Identification of Erosion Prone Areas around Mining Regions using Remote Sensing and GIS Technique: A Case Study of Dipka, Gevra and Kusmunda Coal Complex, Chhattisgarh, India

Hitesh Malagar[1], Ramkamal Bani[1], Manoj Kumar Sahu[1*], Bhaskar Prasad[1], Bhargava Kumar Iyengar[2], Tanveer Haidar[2]
[1]Chhattisgarh Council of Science and Technology Raipur, Vigyan Bhawan, Chhattisgarh- 492 014, India
[2]Department of Applied Geology, National Institute of Technology Raipur, Chhattisgarh- 492 010, India
*Corresponding email: mksahu1989@gmail.com

Abstract: The process of soil erosion involves tearing loose soil particles of transportable nature and their subsequent deposition. In the mining areas, overburden/dumps are composed mostly of unconsolidated and fragmented which get easily detached and are transported by the wind and surface overland flow during the rainy session. The main aim of this study is to estimate the soil loss annually from mining areas and identify and delineate areas that are erosion prone using the USLE model for Dipka, Gevra, and Kusmunda Coal Mine Area, Korba, Chhattisgarh. In the study area, the highest value of soil erosion estimated potentially was found to be 247 tons/ha/yr and the average annual soil loss for the whole study area is 1.69 tons/ha/yr. The USLE model depicts, that the entire study area can be classified into these five categories: Low, Moderate, High, very high, and Severe. Overburden dumps area has shown high erosion impacts in the study area which was validated during field visits. The modeled output and the field observation were put together to derive measures for erosion control within the study area.

Keywords: Coal mining region, Erosion potential, Erosion prone, Overburden dump, Geographic Information System (GIS) and Remote Sensing (RS), Soil erosion, Universal Soil Loss Equation (USLE).

Introduction

The process of soil erosion involves tearing loose soil particles of transportable nature and their subsequent deposition (Park et al., 1982). Soil erosion is a naturally occurring phenomenon resulting from the removal of topsoil by natural factors like wind and water. Anthropogenic activities (Mining and Deforestation) may also cause soil erosion to a great extent (Parveen and Kumar, 2012). Urbanization, deforestation, and mining activity, which lead to changes in land use patterns, are the leading causes of soil erosion in recent times (Parveen and Kumar, 2012). Changes in the land cover has attracted worldwide attention because of their potential effects on soil erosion and run-off (Joshi et al., 2009). Mining is one of the most key economic activities in Chhattisgarh, the Korba coalfield has been recognized as one of the most dormant coalfields in India. There are two major problems caused due to mining. The first is the pollution in rivers and their tributaries and the other is alluvial erosion (Joshi et al., 2006). Excessive silt migration from the Opencast Coal mining region is a serious environmental problem. Mining induces the physical detachment of the land surface and generation of the fragmented, unconsolidated, and coarse to fine, a mixed type of material in the area. This type of material is susceptible to erosion during the rainy season and generates excessive silt migration or soil erosion from the mining field. In the mining areas, overburden/dumps are composed mostly of unconsolidated and fragmented materials which get detached easily and are transported by the wind and surface overland flow during the rainy session. Therefore, mining areas surrounded by watersheds are creating environmental issues. The erosion phenomenon is also influenced by factors like slope steepness, climate (e.g., long dry session followed by downpour), inappropriate land use patterns, landcover (e.g., sparse vegetation), and ecological disasters (e.g., forest fires) (Renschler et al., 1999; Pradhan et al., 2021).

To estimate soil erosion various models have been developed and used. The application of remote sensing (RS) and geographic information system (GIS) techniques has been utilized in the present study. The major objective of this study is to estimate the annual loss of soil from mining areas, identification, and delineate erosion-prone areas using the Universal Soil Loss Equation (USLE) model for Dipka, Gevra, and Kusmunda Coal Mine Area, Korba, Chhattisgarh using GIS and RS techniques. Universal Soil Loss Equation is the most commonly used model. The USLE model was developed by the United States Agricultural Research Service. USLE was designed by Wischmeier (1978) for soil loss prediction. Based on the product of rainfall erosivity factor (R), erodability of the soil factor (K), slope length factor in meter (L), slope factor in percent (S), cover management parameter factor (C) and support practice parameter factor (P) USLE estimates soil loss (Devatha et al., 2015).

One of the main factors to assess the erosion of any area successfully is to estimate the soil loss risk and its spatial distribution. Spatial and quantitative information on soil erosion on a regional scale contributes to erosion control, conservation planning, and management of the surrounding environment. It is important to define quantitative assessments of erosion-prone areas and soil loss rates with the utmost accuracy to design and implement appropriate erosion control or soil and water conservation practices (Shi et al., 2004).

Study Area

The study area lies in the Korba district of the State of Chhattisgarh. The study area (Fig. 1) is an opencast coal mines area of SECL (South Eastern Coalfields Limited). There are three working Mines namely Kusmunda, Gevra, and Dipka. We have studied within the mine area and 5 km buffer. Kusmunda, Gevra, and Dipka mine area are estimated to be 98.97 km^2 and the 5 km buffer area is estimated to be 443.694 km^2. The study area is bounded by latitude 22°15'07" N to 22°24'57" N and longitude 82°26'55" E to 82°45'17" E. Soil erosion has been widely estimated using the USLE model in watershed/catchment area by many researchers. In the present study, we have applied and studied the USLE model in the mining region and the surrounding area. The study area is part of the Mahanadi River basin, the catchment of the Hasdo and Seonath Rivers. The study area is a part of three watersheds namely Ahiran, Litagur, and Lower Hasdo Watershed as per the classification of NBSS-LUP National Watershed Atlas (Fig. 2). Hasdo River is the main river flowing northerly from the eastern part of the study area with Aharan Nadi, Kholar Nala and Lilagar Nadi as its major tributaries. The study area has somewhat undulating and also flat terrain with a sub-tropical climate marked by extreme cold in winter and extremely hot in summer. The normal annual rainfall for the area is 1329 mm. The annual temperature varies from 10°C in winter to 46°C in the summer. The relative humidity varies from 82% during the rainy season to 35-40 % in winter. The elevation ranges from 275 m to 330 m above the mean sea level.

