7/2	1.44	0.130
Stream power index	6/9	6/8	6/7	6/7	6/6	6/5	6/4	6/3	6/3	6/2	1.23	0.111
Curvature	5/9	5/8	5/7	5/7	5/6	5/5	5/4	5/3	5/3	5/2	1.03	0.093
Lithology	4/9	4/8	4/7	4/7	4/6	4/5	4/4	4/3	4/3	4/2	0.82	0.074
Elevation	3/9	3/8	3/7	3/7	3/6	3/5	3/4	3/3	3/3	3/2	0.62	0.056
Drainage density	3/9	3/8	3/7	3/7	3/6	3/5	3/4	3/3	3/3	3/2	0.62	0.056
TWI	2/9	2/8	2/7	2/7	2/6	2/5	2/4	2/3	2/3	2/2	0.41	0.037

Source: Saaty's CR= (<0.1); CR=0.000000079, the computed matrix is accepted based on derived CR value

Table 3 Classification of factors and the rank of sub-classes on the basis of influencing capacity in susceptibility in gully erosion

Factors	Normalized weight	Sub-classes	Area (%)	Normalized weight	Rank
Geomorphology	0.167	Valley fill	4.93	0.05	1
		Inselberg	0.95	0.14	3
		Pediment	24.26	0.19	4
		Pediplain	36.64	0.10	2
		Residual hill	0.87	0.24	5
		Dissected hills and valleys	30.36	0.29	6
Slope (degree)	0.148	<3	71.87	0.18	3
		3-9	15.58	0.19	4
		9-17	8.14	0.20	5
		>26	4.41	0.21	6
LULC	0.130	Hilly surface with dense forest	18.67	0.05	1
		Vegetation	33.48	0.15	3
		Fallow land	36.45	0.35	7
		Agricultural fallow land	10.06	0.25	5
		Built up area and others	1.34	0.20	4
Soil	0.130	Gravelly loamy	4.19	0.07	1
		Fine loamy to coarse loamy	28.77	0.20	3
		Fine loamy	26.53	0.33	5
		Fine	40.49	0.40	6
Stream power index	0.111	-0.21- -0.04	9.30	0.05	1
		-0.04 - 0.00	77.67	0.10	2
		0.00 – 0.02	9.02	0.20	4
		0.02 – 0.05	3.33	0.30	6
		0.05 – 0.18	0.67	0.35	7
Curvature	0.093	Convex	17.54	0.60	6
		Flat	47.82	0.30	3
		Concave	34.64	0.10	1
Lithology	0.074	Biotite gneiss	19.66	0.14	4
		Granite	5.21	0.07	2
		Granite gneiss	72.10	0.11	3
		Limestone & impure marble	0.32	0.18	5
		Pegmatite vein	0.06	0.04	1
		Tuff, tuffaceous psammo-pelite	0.12	0.21	6
		Unclassified soil & alluvium	2.50	0.25	7
Elevation (m)	0.056	181-228	37.71	0.06	1
		228-268	35.43	0.13	2
		268-326	17.10	0.19	3
		326-401	9.05	0.25	4
		401-645	6.70	0.38	6
Drainage density (km/km ²)	0.056	0.042-0.466	12.08	0.18	3
		0.466-0.889	31.30	0.19	4
		0.889-1.313	29.85	0.20	5

TWI	0.037	1.313-1.736	19.90	0.21	6
		1.736-2.160	6.85	0.22	7
		6.32-9.32	26.23	0.09	1
		9.32-11.76	58.94	0.19	2
		11.76-14.95	11.33	0.28	3
		14.95-22.28	3.49	0.44	4

Table 4 Area of gully erosion susceptibility zone

Gully erosion susceptibility zone	Area (km ²)	Area (%)
Very low	28.09	19.72
Low	40.60	28.49
Moderate	33.08	23.22
High	28.34	19.88
Very high	12.37	8.68

Table 5 Accuracy level of the study

Gully erosion susceptibility zone	Number of sites	Total sites	Level of accuracy (%)
Very low	1	11	72.72
Low	2		
Moderate	2		
High	3		
Very high	3		

Figures

Figure 1

Location of the study area

Figure 2

Showing details of methodology

Figure 3

Geomorphology map of Rupai river basin

Figure 4

Slope map of Rupai river basin

Figure 5

Land use land cover (LULC) map of Rupai river basin

Figure 6

Soil map of Rupai river basin

Figure 7

Stream power index (SPI) map of Rupai river basin

Figure 8

Curvature map of Rupai river basin

Figure 9

Lithology map of Rupai river basin

Figure 10

Elevation map of Rupai river basin

Figure 11

Drainage density map of Rupai river basin

Figure 12

Topographical wetness index (TWI) map of Rupai river basin

Figure 13

Gully erosion susceptibility zones map of Rupai river basin

Figure 14

GPS location map of gully in field with HSZ and VHSZ in Rupai river basin

Supplementary Files

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