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ORIGINAL ARTICLE

Modeling of water induced surface soil erosion and the potential risk zone prediction in a sub-tropical watershed of Eastern India

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Abstract

Soil is the earth's fragile skin that anchors all life on earth. Half of the topsoil on the planet has been lost in the last 150 years. Land degradation due to soil loss is one of the major environmental concerns which can be influences by the natural as well as anthropogenic activities. These impacts include compaction, loss of soil structure, nutrient degradation, and soil salinity. The effects of soil erosion go beyond the loss of fertile land. It has led to increased pollution and sedimentation in streams and rivers. And degraded lands are also often less able to hold onto water which can worsen flooding. Revised Universal soil Loss Equation (RUSLE) model and integration with Geographical Information System (GIS) have been taken into consideration for estimating the average annual soil loss in Arkosa watershed. The Overlay Analysis technique have been adopted in RUSLE model for estimating the influences of different factors namely rainfall and runoff erosivity factor (R), soil erodibility factor (K), slope length and steepness factor (LS), cover and management factor (C) and support practice factor (P) etc. The average annual soil loss of Arkosa watershed ranged between 0 to 10 tons/ha/year. Here the combined index method has been adopted to show the impact spatially of combine index of these five factors, i.e., R, K, LS, C and P. Apart from this there are total 29 points have been selected randomly for securing that the present soil loss model sounded with ground reality or not. The actual soil loss and predicted soil loss show the positive relationship with them in an r2 value of 0.882. Besides this the present study provides a reliable prediction for future on potential soil erosion risk zones which ranged between 0 and 16 tons/ha/year. To overcome from extreme or severe soil loss situation suitable soil conservation practices or support practices have to be taken care off for minimizing the erosion of the fertile soil or the top soil for making the region less vulnerable from soil erosion in present rate. Sustainable land use can help to reduce the impact of agriculture and livestock, preventing the soil degradation and erosion and the loss of valuable land to deforestation.

Keywords Land degradation · RUSLE · GIS · Overlay analysis · Sustainable land use · Deforestation

Introduction

Soil is the most important exhaustible natural resource because it is not possible to return if it is destroyed or lost through anthropogenic activities. Soils are mostly eroded through the different processes like sheet erosion, tunnel erosion, rill and formation of gully which are the extreme forms of degradation of land resources (Ghosh et al. 2016). It is found that soil erosion costs the United State economy between US $ 30 billion to US $ 44 billion annually. In Indonesia this cost is nearly US $ 400 million per year in Java alone (Morgan 2005).The weathered materials of rocks are transported by a particular process are popularly familiar as erosion. There are numerous agents which are associated with erosion these are water, glacial, wind, waves etc. There are two clear cut phases of soil erosion these are the process of detachment of particles from top soil and transportation of the same materials by active agent like water and wind (Bhandari et al. 2015). Soil degradation is one of the most important elements of land degradation by which the physical, biological as well as chemical environment are degraded. Chemical degradation is mainly associated

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with the process of leaching, exploitative cropping system and poor irrigation practices (Chemeda 2007). Leaching process of chemical degradation is common in most of the tropical and sub tropical countries. Biological degradation of soil means the decreasing tendency of biological activity. When the amount of vegetation of a specific area is destroyed then the biological and ecological association of a soil is declined. Physical degradation is the amalgamation of numerous interrelated processes and it is included with chemical and biological degradation process (Chemeda 2007). Land degradation from soil loss is a monotonous issue in most of the developing countries like India and it is estimated that about 3.975 million hectors land in India have been degraded due to soil loss (Ghosh et al. 2010). Land degradation from soil loss is a common issue and it is growing rapidly. There are numerous works on land degradation due to soil loss (Foster and Meyer 1972; Renard et al. 1997; Millward and Mersey 1999; Van der Knijff et al. 1999; Sadiki et al. 2004; Hasim et al. 2005; Ghosh and Guchhait 2012; Prasannakumar et al. 2012; Aiello et al. 2015; Belasri and Lakhouili 2016).

Several researchers identified that GIS and Remote Sensing is the most reliable and dependable tools in the measurement of soil erosion through different empirical and semi empirical models (Irvem et al. 2007; Terranova et al. 2009; Kouli et al. 2009; Demirci and Karaburun 2012; Ganasri and Ramesh 2016). This is the arrangement of empirical/semi-empirical nature and process based model (Biswas and Pani 2015).

In RUSLE, the rainfall runoff factor of the original USLE (Universal Soil Loss Equation) was replaced by the rainfall erosivity factor (Renard et al. 1997; Dutta 2016; Bera 2017). The Universal Soil Loss Equation (RUSLE) was used for predicting the long term average annual soil erosion on the basis of different factors which is directly and indirectly related with soil loss in a specific area. The RUSLE is an empirical equation that computes the average annual soil loss in tons /ha/year. The RUSLE is the earliest quantitative soil loss models, is relatively easy and acceptable and that has been applied in various region of the world in modified form (Roche 1954; Yin et al. 2006; Angima et al. 2003). But its initial function and formula changes and its modified form applied in the Asia, Africa and Australia's environment (Angima et al. 2003).

The Revised Universal Soil Loss Equation (RUSLE) is one of the most popular and reliable method and it is based on ground based observation and integrated with Remote Sensing and GIS (Pandey et al. 2007; Sharma 2010; Pal and Samanta 2011; Shit et al. 2015; Biswas et al. 2015; Samanta et al. 2016a, b; Pal and Shit 2017). This model have been use widely for its simple function and available data function (Jain and Kothyari 2000; Bhattarai and Duttta 2007; Pandey et al. 2007; Sinha and Joshi 2012; Jiang et al. 2015; Balasubramani et al. 2015, Biswas et. al. 2015).

In RUSLE model, the amount and direction of slope and characteristics of aspect are applied for mainly the purpose of segmentation (Lewis et al. 2005; Tetford et al. 2017; Tilahun et al. 2018; Wijesundara et al. 2018). Integration of statistics and GIS is one of the important synthetic tools for predicting the present status of soil erosion as well as the prediction about the future scenario of soil loss. Selected factors have to be assign according to their weight then soil erosion hazard have been identified with the help of Z score (Rahman et al. 2009). This model can easily indent the nature of eroded materials which is deposited through sediment transportation (McCool et al. 2004).

In RUSLE with integration of GIS the sediment yields have been measured through the Sediment Assessment Tool for Effective Erosion Control (SATEEC) (Lim et al. 2005). The amount of potential soil loss through RUSLE model in GIS framework can identify the vulnerable areas which is very much susceptible for development of rill, gully etc. (Fagbohun et al. 2016). The vulnerable land use classes can be estimated from the RUSLE model in GIS environment for mainly in planning purposes (Balasubramani et al. 2015). Beside this several researchers applied RUSLE model for accounting the soil loss in numerous fields: (Mccool et al. 1987; Moore et al. 1992; Busacca et al. 1993; Renard et al. 1994; Yoder and Lown 1995; Liu et al. 2000; Wang et al. 2000; Stolpe 2005; Prasannakumar et al. 2012; Mallick et al. 2014; Predeep et al. 2015; Mondal et al. 2016).

MCDA (Multi Criteria Decision Analysis) is one of the most reliable toll for identifying the vulnerable areas of soil erosion and their associated surface lowering with incorporating the all phenomena that is related with soil loss in precise manner (Pal 2016). Samanta et al. (2016a, b) has been used the RUSLE in GIS environment for indentifying the vulnerable areas with the help of soil erosion susceptibility mapping as well as and measures the soil conservation planning in the soil erosion vulnerable areas. Hembram and Saha (2018) established that the morphometric attributes of a drainage basin can play a significant role in relation to soil erosion and prioritization of sub-watersheds with the help of fuzzy AHP and compound factor can reduce the reduce the rate of soil erosion within this basin. Assessment of soil erosion susceptibility is essential through soil erosion susceptibility mapping is essential in the soil erosion vulnerable areas and take initiative through proper land use and management practices (Pal and Debanshi 2017). Gayen and Saha (2017) used weights from evidence and evidential belief function for preparing the soil erosion susceptibility mapping which established in ground reality with adequate accuracy.

When the adequate primary information regarding the rainfall in storm period is unavailable then the TRMM data is one of the most important reliable sources for predicting the rainfall and runoff erosivity factor (MJ mm/ha/hr/year) because it provides the high resolution precipitation datasets which almost similar to ground reality (Heiblum et al. 2011; Dutta et al. 2015).

The availability the quantitative data with good quality is not sufficient in most of the developing countries hence the application of such type model is limited. Every empirical and semi empirical model have some unique function so one single model is not enough to fulfill the objectives. Determinations of RUSLE variables are necessary but the acquiring and fitting of observed data is time dependent and become costly. The major objective of this work is to estimate the average annual soil loss and to highlight the future potential soil loss risk zones with spatial coverage of Arkosa watershed for future which may help to take suitable remedies for sustainable land use practices.

Location of the study area

Arkosa is a right bank and important tributary of river Dwarkeswar. It originates near Hura of Puruliya District and meets with River Dwarkeswar near Ramnagar village

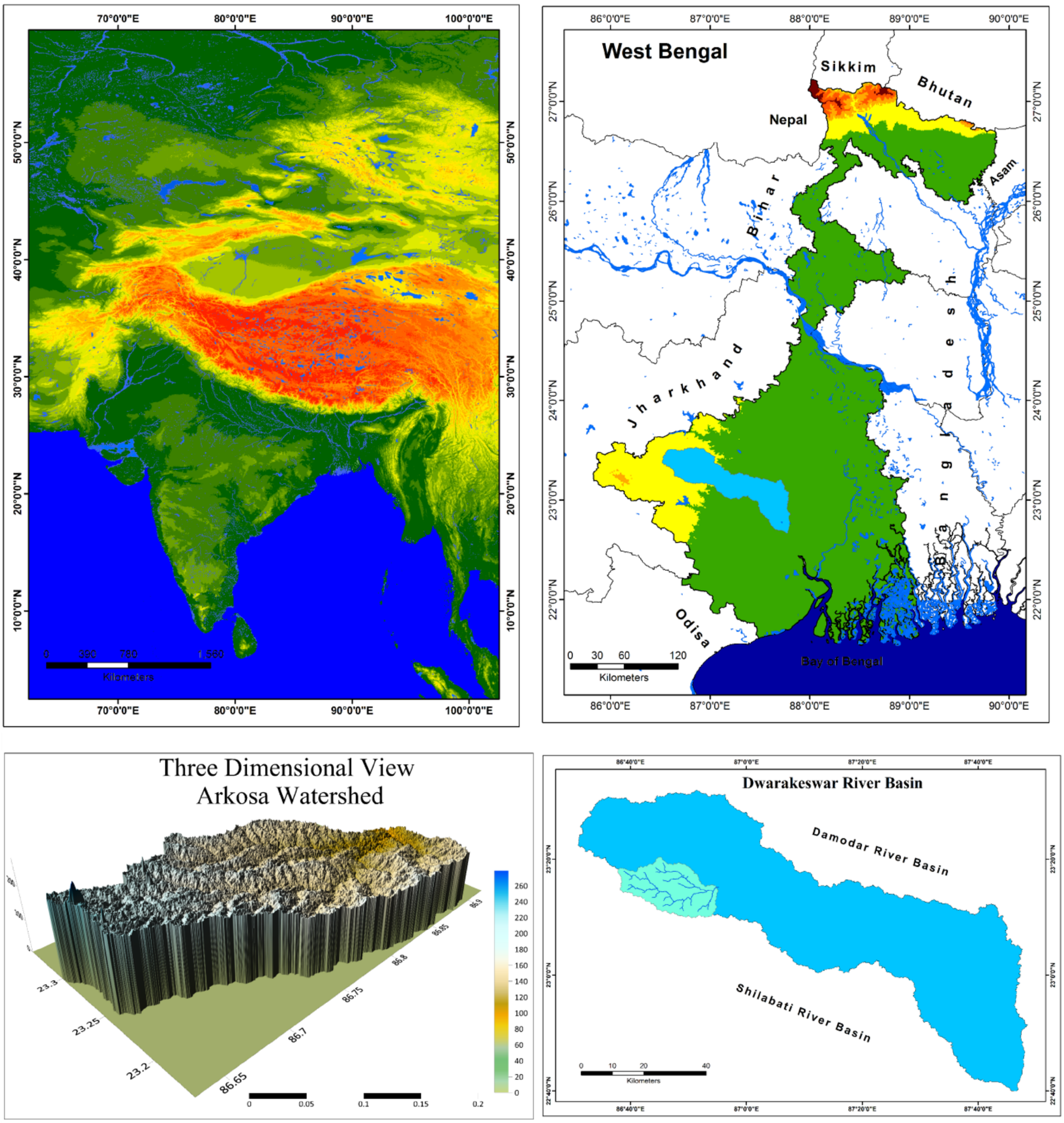


Fig. 1 Location of the study area

near the town of Bankura Sadar of Bankura District. It is bounded by latitude 23° 9′49.49"N to 23°20′24.18"N and longitude 86°37′48.30"E to 86°54′53.24"E in corresponding area of 348.5 Km^2 (Fig. 1). According to the watershed atlas of India this study area belongs to the watershed codification of 2A2C8. The river originates from near Tilaboni hill of Puruliya district and enters the Bankura district in Chhatna C.D. block (Chakrabortty et al. 2018). It passes through Bankura town and enters into the southeastern part of Purba Bardhaman district. The River Dwarkeswar ultimately leaves behind into Hooghly district.

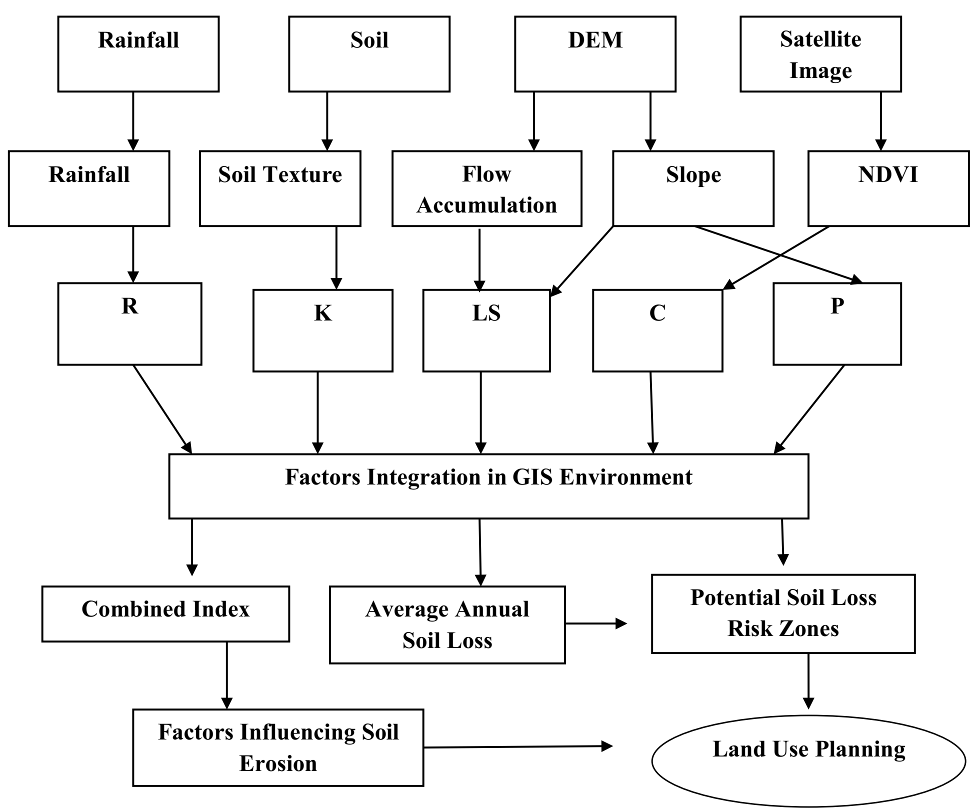
Data used

Keeping in the view of objectives of this work the following datasets have been use to continue this work, these are: Topographical map by Survey of India, Landsat 8 OLI sensor satellite data by United State Geological Survey (http://www.usgs.gov/), Shuttle Radar Topographic Mission (SRTM) Digital Elevation Model (DEM) by United State Geological Survey (http://www.usgs.gov/), Soil Texture map by NBSS&LUP Kolkata, Rainfall records from rain gauge station etc. the R (rainfall and runoff erosivity) factor raster has been created from the observed rainfall records in storm rainfall periods. The K (soil erodibility) factor raster has been estimated from the soil texture records and its chemical properties that is established by NBSS&LUP Kolkata. The LS (slope length and steepness) factor has been estimated from the SRTM MEM with considering the nature of flow accumulation and characteristics and nature of slope in GIS environment. The vegetation algorithm raster like NDVI (Normalized Difference vegetation Index) form Landsat 8 OLI sensor satellite data has been taken into consideration for estimating the C (cover and management) factor in GIS environment. The P (support practice factor related to slope direction) factor raster has been estimated from the percentage slope in SRTM DEM and observed support and management practices within this region during the field visit.