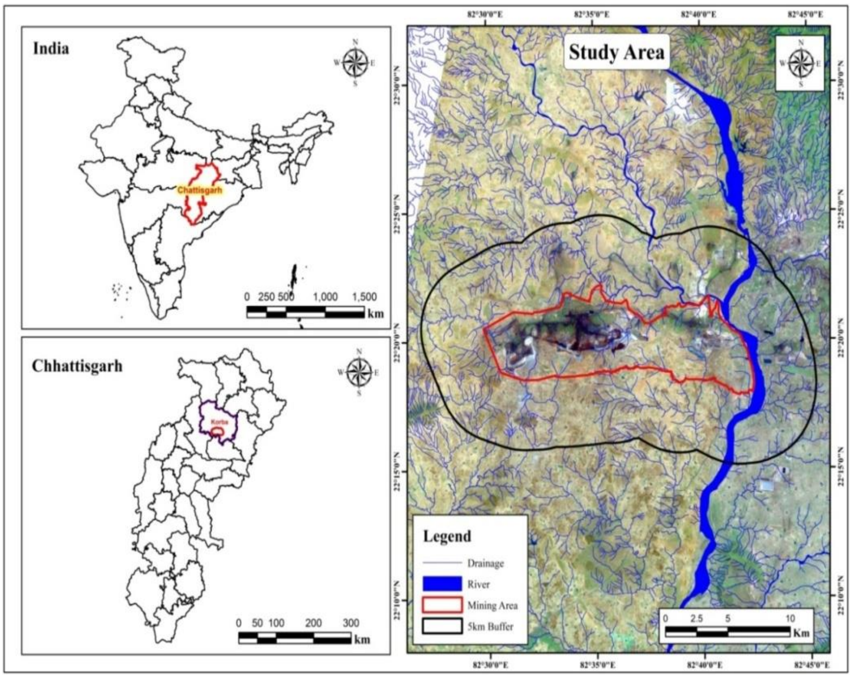

Fig. 1. Location Map of the Study Area.

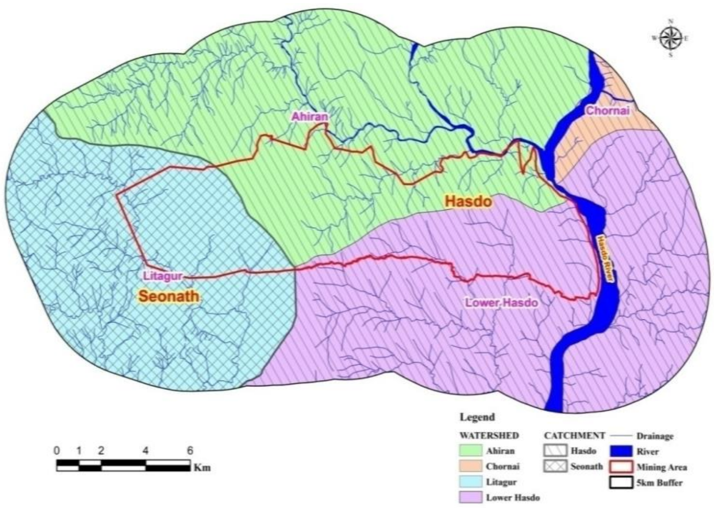

Fig. 2. Watershed Map of the Study Area.

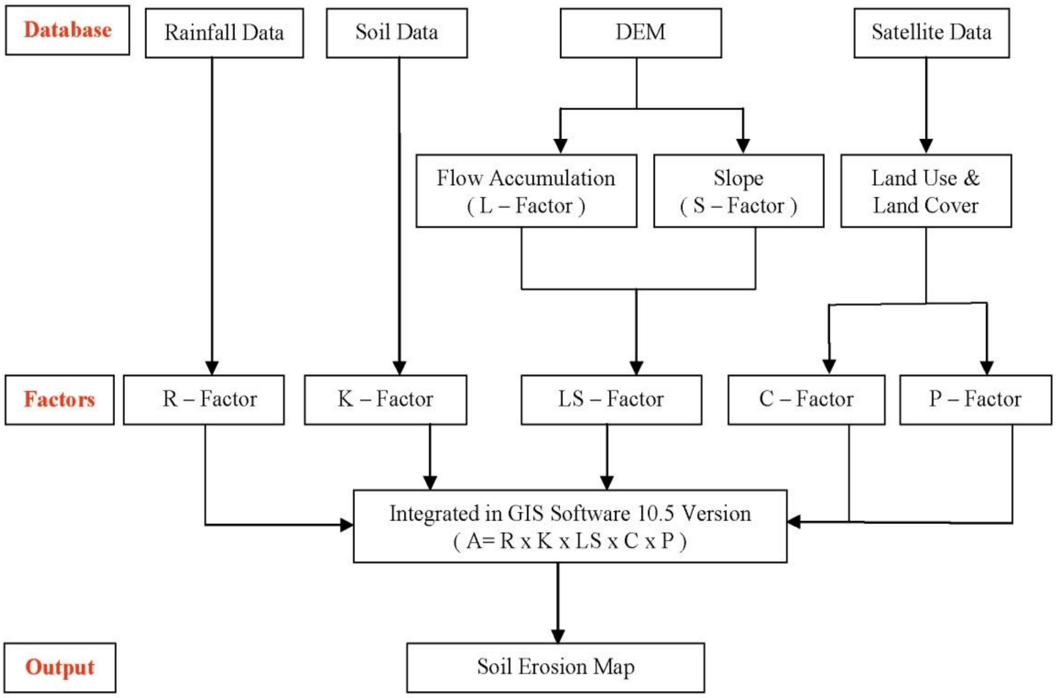

Fig. 3. Flow chart of the methodology adopted in the study to prepare soil loss assessment map.

Materials and Methods

In recent days, Remote Sensing and Geographical Information System techniques are majorly used over conventional methods of mapping (Pradhan et al., 2021) and monitoring the evolution of degraded areas. These techniques have become fast and versatile tools for assessing and monitoring environmental impacts as a result of natural and man-made activities (like mining, and deforestation). These techniques provide an excellent overview of the status of mining areas and the impact of mining activities (Joshi et al., 2006). Land use, land cover, and topographical data for the study area were derived using standard GIS tools and systematically executing data analysis. Data collection and analysis included the study of annual rainfall data, the creation of a digital elevation model (DEM), and land use classification. To estimate the soil erosion from the mining region, derivatives from the Remote Sensing data and Geographical Information System were used as inputs to the Universal Soil Loss Equation (USLE). Figure 3 shows a flow chart of the methodology adopted in the study to prepare a soil loss assessment map. The present study area expressed the erosion-sensitive sites of the Coal mines and also suggests suitable catchment area treatment (CAT) planning using Remote sensing and GIS. Various thematic maps and related GIS integration have been done in ArcGIS 10.5 software. Finally, different types of erosion control practices and structures were suggested to protect the adjacent Hasdo and Seonath river basins.

Universal Soil Loss Equation was employed to calculate the average annual soil loss (A) in tons per hectare per year (ton/ha/yr), denoted by the following equation (1) (Kimberlin and Moldenhauer, 1977; Foster et al., 1981; Renard et al., 2011; Parveen and Kumar, 2012; Dewangan, 2016; Pham et al., 2018) for the entire study area.

$$A = R \times K \times LS \times C \times P \quad \ldots (1)$$

Where: A is the Average annual soil loss rate tons per hectare per year (ton/ha/yr)
R is the Rainfall Erosivity factor megajoule millimeter per hectare hour year (MJ.mm/ha.hr.yr)
K is the Soil Erodibility factor tons hour per megajoule millimeter (ton.hr/MJ.mm)
LS is the Combined slope length and steepness factor (dimensionless)
C is the Vegetation factor (dimensionless)
P is the Conservation support practice factor (dimensionless)
The average yearly soil loss was estimated at 10m×10m cell size by overlaying the five digital thematic layers (R, K, LS, C, P) in raster format using ArcGIS 10.5 software package.

Rainfall Erosivity (R) factor

Linear relationships were established between yearly rainfalls using data for storms from four rain gauge stations located in Korba, Katghora, Pali, and Podi Uprora. To calculate the average annual R-factor values (Table 1), a ten year average annual data has been used. For rainfall distribution map of the study area an interpolation was done of average annual rainfall data as the data which is available for the area is not distributed uniformly. R factor was determined for the study area using equation (2) (Parveen and Kumar, 2012; Vemu and Pinnamaneni, 2012; Dewangan, 2016). This rainfall distribution map was used as input for the calculation of the R-factor.

$$R = P \times 0.5 \quad \text{.... (2)}$$

Where: P is the mean annual rainfall in mm and R is the rainfall erosivity factor in MJ mm/ha.hr.yr.

Table 1. Rainfall data of the study area.

Year	Rainfall (mm)
2020	1467.1
2019	1323.8
2018	1464.6
2017	1203.6
2016	1314.8
2015	1085.3
2014	1304.0
2013	1219.4
2012	1409.6
2011	1522.7
Average	1331.49

Table 2. Study area Soil Erodibility factor K.

Soil Texture	K Factor Value
Fine Loamy	0.41
Fine	0.47
Coarse Loamy	0.48
Coarse (Contrasting)Fine Loamy	0.42
Fine Silty	0.16
Loamy Skeletal	0.01

Soil Erodability (K) Factor

A soil physiographic class-type map of the study area was used to determine the erodability factor. K depends upon soil contents like soil texture, organic matter, and soil structure. Some researchers (Schwab et al., 1981; Nguyen et al., 1999; Sheikh et al., 2011; Parveen and Kumar, 2012) have reported a relationship between soil organic matter content and soil texture. Soil erodability of the study area was calculated using the linkage between soil texture class and organic matter and generate K factor map. Table 2 soil erodability factor (K) are the values assigned to different soil texture classes using the GIS technique. Earlier studies have proposed K values ranging from 0.48 to 0.009 with the highest values for soils with a high content of silt or very fine sand. The soil erodibility factor (K) based on the soil texture class are expressed as a low K value indicating soil particles are less susceptible to detachment and result in moderate runoff (Gitas et al., 2009; Parveen and Kumar, 2012; Ahmad and Verma, 2013).