Materials and method

Catchment wise soil erosion is estimated through numerous methods, these models have been classified according to their nature i.e., empirical model, semi-empirical model, physical based model and conceptual model. Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1978) and Revised Universal Soil Loss Equation (RUSLE) (Renard et al. 1997) are included in the empirical model. Modified Universal Soil Loss Equation (MUSLE) (Williams and Bernd 1977), Morgan, Morgan, and Finney (MMF) Model (Morgan et al. 1984) and Revised Morgan Morgan Finney (RMMF) Models are included with semi-empirical model. Water Erosion

Fig. 2 Methodology flow chart



Prediction Project (WEPP), Soil and Water Assessment Tool (SWAT), Agricultural Non Profit Source Pollution Model (AGNPS), European Soil Erosion Model (Morgan et al. 1998, 1999; Kinnell 1999) are included with the physical based model. Sediment Concentration Graph (Johnson 1943), Renard-Laursenn Model (Renard and Laursen 1975), Unit Sediment Graph (Rendon-Herrero 1978), Instantaneous Unit Sediment Graph (Williams 1978), EMSS (Vertessey et al. 2001), HSPF (Johanson et al. 1980), IQQM (DLWC 1999), LASCAM (Viney and Sivapalan 1999) and SWRRB (USEPA 1994) are included with conceptual model.

In this study Revised Universal Soil Loss Equation (RUSLE) has been taken into consideration to estimate the average annual soil loss of Arkosa watershed. Application of RUSLE model in GIS framework was vastly used even in rugged topography, tropical forests and the watershed with a steep slope (Samanta et al. 2016a, b) and even in rugged topography. Universal Soil Loss Equation (USLE) is generally accepted for its simplicity but it is difficult to measure rainfall-runoff factor in a single framework. So in RUSLE in this factor replaced as a rainfall and runoff erosivity factor (Fagbohun et al. 2016). So different researcher of the world has been used RUSLE in GIS environment to fulfill the research objectives in less quantity data sets but an adequate accuracy (Zhihua et al. 2002; Lu et al. 2004; Fu et al. 2006; Yue-Qing et al. 2008; Chen et al. 2011; Kumar and Kushwaha 2013).

The factors that are used in RUSLE acquired from rain gauge station, soil data, DEM and satellite image etc. The five thematic layers have been taken into considerations as input of RUSLE model in GIS environment for estimating average annual soil loss of the Arkosa watershed. Raster calculator of Spatial Analysis Tool has been used for creating each layer in ArcGIS 10.4 environment. In RUSLE the five thematic layers are multiplied in the following equation (Fig. 2):

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

Where

A = Average annual soil erosion (ton/ha/year)

R = rainfall and runoff erosivity factor (MJ mm/ha/hr/year)

K = soil erodibility factor (ton/ha)

LS = slope length and steepness factor

C = cover and management factor

P = support practice factor related to slope direction

Principal Component Analysis (PCA) has been used for identifying the importance of each factor in an index. Therefore, to fulfill this criterion of overall area has been divided in to 2 Km and 2 Km grid and their central values (89 points of each thematic layer and total 445 points) have been taken into consideration. Then the combined factor indexes indices of different factors which have been calculated for showing the combine impact of all factors in soil loss. This index has been calculated from the following formula:

Table 1 Average rainfall data from rain gauge station

Rainfall gauging station	Latitude and longitude	Total storm rainfall in mm.	Average storm rainfall in mm.
Bankura	87°2′36.796"E and 23°14′50.867"N	537.06	59.6733
Vishnupur	87°18′44.798"E and 23°4′40.14"N	514.7	57.1889
Khatra	86°51′24.55"E and 22°59′42.417"N	502.8	55.8667
Indus	87°38′2.504"E and 23°9′10.376"N	482.9	53.6556
Kotalpur	87°35′45.769"E 23°0′53.261"N	524.4	58.2667
Onda	87°11′21.373"E and 23°8′37.234"N	440.2	48.9111
Gangajalghati	87°6′26.267"E and 23°26′52.349"N	517.6	57.5111
Sonamukhi	87°24′47.297"E and 23°1′32.685"N	510.5	56.7222
Taldangra	87°5′58.171"E and 23°1′34.513"N	560.9	62.3222
Arambagh	87°46′1.204"E and 22°52′32.967"N	504.8	56.0889
Purulia	86°22′45.783"E and 23°19′49.133"N	535.2	59.4667
Raghunathpur	86°39′27.132"E and 23°33′12.465"N	468.1	52.0111
Barabazar	86°24′21.757"E and 23°1′53.132"N	507.6	56.4
Jhalda	85°58′40.593"E and 23°21′52.581"N	566.3	62.9222
Manbazar	86°39′4.77"E and 23°3′50.101"N	530	58.8889
Chandrakona	87°30′46.153"E and 22°43′29.21"N	558.7	62.0778
Silda Belpahari	86°47′24.614"E and 22°38′20.619"N	531.2	59.0222
Amlagora	88°46′1.438"E and 22°55′35.73"N	565.6	62.8444
Chas	86°8′49.89"E and 23°38′20.734"N	462.3	51.3667
Saraikela	85°57′6.359"E and 22°43′44.682"N	501.6	55.7333

$$\frac{\frac{1}{n}\sum_{i=1}^{n}(xi-\bar{x})\,(yi-\bar{y})}{\frac{1}{n}\sum_{i=1}^{n}(x-\bar{x})^2}$$

For predicting the future average annual soil loss, rainfall and runoff erosivity factor, soil erodibility factor and slope length and steepness factor have been taken into consideration (Biswas and Pani 2015).

Results and discussion

R factor

The rainfall and runoff erosivity factor specify the erosive capacity or erosive power which take place in the storm rainfall period (Pal and Shit 2017). It indicates the average annual storm rainfall value and it is associated with possible soil erosion of a particular region (Das et al. 2018). The R factor calculated from the annual average observed rainfall data (Table 1).There is a positive relationship between the amount of rainfall and runoff, though there is a direct and indirect impact of slope and it is acted as a determining element of runoff. The R factor of a specific region is expressed as MJ mm ha-1 year-1 (Wischmeier and Smith 1978).

$$R = 38:5 + 0:35 \times \mathrm{Pr}$$

where, R is rainfall and runoff erosivity factor and Pr is the average weekly precipitation (mm) in storm rainfall period. In sub-tropical monsoon dominated countries like India, the monsoon period is considered as storm rainfall event for estimating the rainfall and runoff erosivity factor.

The R value of this region ranges between 58.347 to 58.778 MJ mm ha-1 year-1. In this region, the highest value of R factor concentrated in eastern and southern portion (Fig. 3). The lowest R value is intense in the northwestern part of this watershed. In other portion, the value of R factor is moderate in nature.

K factor

Soil erodibility indicates the capacity to loss the soil and it depends upon various chemical and physical characteristics properties of the soil (Pe´rez-Rodrı´guez et al. 2007).

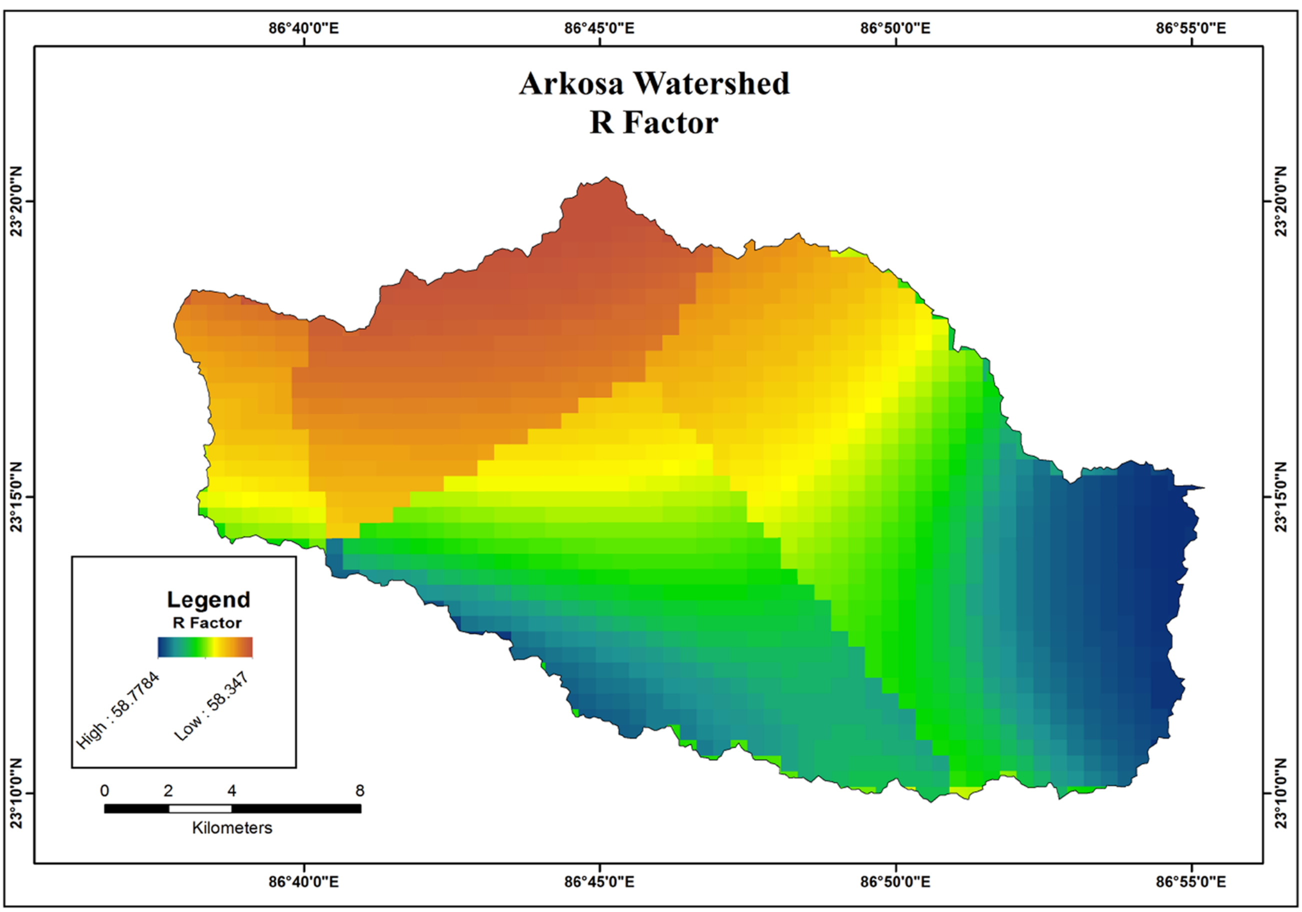


Fig. 3 R factor of Arkosa Watershed

Though the mineral components and morphological characteristics of various parameters of soil, take part in a significant function in erosion susceptibility (Biswas and Pani 2015). The K factor signifies the combining effort of rainfall, runoff and amount of infiltration that is associated to soil loss in a storm event (Renard et al. 1997). K factor emphasis on the erosion vulnerability and amount of runoff (Pal and Shit 2017). A general soil texture map prepared by NBSS&LUP, Kolkata has been used for estimating the soil erodibility factor. The K factor was identified with the help of Soil erodibility monograph (Wischmeier and Smith 1978) by considering soil composition and organic content. Soil types are classified into four textural classes: Fine (120.66 Km^2), Fine Loamy (121.22 Km^2), Fine Loamy-Coarse Loamy (1.67 Km^2) and Gravelly Loam (104.90 Km^2).

The soil K factor was calculated using this formula (Wischmeier and Smith 1978):

$$K = 2.1 \times 10 - 6M1.4 \times (12 - OM) + 0.0325 \times (P - 2) + 0.025 \times (S - 3)$$

Where, K = soil erodibility factor (ton ha-1 unit of R); M = (% silt +% fine grained sand) (100 − % clay); OM = organic matter in percentage; P = permeability; and S = structural classess (Pal and Shit 2017).

The K factor of this region ranged between 0 and 0.33 ton/ha. The lowest K factor value (0 to 0.14) mainly concentrated in the western part of the watershed (Fig. 4). The moderate K factor value (0.14 to 0.19) also concentrated in the northern portion and the higher value (0.19 to 0.23) concentrated only in the eastern portion. The other portion of this watershed are belongs to very high K factor value (0.23 to 0.33).