Topographic Factor (LS)

The Topographic factor (LS) included in the USLE model is a combination of the Length factor and Steepness factor of the terrain. The interaction of slope size, angle of slope, and length affect the magnitude of erosion. This interaction result, the effect of slope length and the degree of slope should always be considered together. Using Digital Elevation Models (DEM) in the GIS, the slope gradient/steepness (S) and slope length (L) can be determined. The precision of slope gradient/steepness has been reported to be a function of the resolution of the digital elevation model (DEM) (Lin et al., 2013; Mondal et al., 2017; Arjita et al., 2020). Here in this study 10m, Cartosat DEM had been used to calculate slope gradient/steepness in the study area. To derive an LS map based on flow accumulation and slope steepness raster operations using a raster calculator of ArcGIS 10.5 was used. It is observed that the general slope of the study area is moderate to steep. Hence, we observe that the analysis of topographic factors plays a crucial role in determining the surface runoff speed which in turn indicates the risk of soil erosion.

Cover Management Factor (C)

The C factor embodies the land use of the study area which is an important factor affecting soil erosion (Pham et al., 2018). The C factor is mainly the vegetation cover expressed in percentage and is defined as the ratio of soil loss from specific crops. Vegetation type, stage of growth and cover percentage have a direct bearing on the C value (Parveen and Kumar, 2012). Vegetation cover is determined with the help of land use land cover maps prepared using satellite imagery using satellite images available in the free domain (Google Earth Images). Table 3 shows the C factor value obtained from previous research (Devatha et al., 2015; Dewangan, 2016) and is assigned to each grid to obtain the C factor map. The broad land use categories of the study area are - cropland 44%, Scrub Land 21%, Mining/Industrial 6%, Forest 5%, and Built-up 10% of the total area (443 km^2). Table 3 shows the land use classes found in the study area and their C-value used in USLE for this study area.

Table 3. Study area Land use and Landcover C and P factor values.

Land use Type	**C -value**	**P-value**	**Area (in km^2)**	**Area (in %)**
Active Dump	0.7	1	9.7342	2.19
Built-up (Urban)	0.1	0.5	2.7809	0.63
Canal	0	0.1	1.0811	0.24
Core Urban	0.1	0.5	17.8453	4.02
Crop Land	0.34	0.4	195.6063	44.08
Dump Slope	0.8	1	1.1032	0.25
Forest	0.01	0.2	23.6356	5.33
Forest Plantation Active Dump	0.01	0.2	3.8964	0.88
Forest Plantation Over Burden	0.01	0.2	17.7692	4.00
Guilled/Ravenious	0.4	1	0.2349	0.05
Hemlets And Dispersed House Hold	0.2	0.5	5.0774	1.14
Lake/Pond	0	0.1	4.8323	1.09
Mining/Industrial	0.1	0.5	27.6717	6.24
Old Dump	0.44	1	4.8495	1.09
Periurban	0.2	0.5	7.3512	1.66
Reservoir/Tanks	0	0.1	2.5437	0.57
River/Stream	0	0.1	6.7460	1.52
Sandy Area	0.01	0.2	6.2243	1.40
Scrub Land Dense	0.2	0.4	14.6113	3.29
Scrub Land Open	0.3	0.6	78.7622	17.75
Urban	0.2	0.5	0.1695	0.04
Village	0.2	0.5	11.0169	2.48
Waterlogged	0.01	0.1	0.1611	0.04
Grand Total			**443**	**100**

Conservation Practice Factor (P)

Different farming practices (like contouring, strip cropping, and terraced contour) also affect soil erosion as they modify the flow pattern, grade, and/or direction of the surface runoff. P factor includes such practices to highlight potential erosion by water runoff. A high P value is an indicator of high erosion (Pham et al., 2018). The P value for the study area ranges between 0.1 to 1 and the P factor map was obtained using the LULC map as input. The P values used for different land use classes (Devatha et al., 2015; Dewangan, 2016) are shown in Table 3.

USLE Model outputs

The average annual soil erosion potential (A) of the study area is evaluated by multiplying the derived raster data from each USLE analysis shown by equation (3):

$$A= R \times K \times LS \times C \times P \quad \text{…. (3)}$$

The final USLE map displays the same Dipka, Gevra, and Kusmunda Coal Mine Area in Figure 4. In the study area, highest value of estimated soil erosion potential was found to be 247 tons/ha/yr and the mean annual soil loss for the entire study area is 1.69 ton/ha/yr. Soil loss which is estimated to be around 100ton/yr is carried away from the area and gets deposited in the river. The soil erosion map was reclassified according to different erosion potential classes and the output map of the soil erosion index was generated. Erosion potential classes and there occupy an area as shown in Table 4. Figure 4 shows the annual soil erosion map and the spatial distribution of different erosion classes for the study area.

Table 4. Study area Soil loss classification.

Soil Erosion Value Range (ton/ha/yr)	Erosion Class	Area in km^2	Area (Percent)
0-50	Low	415.169	93.63
51-100	Moderate	23.503	5.30
101-150	High	1.744	0.39
151-200	Very high	1.400	0.32
201-250	Severe	1.604	0.36

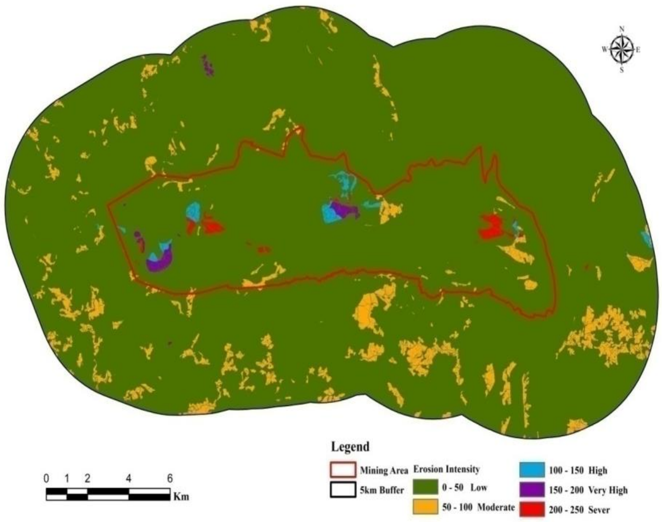

Fig. 4. Soil Erosion Potential Map of the Study Area (based on USLE Model).

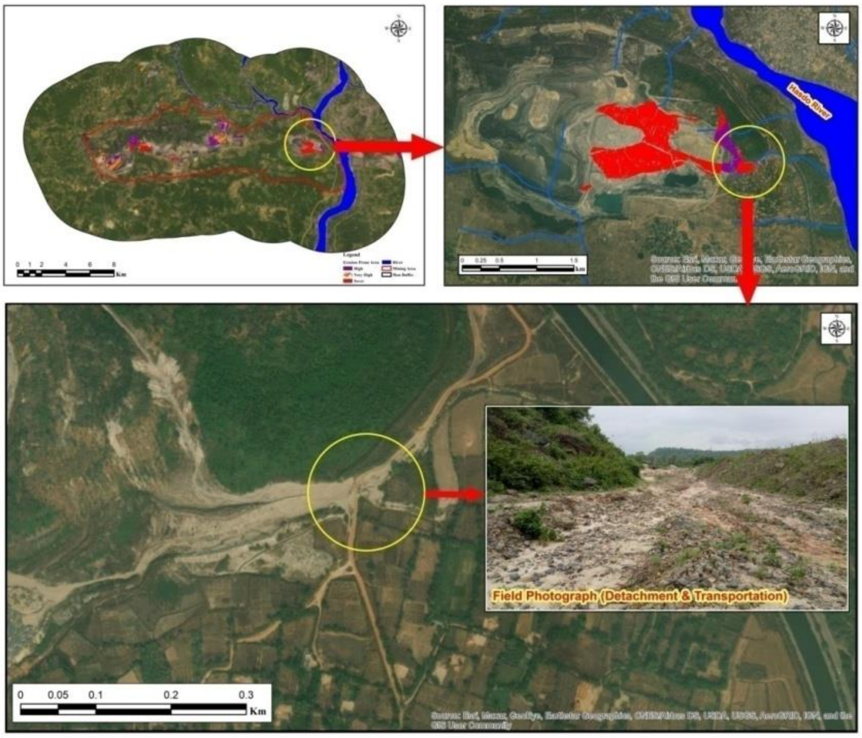

Fig. 5. Identification of sediment source areas of the study area.

Result and Discussion

The open-cast mining process progresses bench by bench for the extraction of Coal in the study area. Economically valuable Coal gets transported to the industry and less economic value coal and extracted soil material is left as an overburden dump within the coalfield area. During the rainy season, these overburden dumps are a major source of soil detachment. Therefore, it is important to target the silt migration of sensitive areas for conservation. There are many sensitive sites located in the study area, especially within the mines area based on USLE model results. The results of soil loss as per the USLE model, silt migration wise the entire study area can be classified into five categories: Low, Moderate, High, very high, and Severe.

Erosion and silt migration sensitive sites of the mine area

Based on the results obtained from the USLE model, we observed soil erosion in more than 100 tons/ha/yr study areas on the map. We have seen that most of this area belongs to the overburden dump area. And dumps have shown high erosion impacts in the study area. Figure 5 shows Erosion and silt migration-sensitive sites of the mine area.