LS factor

In RUSLE, LS factor have been generated with the integration of slope length factor (L) and the steepness factor (S). It is also recognized as topographic factor (Pal and Shit 2017). There are two processes to estimate the LS factor; these are direct field measurement and Digital Elevation Model (DEM). The slope and flow accumulation grid (Figs. 5, 6)

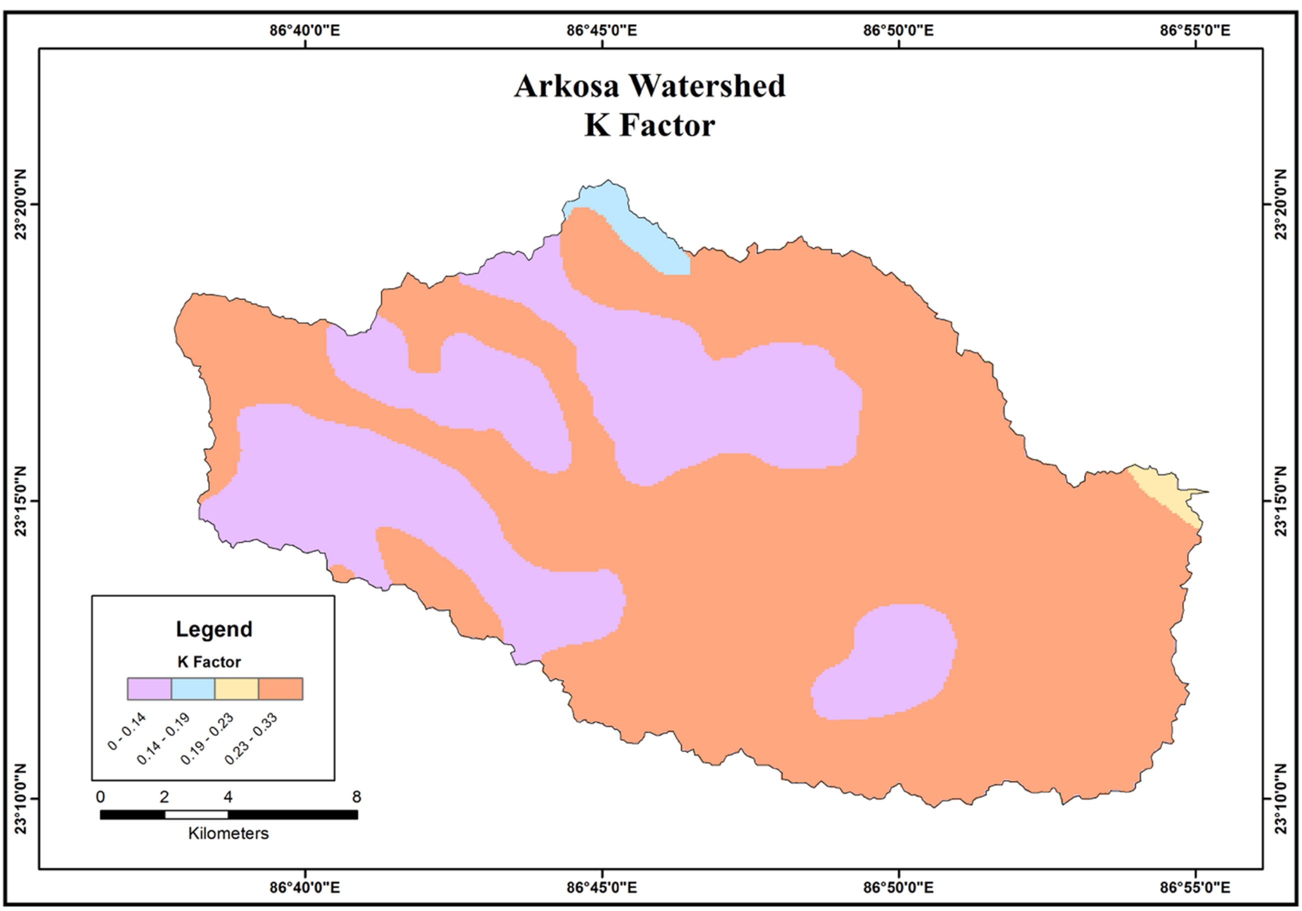


Fig. 4 K factor of Arkosa Watershed

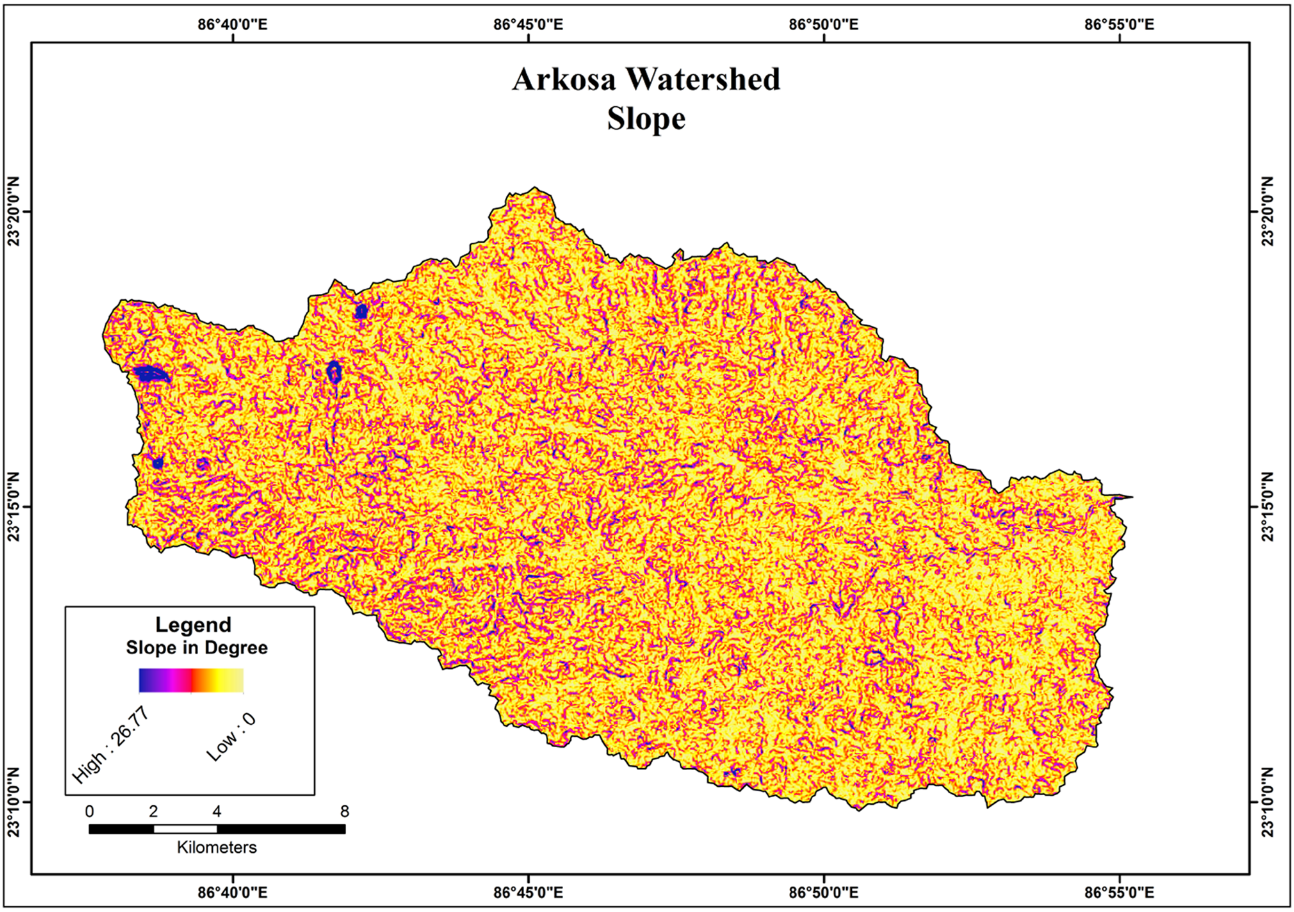


Fig. 5 Slope of Arkosa Watershed

was extracted from the Digital Elevation Model (DEM), and then these two parameters employed for estimate the LS factor in GIS environment. The integration of slope length factor (L) and the steepness factor (S) create the LS factor in GIS environment with considering the following equation (Moore and Burch 1986):

$$LS = (Flow\ Accumulation \times cell\ size/22.13)0.4 \times (Sin\ [Slope\ grid\ \times\ 0.01745]\ /\ 0.0896,\ 1.4)\ \times\ 1.4$$

The model builder tool in GIS environment use to considerate for estimating the LS raster of this study area. The equation of LS grid was (Pal and Shit 2017):

$$LS = Pow\ ([Flow\ Accumulation\ Grid] \times\ 10/\ 22.13, 0.4) \times Pow\ (Sin\ [Slope\ grid\ \times\ 0.01745)/0.0896,\ 1.4) \times 1.4$$

Where Pow denotes for Power equation in GIS environment, Flow Accumulation created in GIS environment from DEM for estimating the flow in grid format, and cell size is the length of a raster cell. The L and S factors were worked out from a DEM of the Arkosa Watershed. The LS factor values ranges between 0 and 3.97. These have been classified into different LS factor threshold like as 0, 0.05, 0.11, 1.75 and 3.97.

The low LS factor (0–0.05) values found in the far away from the major and minor streams of this watershed. The moderate LS factor (0.05–0.11) values mainly concentrated only few portion of this watershed. The high LS factor (0.11–1.75) values mainly concentrated in the nearest to the major and minor streams and the very high LS factor (1.75–3.97) values mainly concentrated basically where the major and minor streams are located of this watershed (Fig. 7).

C factor

In USLE the C factor was mainly associated with the field observation but in RUSLE there are four sub factors which are associated and considered for accounting this amount. These are specified land use of this area, the status of

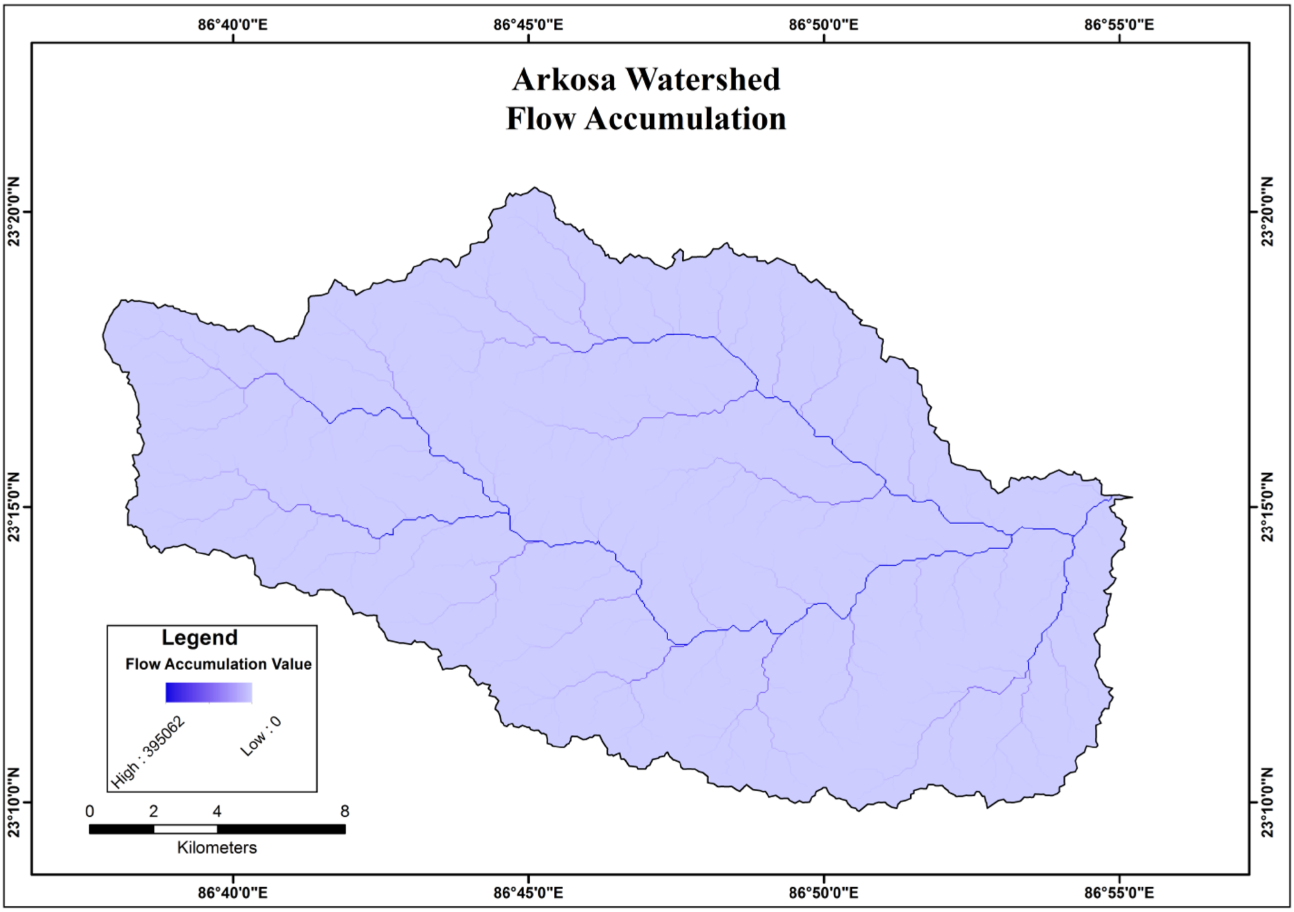


Fig. 6 Flow accumulation of Arkosa Watershed

vegetation cover, the characteristics and cover of the land surface and the roughness of the surface. C factor is one of the important dimensionless factors that indicate the amount of soil loss directly related to the vegetation cover. This factor is the proportion of soil loss by the areas of defensive vegetation cover (Donahue et al. 1972). Here Landsat 8 OLI satellite data have been used to generate NDVI map of the study area.

Normalized difference vegetation index (NDVI) is one of the most dependable and famous method to estimate the vegetation cover (Pal et al. 2018). NDVI generally estimated from the following equation by Rouse et al. (1974):

$$NDVI = (NIR - \text{Red})/(NIR + \text{Red})$$

It is mainly ranged with Negative one (− 1) to positive one (+ 1). Negative one (− 1) to zero (0) represents the water body to saturated or moist soil and zero (0) to positive one (+ 1) represents bare soil surface to completely developed vegetation cover (Pal et al. 2018). NDVI values of the study area ranged from − 0.17 to 0.44 (Fig. 8). After the generation of NDVI thematic layer the following equation have been taken into consideration for estimate the C factor:

$$C\,factor = 1.02 - 1.21 \times NDVI$$

C factor was created in using the specified equation that included field information of land cover (Wischmeier and Smith 1978; Renard 1997; Renard et al. 1997). The values of C factor in this study area varied between 0.48 and 1.23. These have been classified into different C factor threshold like as 0.48, 0.84, 0.90, 0.94 and 1.23. There is a positive relationship between the values of NDVI and C factor. The lowest values of C factor (0.48–0.84) mainly found low in the western, northern and southeastern part of this watershed in some small pockets (Fig. 9). The moderate C (0.84–0.90) values mainly concentrated in the northern, eastern,