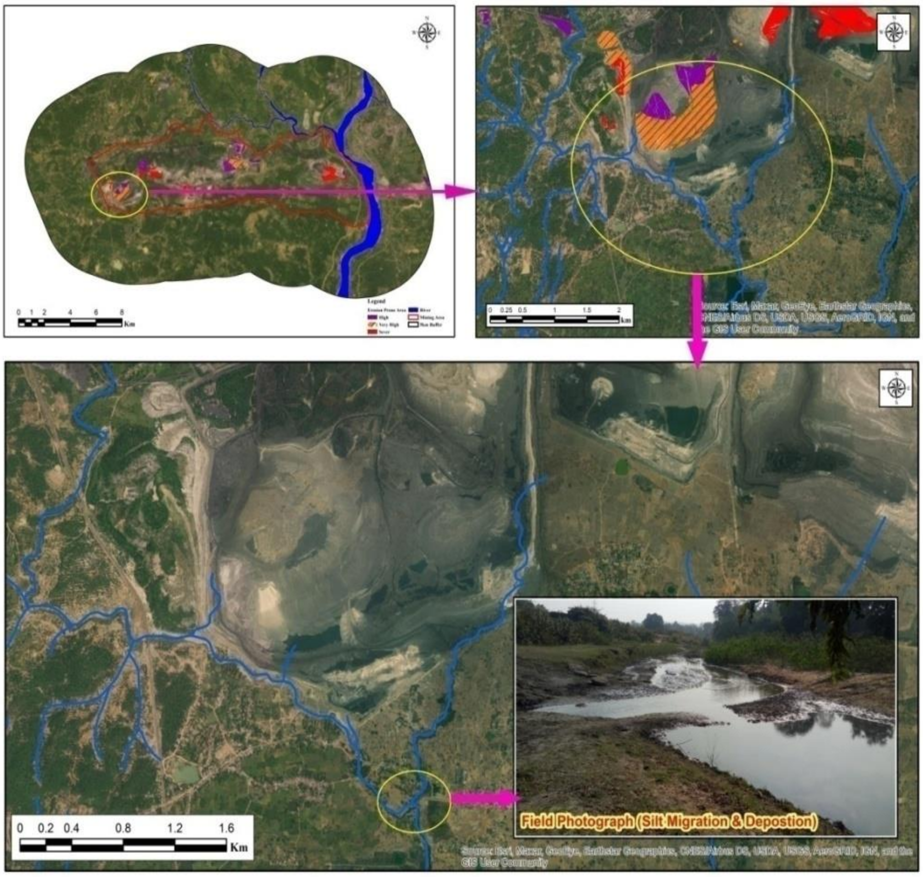

Fig. 6. Deposition of silt at a river bed in the study area.

Identification of sediment source areas

After the final erosion-prone map visited the study area in the dry season and rainy season. During field visits, high erosion zones were observed based on the USLE model, with most of the observed silt and sediment source areas being of the dump area (Fig. 6). We have found that these areas are source areas of sediment and silt. And they are carried through the drainage network surrounding the dump and accumulate in the river bed (Fig. 7). Within the mines area, large numbers of small and large-sized overburden dumps exist. The total area of overburden dumps is about 8.47 percent (37.58 km^2) of the study area. About 57.64 percent (21.66 km^2) of the total overburden dump area has already been planted and plantation work is going on in some areas. And plantation work has not been done in the remaining dump areas. Even in the planted area, some areas do not have dense plantations. And some plantation gap patches exist within the existing plantation area. Most of the mining dumps have acquired a height of 45m on average, with a slope of around 30°. Dump slopes and plantation gaps are a high potential for water and wind erosion.

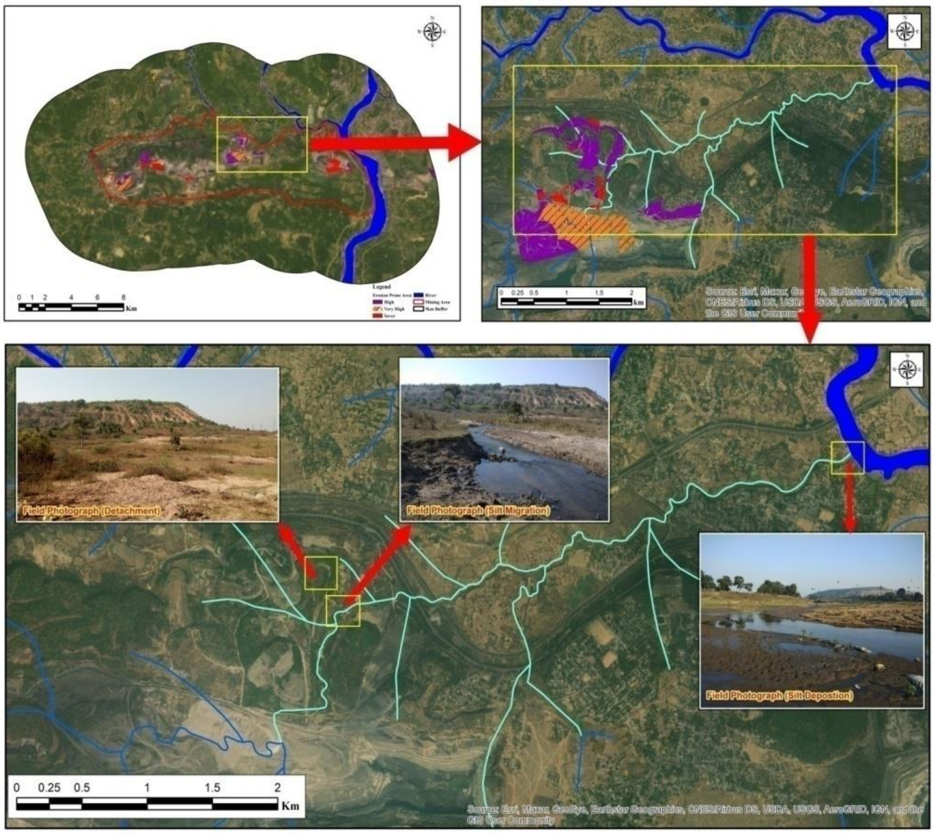

Fig. 7. Show soil erosion process: Detachment of sediments, transport of sediments throws stream and subsequent deposition of silt at a river bed.

Prioritization of the drainage for the erosion control measures

During the investigation and identification of the tributaries of the river found that they have high sediment loads. And sediment loads are directly discharged into the river from their tributaries. We identify the silt migration paths, which are directly or indirectly connected (through a drainage network) to the mine and carry the silt towards the Hasdo and Shivnath rivers. Figure 8 shows the soil erosion process Detachment of sediment, transport through the stream, and subsequent deposition of silt at the river bed.

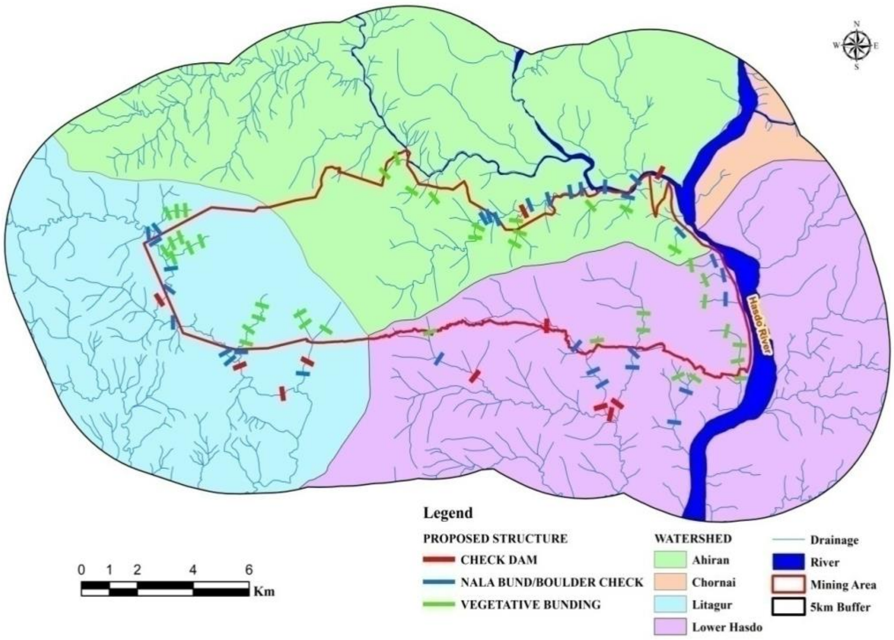

Fig. 8. Catchment Area Treatment Planning in the study area.

Catchment Area Treatment Planning

Based on surface hydrology, GIS-USLE outputs, and field survey, suitable locations were determined to construct the silt control structures. Within the mines area active dump 9.73 km^2 area, dump slop 1.33 km^2 area and plantation gap 1.05 km^2 area occupy. These are the main sources of silt migration towards the rivers. Therefore, suitable and sustainable silt migration control planning is required for the protection of adjacent watersheds.

Erosion Control Recommendation

The field observations were further seen expressed on the satellite images and have been mapped for deriving erosion control measures in the study area. Also, the outputs of the Universal Soil Loss Equation (ULSE) bring out the areas of erosion. Both the modeled output and the field observation were put together to derive the recommendations for change in existing land use and built erosion control measures within the existing drainage (small nalas, streams, and rivers). The following measures are as follows:

(A) Erosion Control Measures for Dump and open land	(B) Erosion Control Measures for existing drainage
i. Phase Wise Plantation in an open area and New dumps	i. Vegetative Bunds
ii. Gap Plantation in the existing Plantation area	ii. Nala Bunds/Boulder Checks
iii. Intensive Plantation on the riverbank	iii. Check Dam
iv. Steep Slope Stability Measures/Carpeting	

Revegetation/plantation is the commonly used method for erosion prevention and dumps slope stabilization. The hydrogeological action and roots of vegetation play an important role to raise dump stability by controlling the interception of rainwater. Local plant species are Easily available and well suited to the local climate, soil condition, and available moisture; therefore, they are good species for plantation. The indigenous species have a good binding capacity of soil and it helps control soil erosion as well as improve the dump stability (Ranjan et al., 2015). In many places of coal mines area, erosion control blankets such as coir mats, Hydroseeding can be used for dump slope protection. Establishing a vegetative layer is critical to sites where there are exposed slopes and no further construction is planned. Examples of some indigenous species are, *Tree Species*: Mahua (Madhuca longifolia), Saja (Terminalia tomentosa), Aam (Mangifera indica), Neem (Azadirachta indica), Jamun (Syzgium cumini), Bargad (Ficus benghalensis), Pipal (Ficus religiosa), Babool (Acacia nilotica), Palas (Butea monosperma). *Shrub Species*: Chilhi (Casearia tomentosa), Adusa (Adhatoda vasica), Karonda (Carissa spinarum). *Grasses Species*: Vetiver grass (Chrysopogon zizanioides) Moonj grass (Saccharum munja) Stylish Hemata grass (Stylosanthes Sp.) For water-logged areas, Bermuda grass is also known as Vilfa stellate (Cynodon dactylon).

Conclusion

The present study is the application of the USLE model and RS-GIS integrated approach at Coal Mines. The developed methodology can be utilized as a decision-making tool to establish a suitable catchment area treatment plan in the Coal mining region. Such sustainable mining practices can reduce environmental stress. Based on GIS-USLE outputs and field survey most of the silt and sediment source areas belong to overburden dump areas and dumps have shown high erosion impacts in the study area. Within the mines area active dump 9.73 km^2 areas, dump slop 1.33 km^2 areas and plantation gap 1.05 km^2 areas occupy. These are the main sources of silt migration towards the rivers. Therefore, mining areas surrounding watersheds are creating environmental issues. Silt deposition affects river depth and water flow.

Acknowledgment

The authors are highly thankful to the Director General, Chhattisgarh Council of Science and Technology (CCOST), Raipur, Chhattisgarh, for providing guidance and necessary facilities to carry out this work and thankful for the cooperation of SECL officers for the field visit and data collection. The authors are also thankful to Shri. P. Kawishwar, Scientist 'E-1' (CCOST) for critical review of the research works.

Conflict of Interest

The authors have no conflict of interest regarding this work.

References

Ahmad, I. and Verma, M. K. (2013). Application of USLE Model and GIS in Estimation of Soil Erosion for Tandula Reservoir. International Journal of Emerging Technology and Advanced Engineering, v.3, pp.570-576.

Saxena, A., Jat, M.K. and Kumar, S. (2020). Uncertainty Analysis of High-Resolution Open-Source Dems for Modelling Soil Erosion. Proceedings of the Roorkee Water Conclave, pp.1–13.