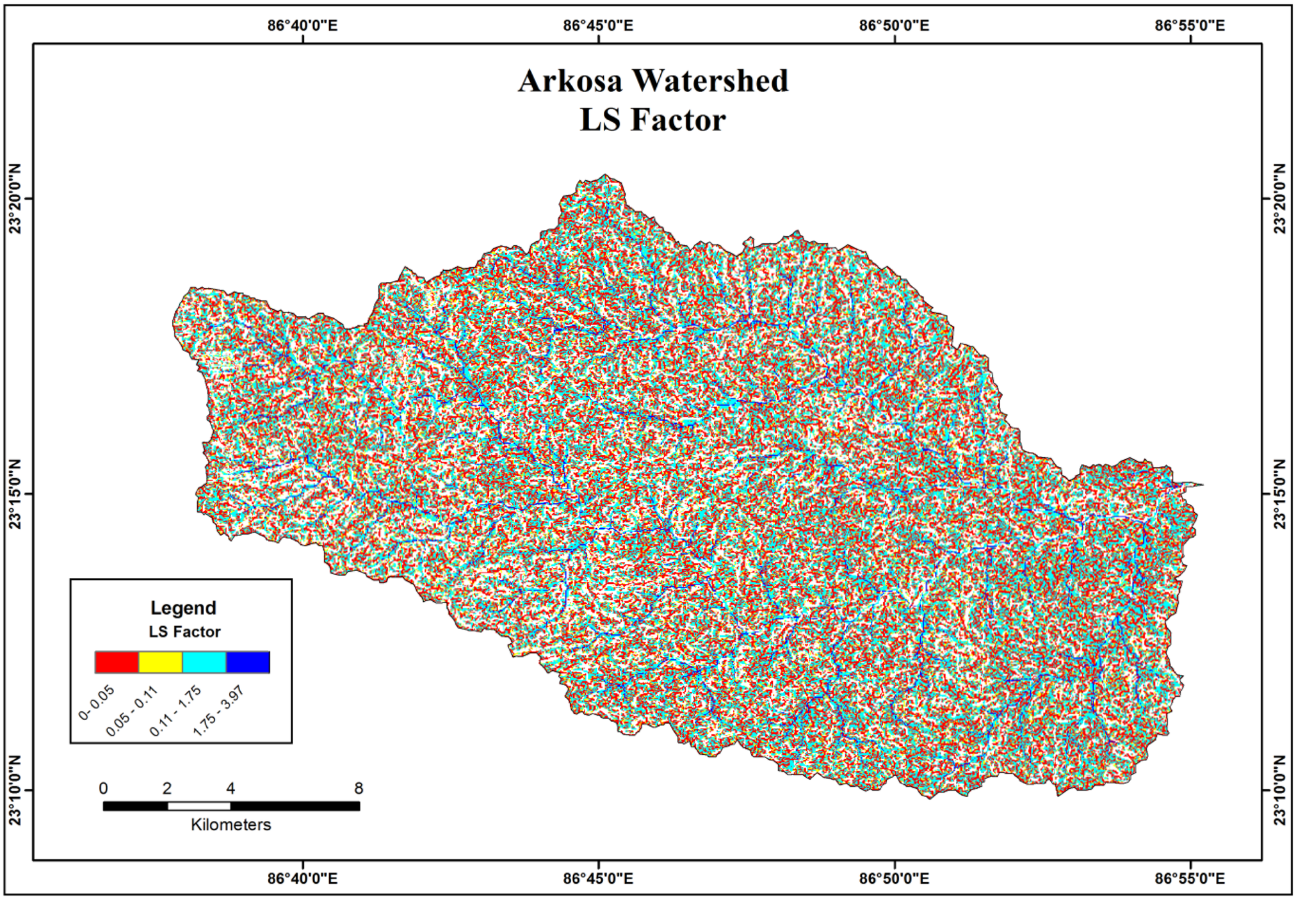


Fig. 7 LS factor of Arkosa Watershed

southern and southwestern portion of this watershed. The high C (0.90–0.94) values concentrated in the northeastern, central portion and the very high (0.94–1.23) values mainly concentrated in the northern, western and central portion of this watershed.

P factor

The P value indicates the percentage of soil loss form a field with support practices (Pandey et al. 2007; Blanco-Canqui and Lal 2008; Blanco and Lal 2010; Brady and Weil 2012). The *P* values generally vary from 0 to 1. The highest *P* value indicates the bare surface lacking any support practices. Maintaining the correspondence between living and dead vegetation and emphasis upon the conservation tillage could reduce the rate of erosion (Bancho and Lal 2008). This factor generally related with the different type of erosion in different cultivated land where different types of cropping practiced have been taken into consideration (Pal and Shit 2017). For minimizing the soil loss in a watershed, use of multi practice is more useful than a mono practice. In this case support practice like contouring, strip cropping and terracing must be encompasses (Bancho and Lal 2008). Apart from this field bunding kind of management practices may be useful for the region where intensive subsistence agricultural practices are going on likewise Arkosa watershed (Fig. 10). Alteration of flow pattern could influence the soil erosion by

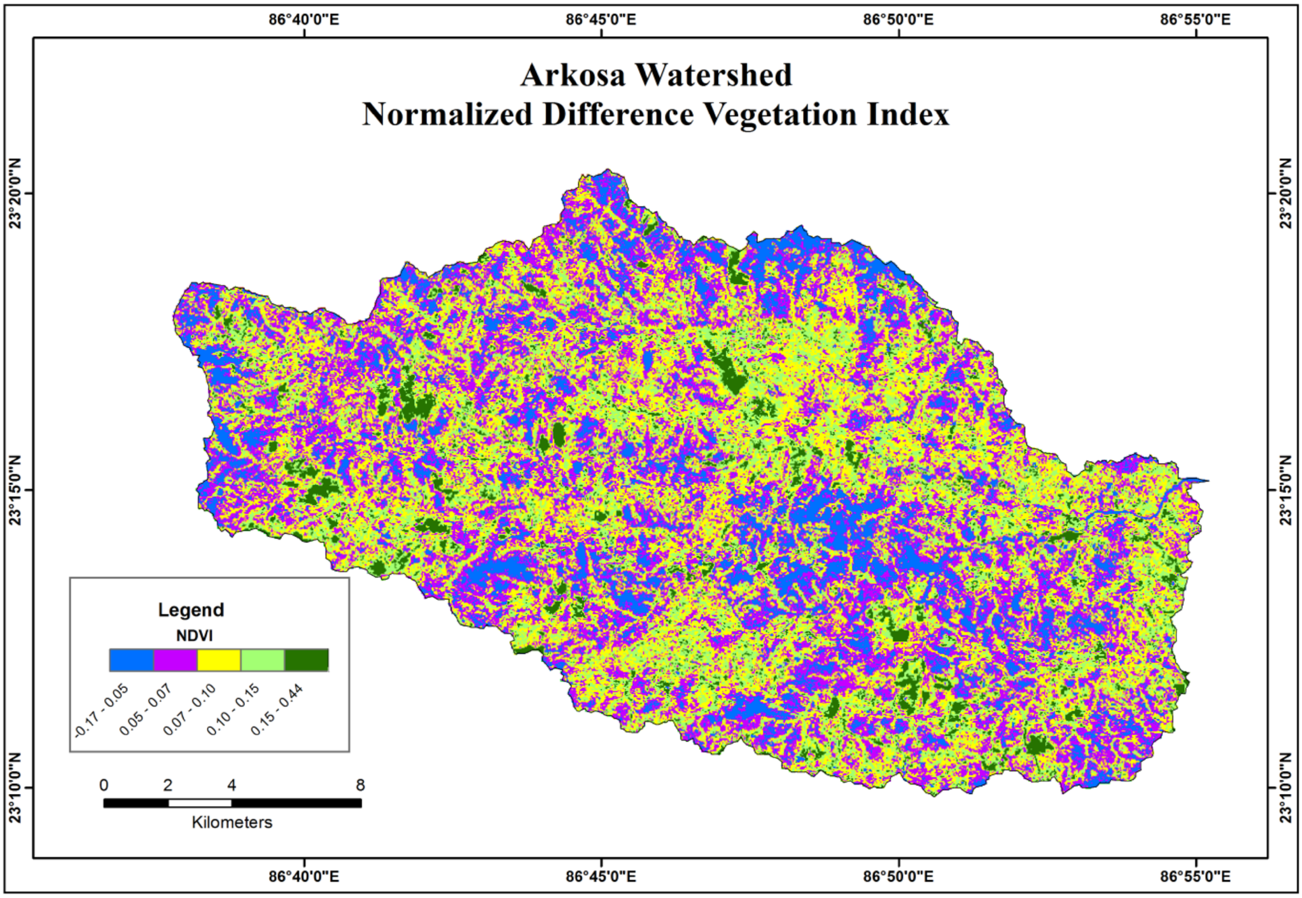


Fig. 8 Normalized difference vegetation index of Arkosa Watershed

support practice (Renard and Foster 1983). Basically this area belongs to the mono crop like paddy cultivation and others area is included with non paddy area. In this study area the *P* value ranged between 0.20 and 0.44. The lower value concentrated beside the streams. The higher value of *P* associated with the undulating topography as well as the non-agricultural areas (Fig. 11).

Estimation of soil erosion

Soil loss estimation through RUSLE in GIS framework not only for time consuming but also it can provide the result in a greater accuracy level. In manual method of soil loss estimation model is unable to predict the catchment wise soil loss status but in GIS framework is suitable for identifying the soil loss status. These study mainly emphasized upon the quantifying various erosion potential zones and to predict the future soil loss status. The correlation matrix between various factors shows a clear cut framework for understanding the importance of all factors in a single dimension (Fig. 12). Future management through suitable techniques by planers should take emphasis of vulnerable areas of present conditions as well as predicted erosion potential areas. The average annual soil loss in Arkosa watershed was estimated through RUSLE model (Fig. 13). The average annual soil loss in Arkosa watershed ranged from 0 to 10 tons/ha/year. Then it classified into different erosion threshold on the basis of a geometric interval for identifying different erosion classes i.e., 0, 2, 4, 8 and 10 tons/ha/year. The very high (8–10 tons/ha/year) soil loss mainly concentrated in the southeastern part

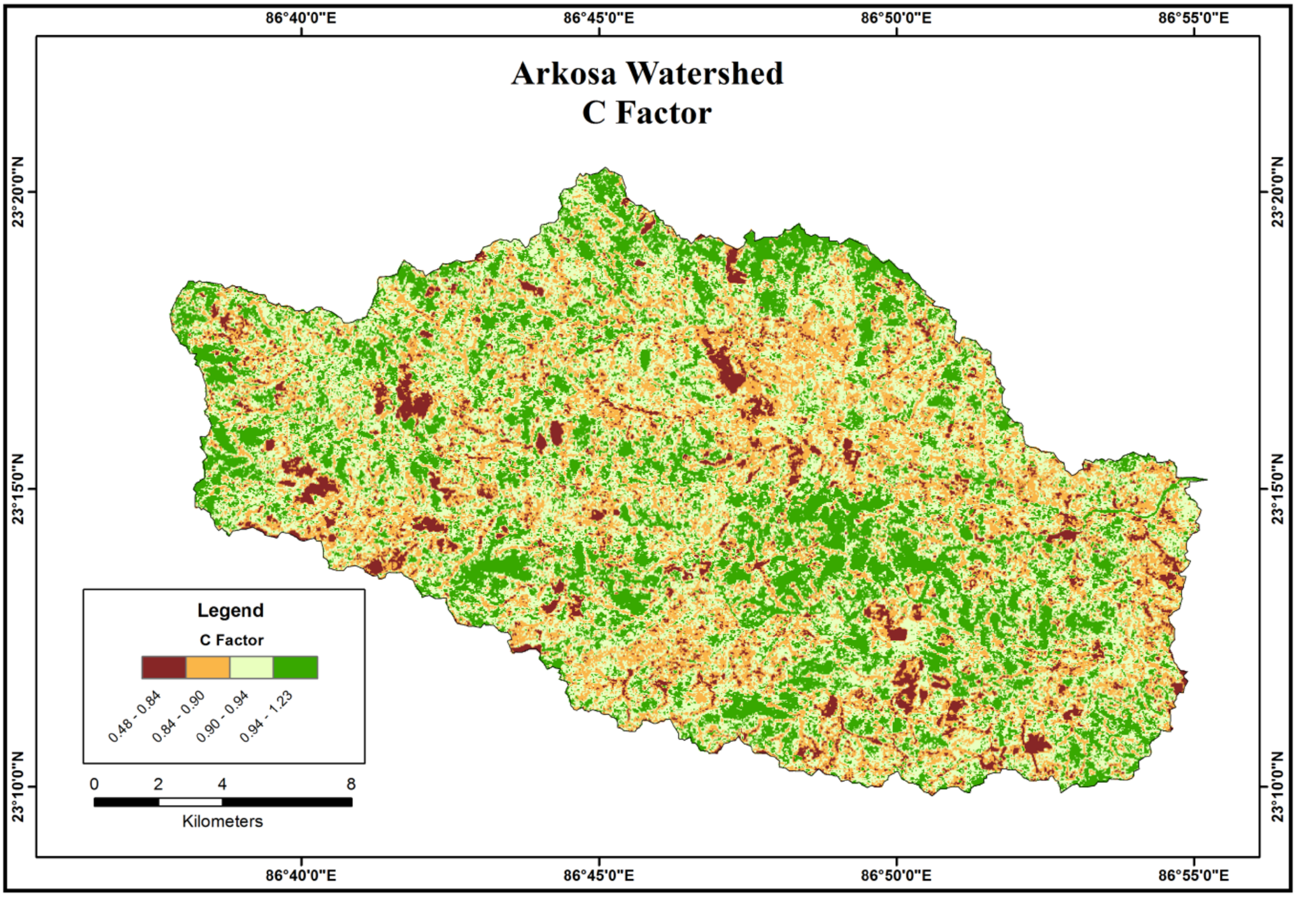


Fig. 9 C factor of Arkosa Watershed

of this watershed. The high (4–8 tons/ha/year) soil loss erosion zones were found in the southern and southeastern part of this watershed. The moderate (2–4 tons/ha/year) soil loss class concentrated in the northern, central and southeastern portion of this watershed. Most of the areas of this watershed belong to the low (0–2 tons/ha/year) soil loss zone. The spatial variations of different factors controlled the overall environment that the quantity of soil loss and severity are different in diverse environmental condition (Fig. 14). It mainly depends on the amount of storm rainfall, soil texture, vegetation cover and amount of slope (Table 2). The combined index of different factor shows the differences of influences on soil loss (Table 3). It is shown that the minimum (0–0.250) influences mainly found in the northwestern part of this watershed (Fig. 15). The minimum (0.749–0.999) influences found in the eastern and southwestern part of this watershed. Besides this, the major part of this watershed is associated with moderate (0.250–0.500) to high (0.500–0.749) influences of combine factor. The 1st component and 2nd component explain almost the 50 Percent (0.4925) of the variables (Table 4), by which we can say that there are a lot of differences found between various variables.The 1st and 2nd component is most important in this distribution because in those components the eigen value is greater

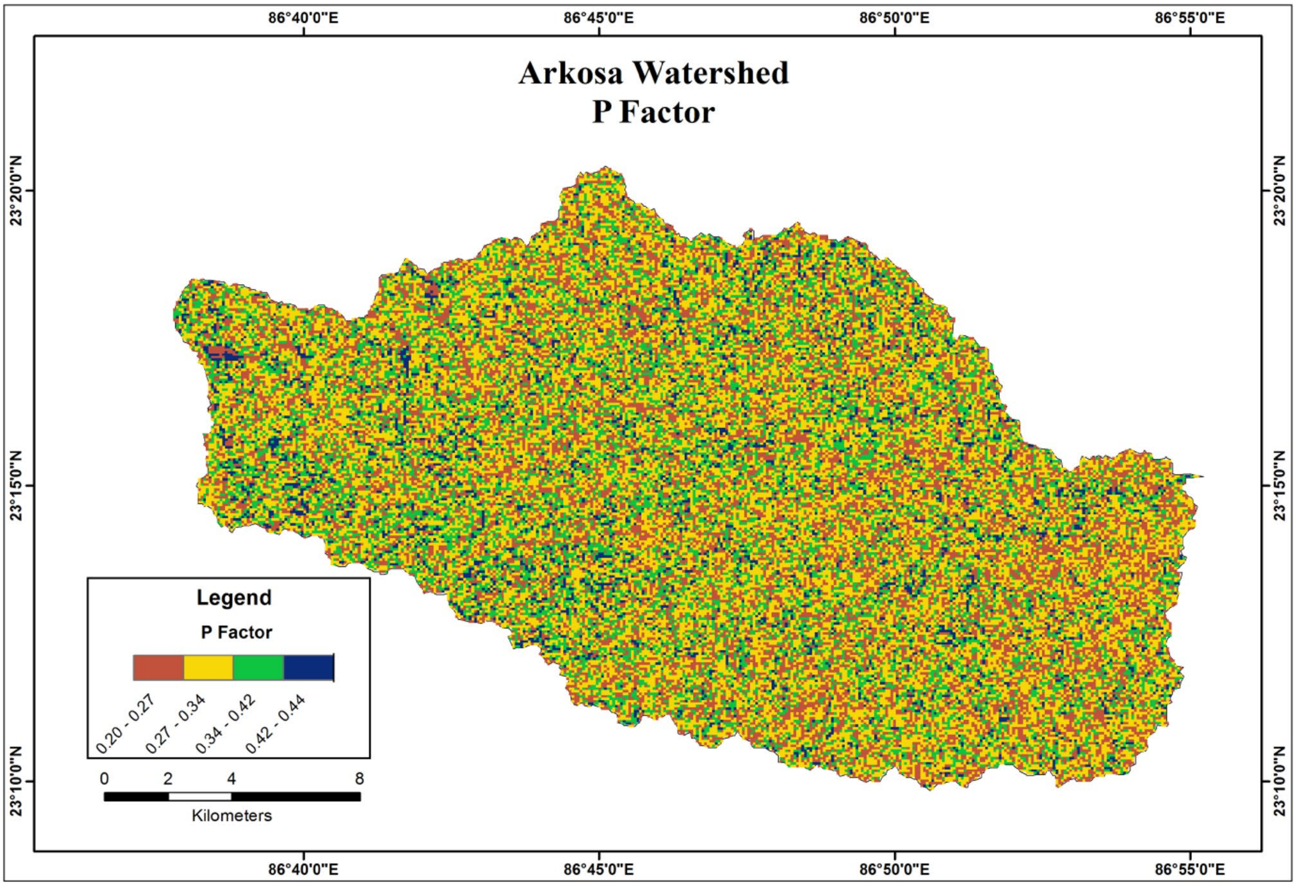


Fig. 10 P factor of Arkosa Watershed

Fig. 11 Support practices adopted by the Villagers: **a** Photograph of Field Bunding for minimizing the removal of the top soil in the single crop Paddy cultivated land in Kashipur and its surroundings; **b** Photograph of Paddy dominated agricultural land where Field Bunding method has been adopted for controlling the soil erosion near the village of Natungram

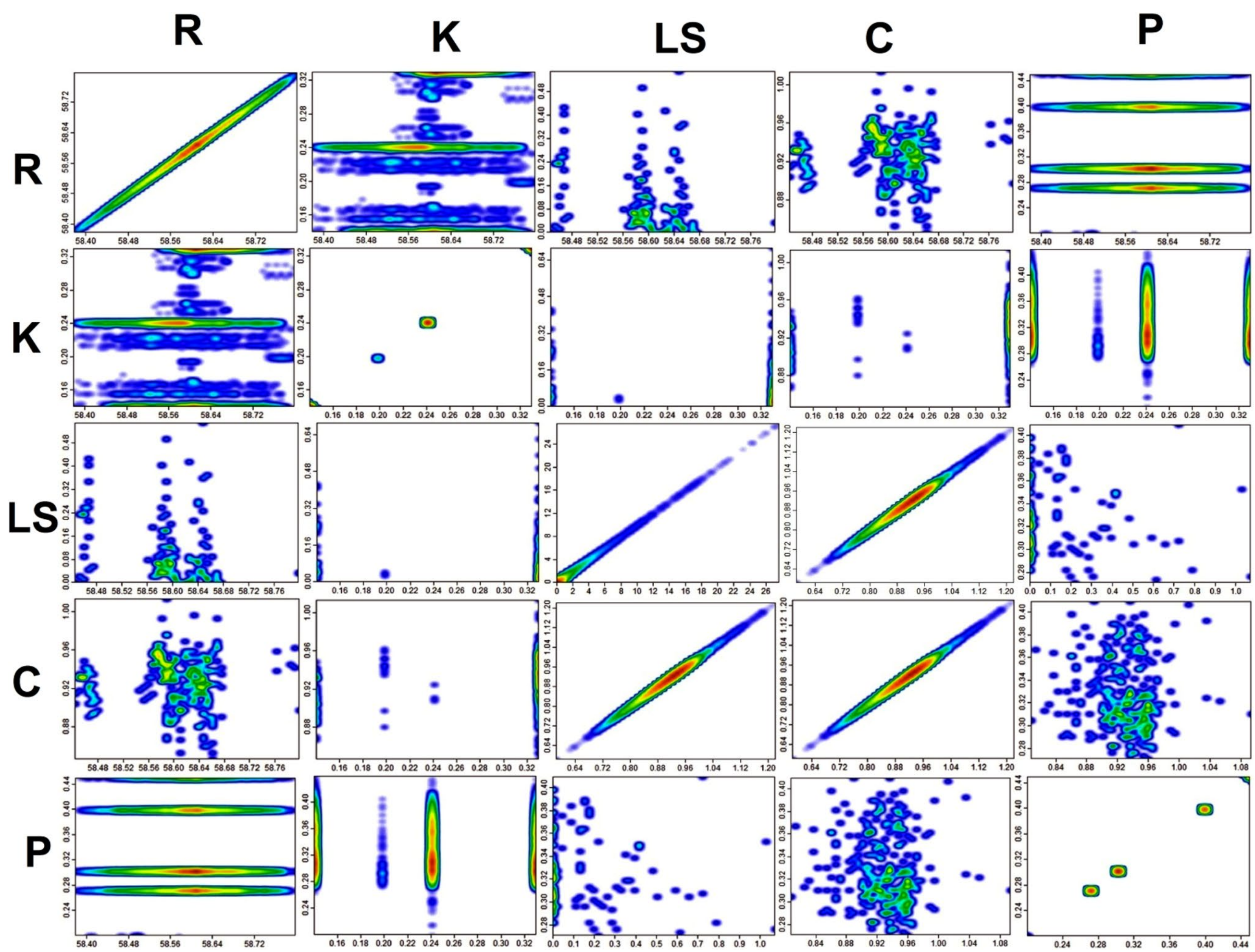


Fig. 12 Correlating matrix between different factors of soil loss

than one (1) (Fig. 16). These differences between variables play a very important role in the overall distribution, while R and P factor is more dominant than other factors. Pair wise Compression Matrix shows the correlation between different factors. It is shown that the maximum correlation between R and C factor (Table 5). Here the partial and semi-partial correlation with Combined Factor Index shows the higher correlation among R factor and Combined Factor Index with important significance (Table 6). Besides this, the correlation of the other factor with Combined Factor Index is minimum because of the larger influences of R factor. We can at a glance says that the importance of different factors on soil loss through the help of the descriptive statistics (Table 7). Apart from this there are total 29 points have been selected randomly for collecting the primary information regarding the average annual soil loss (Fig. 17; Table 8). There is a highly positive correlation between the actual soil loss and estimated soil loss from regression analysis have been found which secure the validity of this present soil erosion model with actual ground reality (Fig. 18). The potential soil loss estimation map shows the future potentiality of soil loss which ranged between 0 and 16 tons/ha/year (Fig. 19; Table 9). This is classified into dissimilar potential soil erosion threshold for identifying different erosion classes i.e., 0, 4, 8, 12 and 16 tons/ha/year. The very high (12–16 tons/ha/year) potential soil erosion are mainly found in the eastern,

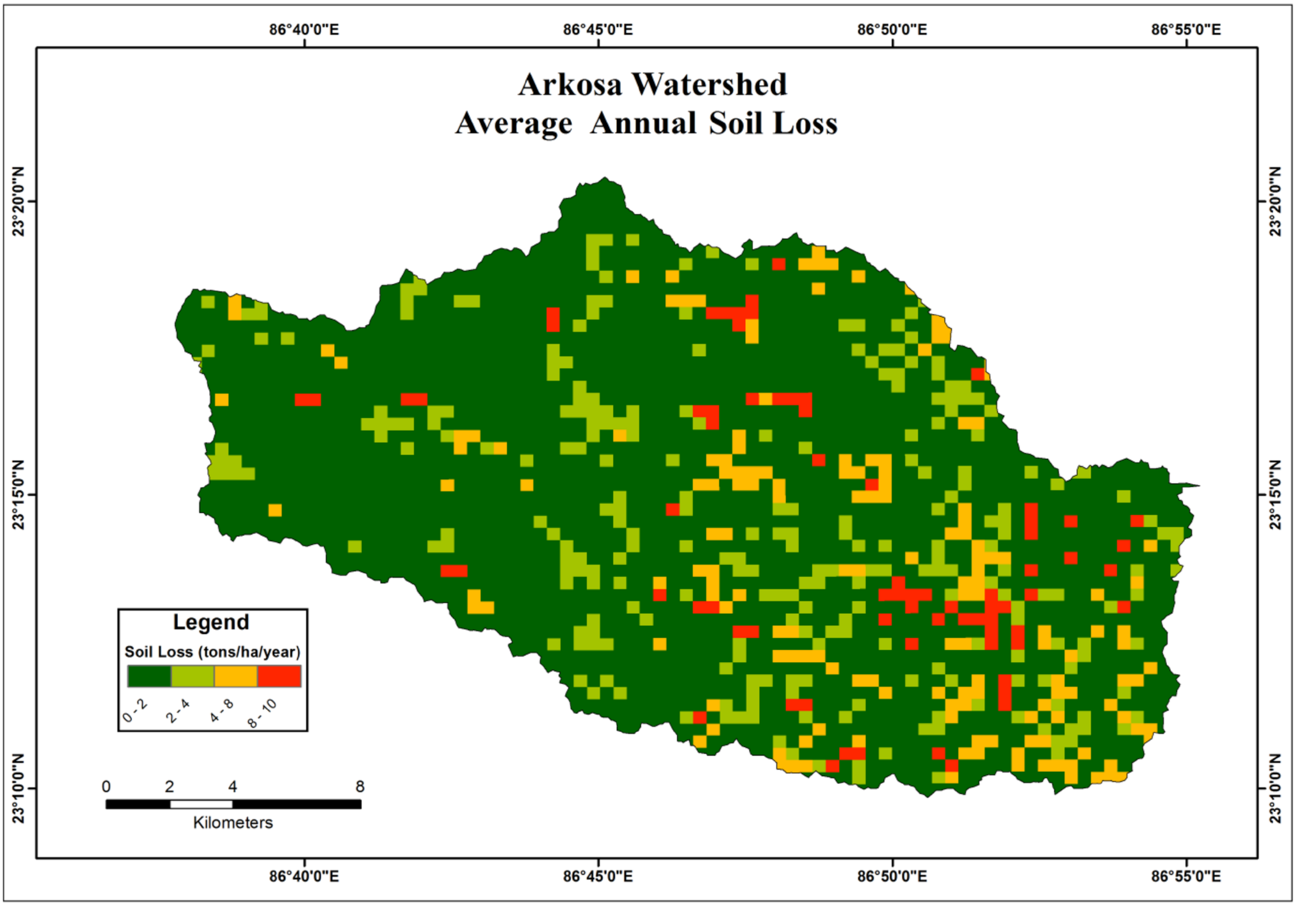


Fig. 13 Average annual soil loss of Arkosa Watershed

northeastern and southeastern part of the Arkosa Watersahed. The high (8–12 tons/ha/year) amount of potential soil loss is mainly found in the eastern and northern part of this area. The spatial distribution of moderate (4–8 tons/ha/year) soil loss mainly concentrated in the southwestern and northwestern part of this watershed. The spatial distribution of marginal (0–4 tons/ha/year) soil loss mainly dominated in the western, southwestern and northwestern part of Arkosa Watershed (Table 9). In the overall study we can say that the quantity and spatial distribution of soil loss mainly controlled by the fluvial activity and the percentage of slope in the overall watershed. The percentage of the slope acts as a threshold in relation to soil loss but there is a direct as well as indirect relationship of the rainfall and runoff erosivity factor, soil erodibility factor, slope length and steepness factor, cover and management factor andsupport practice factor which are also related with the amount and direction of slope etc.

Conclusion

Ground truth base primary investigation for creating database is time-dependent, costly and difficult but when it is applied with GIS framework it is capable to estimate the quantity of soil loss and its spatial distribution. This study mainly deals with the identification and demarcation of probable or potential soil erosion risk zones with the aid of RUSLE model and combined factor index method in GIS environment. This study provides a reliable prediction regarding soil erosion. From the above study, it

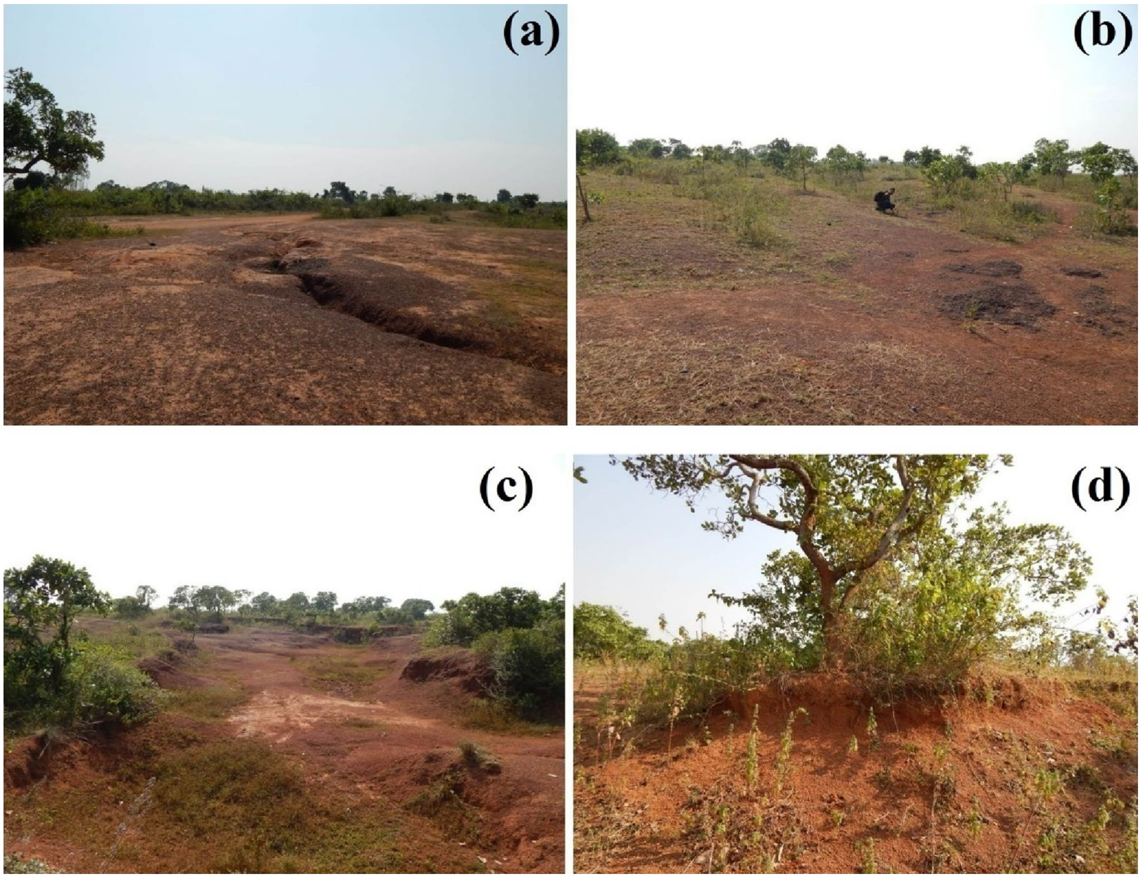


Fig. 14 Field photograph on soil erosion: **a** Rill formation already started near Dalanbani village; **b** Sheet erosion and Rill development is going on near the Dalanbani village; **c** erosion of the top soil and exposed lateritic soil features are very common near Anandapur village and its surrounding region; **d** Root of the vegetation gets exposed due to severe soil erosion near Anandapur village