Dept. of Mining Engineering, IIT Kharagpur. Silt Migration Problems and its Related Environmental Issues in the Hilltop Mining Region: A Case Study, Gua Iron Ore Mine Gua Iron Ore Mine.

Devatha, C. P., Deshpande, V. and Renukaprasad, M. S. (2015). Estimation of Soil loss Using USLE Model for Kulhan Watershed, Chattisgarh- A Case Study. Aquatic Procedia, v.4, pp.1429–1436.

Dewangan, A. (2016). Modeling Surface Runoff Path and Soil Erosion in Catchment Area of Hanp River of District Kabeerdham, CG, India, Using GIS. International Journal of Scientific and Research Publications, v.6, pp.645–650.

Foster, G. R., McCool, D. K., Renard, K. G. and Moldenhauer, W. C. (1981). Conversion of the universal soil loss equation to SI metric units. Journal of Soil and Water Conservation, v.36, pp.355–359.

Gitas, I., Silleos, G., Karydas, C., Minakou, C. and Douros, K. (2009). Multi-temporal soil erosion risk assessment in N. Chalkidiki using a modified USLE raster model. EARSeL E Proceedings, March 2014.

Joshi, P. K., Kumar, M., Midha, N., Vijayanand and Paliwal, A. (2006). Assessing areas deforested by coal mining activities through satellite remote sensing images and GIS in parts of Korba, Chhattisgarh. Journal of the Indian Society of Remote Sensing, v.34, pp.415–421.

Joshi, P. K., Kumar, M., Paliwal, A., Midha, N. and Dash, P. P. (2009). Assessing impact of industrialization in terms of LULC in a dry tropical region (Chhattisgarh), India using remote sensing data and GIS over a period of 30 years. Environmental Monitoring and Assessment, v.149, pp.371–376.

Kimberlin, L. W. and Moldenhauer, W. C. (1977). Predicting Soil Erosion. In: ASAE Publ., pp. 31–42.

Lin, S., Jing, C., Coles, N. A., Chaplot, V., Moore, N. J. and Wu, J. (2013). Evaluating DEM source and resolution uncertainties in the Soil and Water Assessment Tool. Stochastic Environmental Research and Risk Assessment, v.27, pp.209–221.

Mondal, A., Khare, D., Kundu, S., Mukherjee, S., Mukhopadhyay, A. and Mondal, S. (2017). Uncertainty of soil erosion modelling using open source high resolution and aggregated DEMs. Geoscience Frontiers, v.8, pp.425–436.

Nguyen, H. V, Nieber, J. L., Oduro, P., Ritsema, C. J., Dekker, L. W. and Steenhuis, T. S. (1999). Modeling solute transport in a water repellent soil. Journal of Hydrology, v.215, pp.188–201.

Park, S. W., Mitchell, J. K. and Bubenzer, G. D. (1982). Splash Erosion Modeling: Physical Analyses. Transactions of the American Society of Agricultural Engineers, v.25, pp.357–361.

Parveen, R. and Kumar, U. (2012). Integrated Approach of Universal Soil Loss Equation (USLE) and Geographical Information System (GIS) for Soil Loss Risk Assessment in Upper South Koel Basin, Jharkhand. Journal of Geographic Information System, v.4, pp.588–596.

Pham, T. G., Degener, J. and Kappas, M. (2018). Integrated universal soil loss equation (USLE) and Geographical Information System (GIS) for soil erosion estimation in A Sap basin: Central Vietnam. International Soil and Water Conservation Research, v.6, pp.99–110.

Pradhan, R.M., Guru, B., Pradhan, B. and Biswal, T.K. (2021). Integrated multi-criteria analysis for groundwater potential mapping in Precambrian hard rock terranes (North Gujarat), India. Hydrological Sciences Journal, v.66, pp.961-978.

Ranjan, V., Sen, P., Kumar, D. and Sarsawat, A. (2015). A review on dump slope stabilization by revegetation with reference to indigenous plant. Ecological Processes, v.4, pp.1–11.

Renard, K. G., Yoder, D. C., Lightle, D. T. and Dabney, S. M. (2011). Universal Soil Loss Equation and Revised Universal Soil Loss Equation. Handbook of Erosion Modelling, pp.135–167.

Renschler, C. S., Mannaerts, C. and Diekkrüger, B. (1999). Evaluating spatial and temporal variability in soil erosion risk—rainfall erosivity and soil loss ratios in Andalusia, Spain. Catena, v.34, pp.209–225.

Schwab, G. O., Frevert, R. K., Edminster, T. W. and Barnes, K. K. (1981). Soil and water conservation engineering. John Wiley and Sons.

Sheikh, A. H., Palria, S. and Alam, A. (2011). Integration of GIS and Universal Soil Loss Equation (USLE) for soil loss estimation in a Humalayan Watershed. Recent Research in Science and Technology, v.3, pp.51–57.

Shi, Z. H., Cai, C. F., Ding, S. W., Wang, T. W. and Chow, T. L. (2004). Soil conservation planning at the small watershed level using RUSLE with GIS: a case study in the Three Gorge Area of China. Catena, v.55, pp.33–48.

Vemu, S. and Pinnamaneni, U. B. (2012). Sediment yield estimation and prioritization of watershed using remote sensing and GIS. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, v.39, pp.529-533.

Wischmeier, H., W. and Smith, D. D. (1978). Predicting rainfall erosion losses. Agric. Handb. no., 537, pp. 285-291.

Manuscript received: 19-06-2023
Manuscript accepted: 18-07-2023