Table 2 Average annual soil loss and its spatial coverage

Annual average soil loss	Range (tons/ha/year)	Area in Km^2	Area in percentage (%)
Very high	8–10	14.463	4.15
High	4–8	47.326	13.58
Moderate	2–4	63.845	18.32
Low	0–2	222.866	63.95
Total		348.5	100

has been observed that 17.73% of the total area included with high to very high annual average soil loss. But in the future potential soil loss, it goes to 35.978%. So the initial and leading work of the planer is to give emphasis within this area for reducing the quantity of eroded soil with the assist of suitable management practices. The low average annual soil loss of this area is 63.95% and in potential soil loss, it has been found about 37.849%. Here it has been observed that the rapid decline of low soil loss is very common within the region. That is the major problem of this watershed. The soil loss was mainly found in the highest elevation and high slope area where the runoff is

Table 3 Combined index value of different Factors

Points	R factor	K factor	LS factor	C factor	P factor	Index	Normalization
1	58.6082	0.33	0.273658	0.847143	0.45	0.073049	0.501
2	58.57797	0.33	0.123214	0.944375	0.4	−0.36018	0.416
3	58.58952	0.33	0.206797	0.954595	0.45	−0.19459	0.449
4	58.62365	0.33	0.107001	0.917746	0.4	0.29433	0.545
5	58.65628	0.33	0.033517	0.847143	0.4	0.761823	0.636
6	58.63424	0.33	0.232131	0.877647	0.3	0.44599	0.574
7	58.6179	0.33	0.97709	0.902903	0.27	0.211917	0.528
8	58.60934	0.33	0.243911	0.893077	0.3	0.089278	0.504
9	58.60547	0.14	0.241284	0.919925	0.3	0.033862	0.494
10	58.61187	0.14	0.021598	0.815231	0.27	0.125626	0.512
11	58.59293	0.33	1.046084	0.891277	0.27	−0.14578	0.458
12	58.63337	0.33	0.209076	0.893582	0.27	0.433528	0.572
13	58.67139	0.33	0.098125	0.928207	0.27	0.978349	0.679
14	58.6206	0.14	0.141189	0.872014	0.3	0.250667	0.536
15	58.61019	0.24	0.172392	0.966051	0.3	0.101517	0.507
16	58.59802	0.24	0.584895	0.866349	0.27	−0.07293	0.473
17	58.59485	0.24	0.049619	0.883662	0.4	−0.11829	0.464
18	58.59703	0.33	1.536922	0.941429	0.45	−0.08697	0.470
19	58.60766	0.14	0.405731	0.770317	0.4	0.065239	0.500
20	58.60889	0.33	0.128595	0.883534	0.27	0.082938	0.503
21	58.64245	0.33	0.645293	0.983772	0.27	0.563651	0.597
22	58.67645	0.33	0.145605	0.983772	0.3	1.050706	0.693
23	58.74427	0	0.723859	0.900704	0.4	2.022422	0.884
24	58.74567	0.14	0.149993	0.974625	0.4	2.042528	0.888
25	58.58839	0.14	0.126242	0.974051	0.3	−0.21076	0.446
26	58.5788	0.24	1.268184	0.948824	0.27	−0.34826	0.419
27	58.57351	0.33	0.083073	0.854604	0.3	−0.42396	0.404
28	58.57723	0.33	3.398946	0.921407	0.3	−0.37077	0.414
29	58.58367	0.33	0.169682	0.996274	0.3	−0.27842	0.432
30	58.6013	0.33	0.482903	0.963154	0.27	−0.02593	0.482
31	58.60668	0.33	0.157895	0.849704	0.27	0.051242	0.497
32	58.63705	0.33	1.026858	0.954	0.27	0.486376	0.582
33	58.67434	0.33	0.554864	0.962381	0.27	1.020594	0.687
34	58.73672	0.33	0.311154	0.86662	0.4	1.914208	0.863
35	58.62978	0.14	0.045497	0.959065	0.3	0.38221	0.562
36	58.61806	0.14	0.093379	0.955467	0.27	0.214211	0.529
37	58.60666	0.14	0.002214	0.8748	0.45	0.050915	0.497
38	58.70848	0.14	0.063231	0.905182	0.27	1.509622	0.783
39	58.70915	0.14	0.128916	0.935972	0.4	1.519294	0.785
40	58.70915	0.14	0.243911	0.935972	0.4	1.519295	0.785
41	58.54572	0.24	0.192127	0.911642	0.27	−0.82209	0.326
42	58.54578	0.24	0.684951	0.953699	0.4	−0.82127	0.326
43	58.55268	0.24	0.706629	0.945918	0.3	−0.72241	0.345
44	58.56693	0.24	0.166577	0.946667	0.27	−0.51834	0.385
45	58.605	0.24	0.095674	0.949855	0.3	0.027192	0.492
46	58.59434	0.33	0	0.865338	0.27	−0.12556	0.462
47	58.62548	0.33	1.719735	0.935972	0.4	0.320511	0.550
48	58.67236	0.33	0.436682	0.822624	0.27	0.992182	0.682
49	58.78563	0.2	0	0.935223	0.4	2.61495	1.000
50	58.57517	0.24	0	0.935223	0.27	−0.40029	0.408
51	58.57723	0.14	0.478649	0.903973	0.45	−0.37078	0.414

Table 3 (continued)

Points	R factor	K factor	LS factor	C factor	P factor	Index	Normalization
52	58.55997	0.14	0.147659	0.928207	0.4	−0.61802	0.366
53	58.65886	0.14	0.002214	0.941655	0.27	0.798765	0.644
54	58.66695	0.24	0.162709	0.914783	0.3	0.914627	0.666
55	58.67786	0.14	0.002214	0.76629	0.27	1.070938	0.697
56	58.50753	0.14	0.323318	0.942766	0.27	−1.36932	0.218
57	58.51403	0.14	0.022219	0.956316	0.3	−1.27614	0.236
58	58.52502	0.14	0.214696	0.873121	0.4	−1.11863	0.267
59	58.54493	0.14	0.166049	0.872439	0.3	−0.83346	0.323
60	58.66998	0.33	0.288022	0.885556	0.27	0.958021	0.675
61	58.66487	0.33	0.005086	0.87971	0.4	0.884897	0.661
62	58.5201	0.33	0	0.920548	0.3	−1.18925	0.254
63	58.50604	0.24	0.23581	0.962381	0.4	−1.39069	0.214
64	58.50328	0.24	0.700944	0.950857	0.27	−1.43015	0.206
65	58.4978	0.14	0.089943	0.887518	0.45	−1.50874	0.191
66	58.61619	0.14	0	0.914783	0.27	0.187433	0.524
67	58.62939	0.24	0.393412	0.905182	0.3	0.376528	0.561
68	58.46405	0.14	0.318377	0.914783	0.27	−1.99213	0.096
69	58.57323	0.14	0.812232	0.874113	0.4	−0.42805	0.403
70	58.58761	0.14	0.283293	0.900704	0.3	−0.22196	0.443
71	58.63005	0.14	0.770934	0.920548	0.3	0.385984	0.563
72	58.6511	0.33	0.208574	0.90844	0.3	0.687603	0.622
73	58.68191	0.24	0.008808	0.906834	0.4	1.128972	0.708
74	58.44794	0.24	1.455515	0.87971	0.3	−2.22303	0.051
75	58.4473	0.24	0.152902	0.940511	0.3	−2.23216	0.049
76	58.4299	0.24	0.157895	0.951831	0.3	−2.48143	0.000
77	58.43811	0.24	0.005059	0.973817	0.3	−2.36382	0.023
78	58.67441	0.14	0.145605	0.922847	0.45	1.021527	0.687
79	58.69334	0.14	0.043941	0.897246	0.4	1.292819	0.741
80	58.53995	0.24	0.629411	0.907067	0.4	−0.90483	0.309
81	58.5811	0.24	0	0.957143	0.3	−0.3152	0.425
82	58.60503	0.24	0.410148	0.908308	0.3	0.027631	0.492
83	58.63302	0.24	0.657134	0.943846	0.3	0.428555	0.571
84	58.61816	0.14	0.166577	0.929701	0.3	0.215688	0.529
85	58.64619	0.24	0.411633	0.952778	0.27	0.617212	0.608
86	58.50546	0.24	0.042372	0.955467	0.27	−1.399	0.212
87	58.54321	0.33	0.160886	0.994965	0.27	−0.85806	0.319
88	58.57265	0.33	0.118681	1.009478	0.45	−0.43637	0.401
89	58.5864	0.16	0.093609	0.877647	0.27	−0.2394	0.439926929

maximum. On the other side, the moderate soil loss areas concentrated in the fallow and scrubland and the low soil loss area confirmed in the vegetative land. It is not possible to stop the soil erosion completely but proper or suitable land use management and suitable support practices can minimize the erosion rate and vulnerability of the top soil contained by the region. These counteractive measures can also retain the fertility of the top soil within the in-situ region which ultimately accelerates the productivity of the land in future.

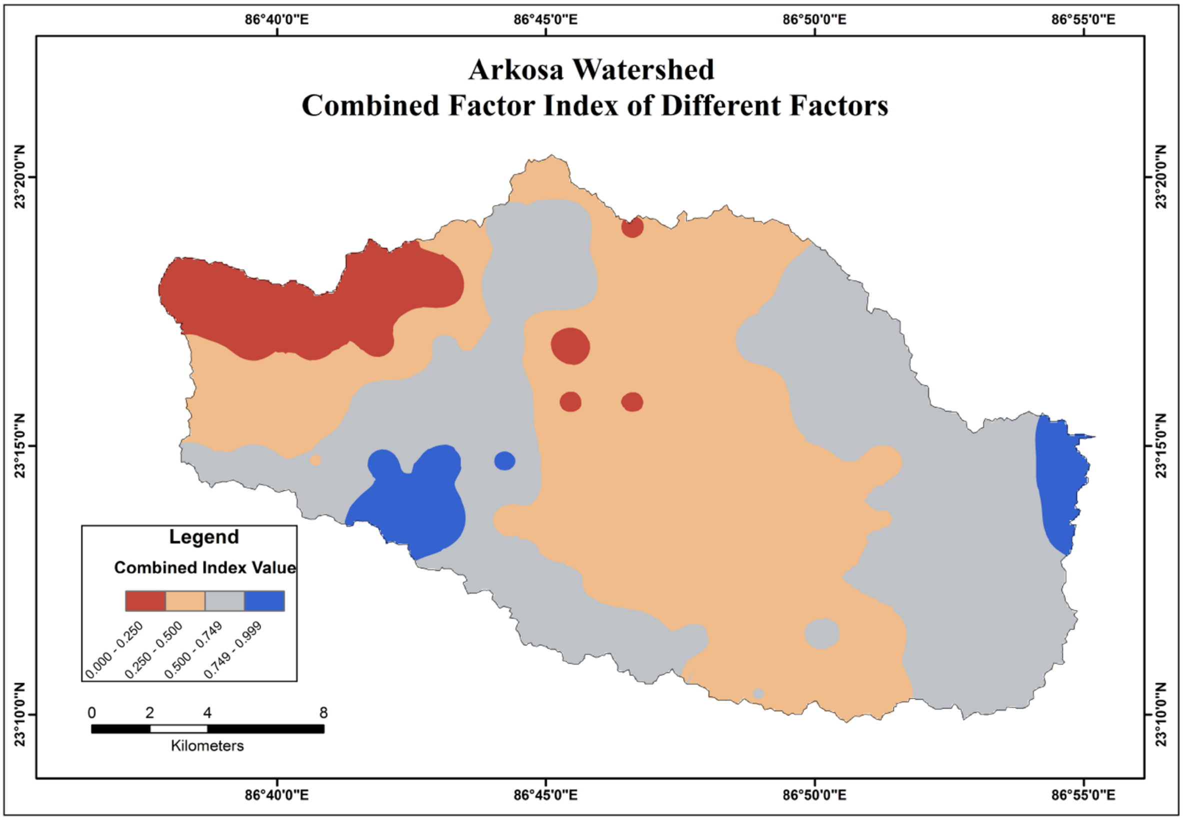


Fig. 15 Combined factor index of different factors

Table 4 Eigen value of different Component

Component	Eigen value	Difference	Proportion	Cumulative
1	1.39477	0.327199	0.279	0.279
2	1.06757	0.116985	0.2135	0.4925
3	0.950584	0.650736	0.1901	0.6826
4	0.88551	0.18394	0.1771	0.8597
5	0.70757		0.1403	1

Table 5 Pair wise compression matrix

Variable	R factor	K factor	LS factor	C factor	p factor
R factor	1.0000				
K factor	−0.0327	1.0000			
LS factor	0.0877	−0.2072	1.0000		
C factor	0.1463	−0.0944	−0.0152	1.0000	
P factor	−0.1433	0.1299	−0.0294	0.0268	1.0000

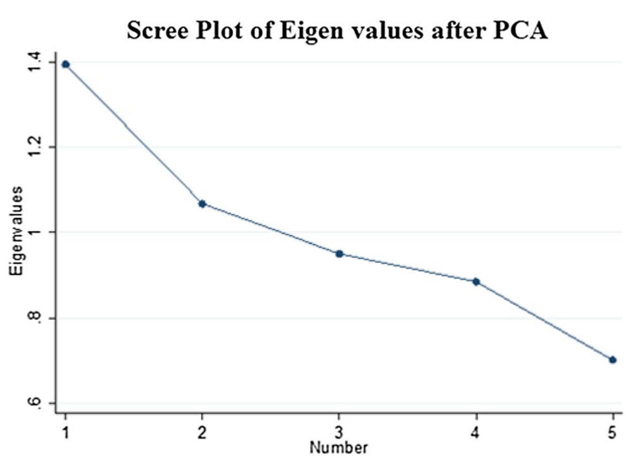


Fig. 16 Scree plot Eigen values

Table 6 Correlation of different factors against combined index

Variable	Partial correlation	Semi partial correlation	Significance value
R factor	1.0000	0.9743	0.0000
K factor	−0.1006	−0.0001	0.3596
LS factor	0.0272	0.0000	0.8046
C factor	−0.0882	−0.0001	0.4223
P factor	0.0494	0.0001	0.6532

Table 7 Descriptive statistics of different factors

Descriptive Statistics of Different Factors					
Variable	R factor	K factor	LS factor	C factor	P factor
Observations	89	89	89	89	89
Sum of Wgt	89	89	89	89	89
Mean	58.60311	0.23573	0.347679	0.916321	0.326629
Standard deviation	0.698002	0.083474	0.487997	0.046044	0.063496
Variances	0.004872	0.006968	0.238114	0.00212	0.004032
Skewness	−0.17801	−0.23992	3.457264	−0.74859	0.76512
Kurtosis	3.320614	1.913841	19.3609	3.977143	1.976369

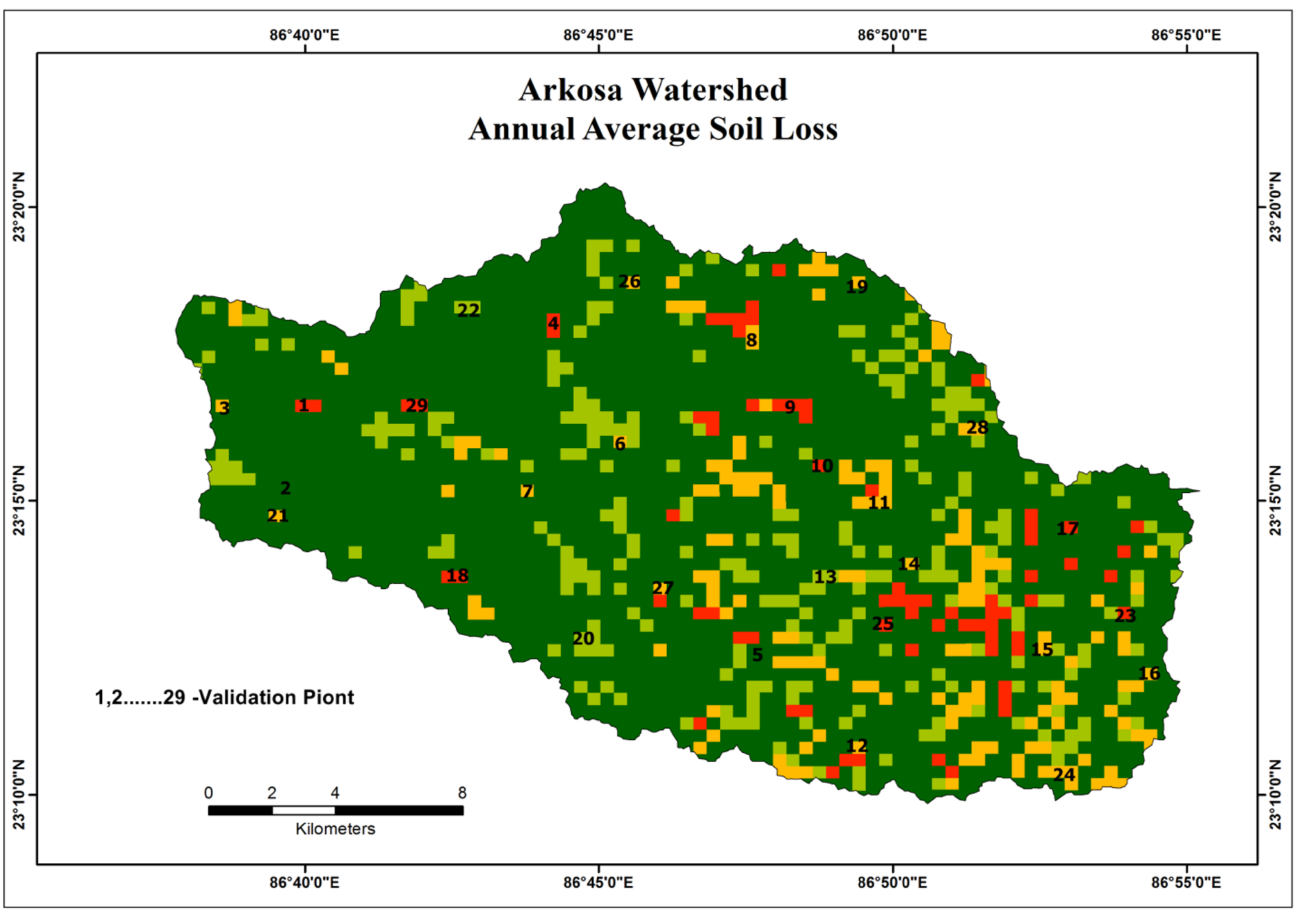


Fig. 17 Location of the validation points

Table 8 Validation of the study

Sl. No.	Observed	Estimated	Location
1	9.5472	11.910497	86°40′8.427"E 23°16′35.217"N
2	1.2132	1.021669	86°40′8.745"E 23°16′37.053"N
3	4.3823	4.167357	86°39′41.965"E 23°15′2.082"N
4	7.1955	8.713645	86°38′36.868"E 23°16′36.103"N
5	8.9951	9.630875	86°44′11.479"E 23°17′52.99"N
6	5.882	5.557058	86°45′24.224"E 23°15′59.51"N
7	2.9574	3.09164	86°45′20.573"E 23°16′0.605"N
8	6.8351	6.63544	86°47′41.015"E 23°17′53.816"N
9	7.8053	9.656019	86°48′22.757"E 23°16′30.912"N
10	8.9427	9.701634	86°48′41.889"E 23°15′33.517"N
11	3.1869	5.017178	86°49′40.162"E 23°14′58.242"N
12	7.2268	9.582526	86°49′28.389"E 23°10′37.135"N
13	3.574	3.770668	86°48′55.229"E 23°13′46.628"N
14	4.0176	6.156642	86°50′59.71"E 23°14′20.133"N
15	7.0153	5.586004	86°52′32.645"E 23°12′29.201"N
16	3.4629	4.222875	86°54′25.634"E 23°12′5.689"N
17	7.2397	9.53582	86°53′3.789"E 23°14′34.531"N
18	8.491	9.510132	86°42′39.079"E 23°13′43.53"N
19	4.5173	4.371514	86°49′24.141"E 23°18′45.416"N
20	1.6928	2.18687	86°44′40.688"E 23°12′41.666"N
21	3.692	4.434177	86°39′28.561"E 23°14′46.403"N
22	2.6091	3.838245	86°42′40.851"E 23°18′18.114"N
23	6.9816	9.453102	86°53′58.528"E 23°13′5.25"N
24	5.0183	4.286405	86°52′48.798"E 23°10′10.845"N
25	8.7491	9.26461	86°50′5.515"E 23°13′18.703"N
26	7.1052	7.755673	86°45′36.034"E 23°18′43.058"N
27	3.5327	4.103736	86°46′1.545"E 23°13′29.374"N
28	6.1094	6.392015	86°51′27.857"E 23°16′12.845"N
29	8.5071	9.269512	86°41′59.093"E 23°16′37.741"N

Table 9 Potential soil loss risk zones and its spatial coverage

Potential soil loss	Range (tons/ha/year)	Area in Km^2	Area in percentage (%)
Very high	12–16	74.708	21.437
High	8–12	50.675	14.541
Moderate	4–8	91.213	26.173
Low	0–4	131.904	37.849
Total		348.500	100

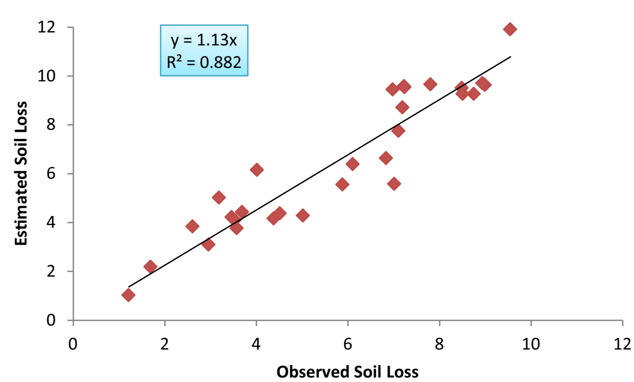


Fig. 18 Regression between estimated and observed soil loss

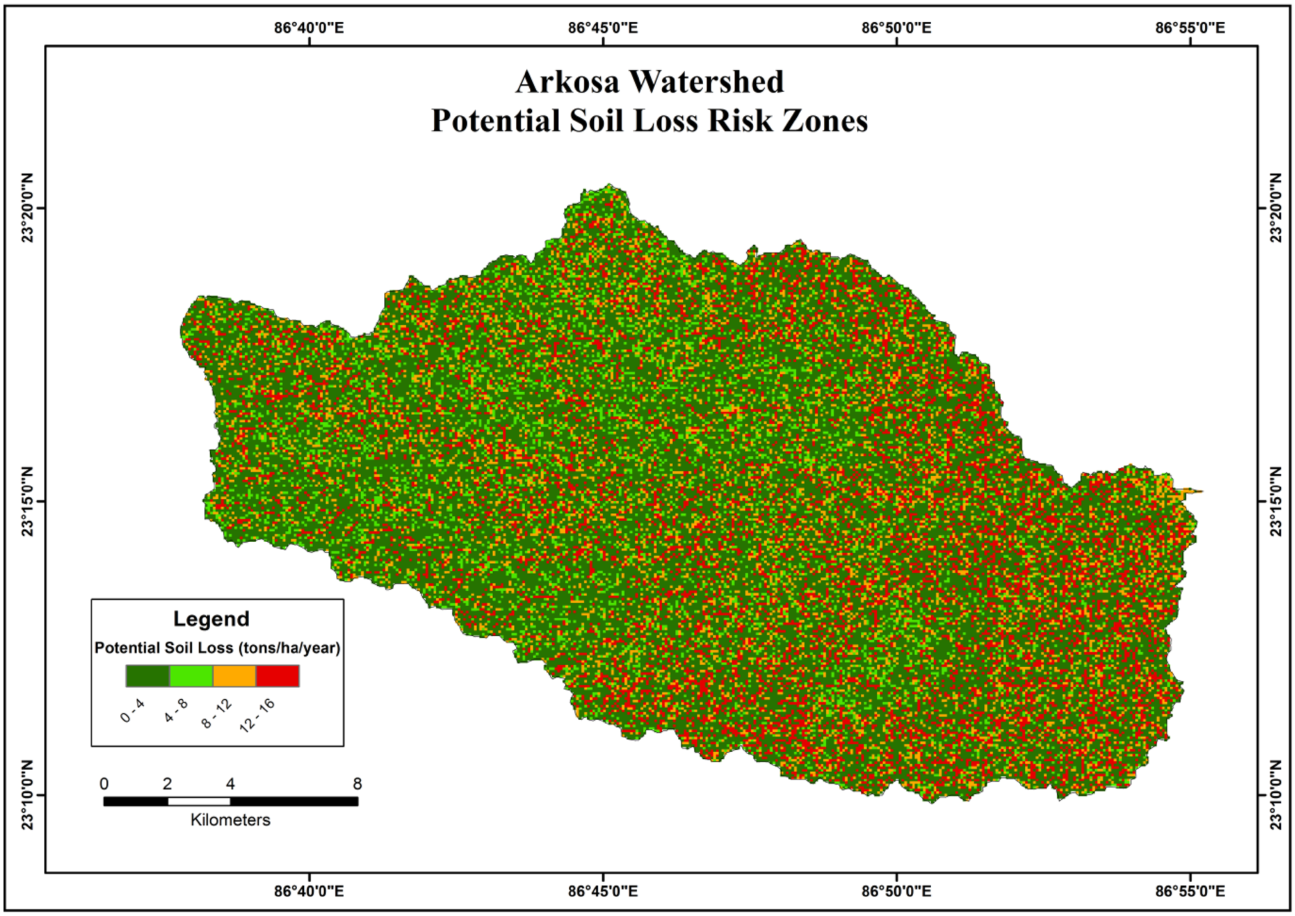


Fig. 19 Potential soil loss risk zones of Arkosa Watershed

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References

Aiello A, Adamo M, Canora F (2015) Remote sensing and GIS to assess soil erosion with RUSLE3D and USPED at river basin scale in southern Italy. Catena 131:174–185

Angima SD, Stott DE, Neill O, Ong MK, Weesies CK GA (2003) Soil erosion prediction using RUSLE for central Kenyan highland conditions. Agric Ecosyst Environ 97(1–3):295–308

Balasubramani K, Veena M, Kumaraswamy K, Saravanabavan V (2015) Estimation of soil erosion in a semi-arid watershed of Tamil Nadu (India) using revised universal soil loss equation (rusle) model through GIS. Model Earth Syst Environ 1(3):10

Belasri A, Lakhouili A (2016) Estimation of soil erosion risk using the Universal Soil Loss Equation (USLE) and geo-information technology in Oued El Makhazine watershed, Morocco. J Geogr Inform Syst 8(01):98

Bera A (2017) Assessment of soil loss by universal soil loss equation (USLE) model using GIS techniques: a case study of Gumti River Basin, Tripura, India. Model Earth Syst Environ 3(1):29

Bhandari KP, Aryal J, Darnsawasdi R (2015) A geospatial approach to assessing soil erosion in a watershed by integrating socio-economic determinants and the RUSLE model. Nat Hazards 75(1):321–342

Bhattarai R, Dutta D (2007) Estimation of soil erosion and sediment yield using GIS at catchment scale. Water Resour Manag 21(10):1635–1647

Biswas SS, Pani P (2015) Estimation of soil erosion using RUSLE and GIS techniques: a case study of Barakar River basin, Jharkhand, India. Model Earth Syst Environ 1(4):42

Biswas H, Raizada A, Mandal D, Kumar S, Srinivas S, Mishra PK (2015) Identification of areas vulnerable to soil erosion risk in India using GIS methods. Solid Earth 6(4):1247

Blanco-Canqui H, Lal R (2008) No-tillage and soil-profile carbon sequestration: an on-farm assessment. Soil Sci Soc Am J 72(3):693–701

Blanco H, Lal R (2010) Principles of soil conservation and management. Dordrecht, ISBN 978-1-4020-8708-0: Springer. https://doi.org/10.1007/978-1-4020-8709-7

Brady NC, Weil RC (2012) The nature and properties of soils. Pearson education, New Delhi

Busacca AJ, Cook CA, Mulla DJ (1993) Comparing landscape-scale estimation of soil erosion in the Palouse using Cs-137 and RUSLE. J Soil Water Conserv 48(4):361–367

Chakrabortty R, Ghosh S, Pal SC, Das B, Malik S (2018) Morphometric Analysis for Hydrological Assessment using Remote Sensing and GIS Technique: A Case Study of Dwarkeswar River

Basin of Bankura District, West Bengal. Asian Jo Res Soc Sci Humanit 8(4):113–142
Chen T, Ni RQ, Li PX, Zhang LP, Du B (2011) Regional soil erosion risk mapping using RUSLE, GIS, and remote sensing: a case study in Miyun Watershed, North China. Environ Earth Sci 63(3):533–541
Das B, Paul A, Bordoloi R, Tripathi OP, Pandey PK (2018) Soil erosion risk assessment of hilly terrain through integrated approach of RUSLE and geospatial technology: a case study of Tirap District, Arunachal Pradesh. Model Earth Syst Environ 4(1):373–381
Demirci A, Karaburun A (2012) Estimation of soil erosion using RUSLE in a GIS framework: a case study in the Buyukcekmece Lake watershed, northwest Turkey. Environ Earth Sci 66(3):903–913
Donahue RL, Shickluna JC, Robertson LS (1972) Soils; an introduction to soils and plant growth. Soil Sci 114(6):497
Dutta S (2016) Soil erosion, sediment yield and sedimentation of reservoir: a review. Model Earth Syst Environ 2(3):123
Dutta D, Das S, Kundu A, Taj A (2015) Soil erosion risk assessment in Sanjal watershed, Jharkhand (India) using geo-informatics, RUSLE model and TRMM data. Model Earth Syst Environ 1(4):37
Fagbohun BJ, Anifowose AY, Odeyemi C, Aladejana OO, Aladeboyeje AI (2016) GIS-based estimation of soil erosion rates and identification of critical areas in Anambra sub-basin, Nigeria. Model Earth Syst Environ 2(3):159
Fu G, Chen S, McCool DK (2006) Modeling the impacts of no-till practice on soil erosion and sediment yield with RUSLE, SEDD, and ArcView GIS. Soil Tillage Res 85(1–2):38–49
Ganasri BP, Ramesh H (2016) Assessment of soil erosion by RUSLE model using remote sensing and GIS-A case study of Nethravathi Basin. Geosci Front 7(6):953–961
Gayen A, Saha S (2017) Application of weights-of-evidence (WoE) and evidential belief function (EBF) models for the delineation of soil erosion vulnerable zones: a study on Pathro river basin, Jharkhand, India. Model Earth Syst Environ 3(3):1123–1139
Ghosh S, Guchhait SK (2012) Soil loss estimation through USLE and MMF methods in the lateritic tracts of eastern plateau fringe of Rajmahal traps, India. Ethiop J Environ Stud Manag 5(4):529–541
Ghosh PK, Das A, Saha R, Kharkrang E, Tripathi AK, Munda GC, Ngachan SV (2010) Conservation agriculture towards achieving food security in North East India. Curr Sci: 915–921
Ghosh BN, Meena VS, Alam NM, Dogra P, Bhattacharyya R, Sharma NK, Mishra PK (2016) Impact of conservation practices on soil aggregation and the carbon management index after seven years of maize–wheat cropping system in the Indian Himalayas. Agric Ecosyst Environ 216:247–257
Hashim GM, Abdullah WW (2005) Prediction of soil and nutrient losses in a highland catchment. Water Air Soil Pollut Focus 5(1–2):103–113
Heiblum RH, Koren I, Altaratz O (2011) Analyzing coastal precipitation using TRMM observation. Atmos Chem Phys 11:13201–13217
Hembram TK, Saha S (2018) Prioritization of sub-watersheds for soil erosion based on morphometric attributes using fuzzy AHP and compound factor in Jainti River basin, Jharkhand, Eastern India. Environ Dev Sustain:1–28
Irvem A, Topaloğlu F, Uygur V (2007) Estimating spatial distribution of soil loss over Seyhan River Basin in Turkey. J Hydrol 336(1–2):30–37
Jain MK, Kothyari UC (2000) Estimation of soil erosion and sediment yield using GIS. Hydrol Sci J 45(5):771–786
Jiang L, Yao Z, Liu Z, Wu S, Wang R, Wang L (2015) Estimation of soil erosion in some sections of Lower Jinsha River based on RUSLE. Nat Hazards 76(3):1831–1847
Johnson JW (1943) Distribution graphs of suspended-matter concentration. Trans Am Soc Civ Eng 108(1):941–956
Kinnell PIA (1999) Discussion on 'The European Soil Erosion Model (EUROSEM): a dynamic approach for predicting sediment transport from fields and small catchments'. Earth Surf Process Landf J Br Geomorphol Res Gr 24(6):563–565
Kouli M, Soupios P, Vallianatos F (2009) Soil erosion prediction using the revised universal soil loss equation (RUSLE) in a GIS framework, Chania, Northwestern Crete, Greece. Environ Geol 57(3):483–497
Kumar S, Kushwaha SPS (2013) Modelling soil erosion risk based on RUSLE-3D using GIS in a Shivalik sub-watershed. J Earth Syst Sci 122(2):389–398
Lewis LA, Verstraeten G, Zhu H (2005) RUSLE applied in a GIS framework: calculating the LS factor and deriving homogeneous patches for estimating soil loss. Int J Geogr Inf Sci 19(7):809–829
Lim KJ, Sagong M, Engel BA, Tang Z, Choi J, Kim KS (2005) GIS-based sediment assessment tool. Catena 64(1): 61–80
Liu BY, Nearing MA, Shi PJ, Jia ZW (2000) Slope length effects on soil loss for steep slopes. Soil Sci Soc Am J 64(5):1759–1763
Lu D, Li G, Valladares GS, Batistella M (2004) Mapping soil erosion risk in Rondonia, Brazilian Amazonia: using RUSLE, remote sensing and GIS. Land Degrad Dev 15(5):499–512
Mallick J, Alashker Y, Mohammad SAD, Ahmed M, Hasan MA (2014) Risk assessment of soil erosion in semi-arid mountainous watershed in Saudi Arabia by RUSLE model coupled with remote sensing and GIS. Geocarto Int 29(8):915–940
McCool DK, Brown LC, Foster GR, Mutchler CK, Meyer LD (1987) Revised slope steepness factor for the Universal Soil Loss Equation. Trans ASAE 30(5):1387–1396
Millward AA, Mersey JE (1999) Adapting the RUSLE to model soil erosion potential in a mountainous tropical watershed. Catena 38(2):109–129
Mondal A, Khare D, Kundu S (2016) Impact assessment of climate change on future soil erosion and SOC loss. Nat Hazards 82(3):1515–1539
Moore ID, Burch GJ (1986) Physical Basis of the Length-slope Factor in the Universal Soil Loss Eq. 1. Soil Sci Soc Am J 50(5):1294–1298
Moore ID, Wilso JP (1992) Length-slope factors for the Revised Universal Soil Loss Equation: Simplified method of estimation. J Soil Water Conserv 47(5):423–428
Morgan RPC (2005) Soil erosion and conservation. 3rd ed, Blackwell Publ., Oxford
Morgan RPC, Morgan DDV, Finney HJ (1984) A predictive model for the assessment of soil erosion risk. J Agric Eng Res 30:245–253
Morgan RPC, Quinton JN, Smith RE, Govers G, Poesen JWA, Auerswald K, Styczen ME (1998) The European Soil Erosion Model (EUROSEM): a dynamic approach for predicting sediment transport from fields and small catchments. Earth Surf Process Landf 23(6):527–544
Morgan RPC, Quinton JN, Smith RE, Govers G, Poesen JWA, Auerswald K, Styczen ME (1999) Reply to discussion on 'The European Soil Erosion Model (EUROSEM): a dynamic approach for predicting sediment transport from fields and small catchments'. Earth Surf Process Landf J Br Geomorphol Res Gr 24(6):567–568
Pal S (2016) Identification of soil erosion vulnerable areas in Chandrabhaga river basin: a multi-criteria decision approach. Model Earth Syst Environ 2(1):5
Pal S, Debanshi S (2017) Influences of soil erosion susceptibility toward overloading vulnerability of the gully head bundhs in Mayurakshi River basin of eastern Chottanagpur Plateau. Environ Dev Sustain:1–37
Pal B, Samanta S (2011) Estimation of soil loss using remote sensing and geographic information system techniques (Case study

of Kaliaghai River basin, Purba and Paschim Medinipur District, West Bengal, India). Indian J Sci Technol 4(10):1202–1207
Pal SC, Shit M (2017) Application of RUSLE model for soil loss estimation of Jaipanda watershed, West Bengal. Spat Inf Res 25(3):399–409
Pal SC, Chakrabortty R, Malik S, Das B (2018) Application of forest canopy density model for forest cover mapping using LISS-IV satellite data: a case study of Sali watershed, West Bengal. Model Earth Syst Environ 4(2):853–865. https://doi.org/10.1007/s40808-018-0445-x
Pandey A, Chowdary VM, Mal BC (2007) Identification of critical erosion prone areas in the small agricultural watershed using USLE, GIS and remote sensing. Water Resour Manag 21(4):729–746
Pérez-Rodríguez R, Marques MJ, Bienes R (2007) Spatial variability of the soil erodibility parameters and their relation with the soil map at subgroup level. Sci Total Environ 378(1–2):166–173
Pradeep GS, Krishnan MN, Vijith H (2015) Identification of critical soil erosion prone areas and annual average soil loss in an upland agricultural watershed of Western Ghats, using analytical hierarchy process (AHP) and RUSLE techniques. Arab J Geosci 8(6):3697–3711
Prasannakumar V, Vijith H, Abinod S, Geetha N (2012) Estimation of soil erosion risk within a small mountainous sub-watershed in Kerala, India, using Revised Universal Soil Loss Equation (RUSLE) and geo-information technology. Geosci Front 3(2):209–215
Rahman MR, Shi ZH, Chongfa C (2009) Soil erosion hazard evaluation—an integrated use of remote sensing, GIS and statistical approaches with biophysical parameters towards management strategies. Ecol Model 220(13–14):1724–1734
Renard KG (1997) Predicting soil erosion by water: a guide to conservation planning with the revised universal soil loss equation (RUSLE), US Department of Agriculture, Washington
Renard KG, Foster GR (1983) Soil conservation: principles of erosion by water. Dryland Agric 23:155–155citation_lastpage
Renard KG, Laursen EM (1975) Dynamic behavior model of ephemeral stream. J Hydraulics Div 101(5):511–528
Renard KG, Laflen JM, Foster GR, McCool DK (1994) The revised universal soil loss equation. Soil Eros Res Methods 2:105–124
Rendon-Herrero O (1978) Unit sediment graph. Water Resour Res 14:889–901
Sadiki A, Bouhlassa S, Auajjar J, Faleh A, Macaire JJ (2004) Use of GIS for the evaluation and mapping of erosion risk by the universal soil loss equation in the Eastern Rif (Morocco): Boussouab Watershed Case Study. Sci Inst Bull Rabat Earth Sci Ser 26:69–79
Samanta RK, Bhunia GS, Shit PK (2016a) Spatial modelling of soil erosion susceptibility mapping in lower basin of Subarnarekha river (India) based on geospatial techniques. Model Earth Syst Environ 2(2):99. https://doi.org/10.1007/s40808-016-0170-2
Samanta S, Koloa C, Pal DK, Palsamanta B (2016b) Estimation of potential soil erosion rate using RUSLE and E30 model. Model Earth Syst Environ 2(3):149
Sharma A (2010) Integrating terrain and vegetation indices for identifying potential soil erosion risk area. Geo-Spat Inf Sci 13(3):201–209
Shit PK, Nandi AS, Bhunia GS (2015) Soil erosion risk mapping using RUSLE model on Jhargram sub-division at West Bengal in India. Model Earth Syst Environ 1(3):28
Sinha D, Joshi VU (2012) Application of Universal Soil Loss Equation (USLE) to Recently Reclaimed Badlands along the Adula and Mahalungi Rivers, Pravara Basin, Maharashtra. J Geol Soc India 80(3):341–350
Stolpe NB (2005) A comparison of the RUSLE, EPIC and WEPP erosion models as calibrated to climate and soil of south-central Chile. Acta Agric Scand Sect B Soil Plant Sci 55(1):2–8
Terranova O, Antronico L, Coscarelli R, Iaquinta P (2009) Soil erosion risk scenarios in the Mediterranean environment using RUSLE and GIS: an application model for Calabria (southern Italy). Geomorphology 112(3–4):228–245
Tetford PE, Desloges JR, Nakassis D (2017) Modelling surface geomorphic processes using the RUSLE and specific stream power in a GIS framework, NE Peloponnese, Greece. Model Earth Syst Environ 3(4):1229–1244
Tilahun AK, Haregeweyn N, Pingale SM (2018) Landscape changes and its consequences on soil erosion in Baro river basin, Ethiopia. Model Earth Syst Environ 4(2):793–803
USEPA (U.S. Environmental Protection Agency) (1994) SWRRBWQ: window's interface users guide. U.S. Environmental Protection Agency, Washington, DC
Vertessy RA, Watson FG, Rahman JM, Cuddy SM, Seaton SP, Chiew FH, Verbunt M (2001) New software to aid water quality management in the catchments and waterways of the south-east Queensland region. In Proceedings of the Third Australian Stream Management Conference, August: 27–29
Viney NR, Sivapalan M (1999) A conceptual model of sediment transport: application to the Avon River Basin in Western Australia. Hydrol Process 13(5):727–743
Wang G, Gertner G, Parysow P, Anderson AB (2000) Spatial prediction and uncertainty analysis of topographic factors for the revised universal soil loss equation (RUSLE). J Soil Water Conserv 55(3):374–384
Wijesundara NC, Abeysingha NS, Dissanayake DMSLB (2018) GIS-based soil loss estimation using RUSLE model: a case of Kirindi Oya river basin, Sri Lanka. Model Earth Syst Environ 4(1):251–262
Williams JR (1978) A sediment graph model based on an instantaneous unit sediment graph. Water Resour Res 14(4):659–664
Williams JR, Berndt HD (1977) Sediment yield prediction based on watershed hydrology. Trans ASAE 20(6):1100–1104
Wischmeier WH, Smith DD (1978) Predicting rainfall erosion losses-a guide to conservation planning. US Department of Agriculture, Washington
Yoder D, Lown J (1995) The future of RUSLE: inside the new revised universal soil loss equation. J Soil Water Conserv 50(5):484–489
Yue-Qing X, Xiao-Mei S, Xiang-Bin K, Jian P, Yun-Long C (2008) Adapting the RUSLE and GIS to model soil erosion risk in a mountains karst watershed, Guizhou Province, China. Environ Monit Assess 141(1–3):275–286
Zhihua S, Chongfa C, Shuwen D, Zhaoxia L, Tianwei W (2002) Soil Conservation Planning at Small Watershed Level Using GIS-Based Revised Universal Soil Loss Equation (RUSLE). Trans Chin Soc Agric Eng 4:043
Rouse J Jr, Haas RH, Schell JA, Deering DW (1974) Monitoring vegetation systems in the Great Plains with ERTS. https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19740022614.pdf
Renard KG, Foster GR, Weesies GA, McCool DK, Yoder DC coordinators (1997) Predicting soil erosion by water: A guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). US Department of Agriculture, Agriculture Handbook 703:404
Johanson RC, Davis HH (1980) Users manual for hydrological simulation program-Fortran (HSPF), Vol. 80, No. 15. Environmental Research Laboratory, Office of Research and Development, US Environmental Protection Agency
McCool DK, Foster GR, Yoder DC, Weesies GA (2004) The revised universal soil loss equation, Version 2. In International Soil Conservation Organization Conference Proceedings
Chemeda S (2007) Soil Erosion Hazard Assessment Using USLE Model: A Case Study of Legedadi& Dire Reservoir Catchment, Doctoral dissertation, MSc thesis Department of Remote

Sensing and Geographical Information Systems. Addis Ababa, Ethiopia\

DLWC (Department of Land and Water Conservation) (1999) Integrated water Quantity-Quality Model (IQQM) user manual. Centre for Natural Resources, NSW Dept. of Land and Water, Conservation Australia

Van der Knijff JMF, Jones RJA, Montanarella L (1999) Soil erosion risk assessment in Italy. European Soil Bureau European Commission. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.397.2309&rep=rep1&type=pdf

Foster GR, Meyer LD (1972) Closed-form soil erosion equation for upland areas. In Sedimentation Symposium To Honor Professor HA Einstein, Berkeley 1971