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Assessment of Soil Erosion using Remote Sensing Techniques: A Global Review

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***Abstract*:** Soil is considered to be an important component of the terrestrial ecosystem. It possesses inherent capability of food and biomass production and maintaining soil biodiversity. Both natural and anthropogenic activities are leading to soil erosion, hence directly affecting the soil fertility as well as food security. Among the different factors, soil erosion is one of the major constraints resulting in low productivity of soils as the macro as well as the micronutrients along with the organic matter are washed away with the soils. Moreover, soil organic carbon also moves out of the carbon cycle which results in depletion of soil fertility. Thus, the prime need in this alarming situation is to shift from our traditional ways of assessment of soil erosion to its estimation through remote sensing. Remote sensing technology proves to be a valuable tool in developing suitable models through utilization of advanced features of data storage and management, interpretation and display of spatial data. Moreover, integrated erosion forecasting models not only estimates the soil loss but also provides spatial distribution of the eroded material. Overall, the aim of this paper is to review the role of remote sensing in determining the extent of soil erosion and to highlight the lacuna associated with these techniques and recommendations for future applications. These would help the researchers to apply these advanced techniques more energetically in a wide range of agro-climatic zones and regions with variations that exists among the data availability and modelling at finer spatial and temporal scales.

Keywords: Degradation, Remote sensing, Sequestration, Soil erosion, Sustainable management

Degradation of agricultural land has become a global issue in the recent few years (Eswaran et al 2001). Escalating population growth, deforestation activities, excessive cultivation and overgrazing has led to expedite erosion activities in the world mainly developing countries (Zemenu and Minale 2014,; Gelagay and Minale 2016). A nation's economic growth predominantly relies on industrialization and agriculture. These directly or indirectly depend on the soil conservation while direct correlation was observed between crop yield and soil loss (Prasad and Tiwari 2019). Soil detachment and transportation hamper the soil fertility, posing threat to agricultural sustainability, productivity and economy of the country (Pimentel et al 1995, Prasannakumar et al 2012). Soil erosion is the most serious form of land degradation which severely affects food production. Out of 30,60,500 km^2 land area, 13,00,000 km^2 area was seriously affected by soil erosion i.e., 42.5% (Prasad and Tiwari 2019). Out of the total 3,280,000 sq. km land area, nearly 53% area is highly prone to soil erosion (1,750,000 sq.km) [GIS, RUSLE and SEDD 2003]. Estimation of soil degradation by remote sensing is instrumental in analyzing the rate and spatial extent of this problem. To prevent the deterioration of agricultural lands, improved management practices should be adopted for managing as well as monitoring the soil resources. Remote sensing plays a crucial role in mapping the extent of degraded soils and monitoring the current scenario in erosion-threatened soils for initiating proper planning response measures and assessing their efficiency (Shoshany et al 2013). Wide applications of remote sensing in soil erosion mapping and modeling have gained considerable momentum in the last few decades where multispectral data (Landsat imagery) is prominently recommended for soil erosion modeling. Besides its few limitations viz. cost and time consuming, remote sensing techniques provide suitable quantitative information which is necessary for the assessment and monitoring of erosion level (Sepuru and Dube 2018). Both remote sensing and GIS techniques have become valuable tools for the digitization of input data and map generation (Agarwal et al 2016). The Universal Soil Loss Equation developed by Wischmeier and Smith (1965), is one of the most widely adopted empirical models for the estimation of soil loss. The Revised Universal Soil Loss Equation (RUSLE) model is a much more advanced version of USLE (Wischmeier and Smith 1978), for predicting the long-term average annual soil loss from slopy fields under specified cropping, and additionally from rangeland (Renard et al 1997). It is quite effective in estimating soil loss from different parts of the world (Rozos et al 2013, Ganasri and Ramesh 2015, Zhao et al 2017). It can even predict erosion potential on a cell-by-cell basis but not on the basis of sediment yield (Anees et al 2018). Other than USLE, substantial efforts have been made to develop various erosion models such as Water Erosion Prediction Project Soil Loss Equation (WEPP) (Gansari and Ramesh 2015), European Soil Erosion Model (EUROSEM) and Soil and Water Assessment Tool (SWAT) (Wishmeir and Smith 1978). Using Geographical Information System environment derived from SRTM DEM, systematic analysis of watershed characteristics was carried out concerning soil erosion under intense weather conditions (Ali et al 2018). Remote sensing technology proves to be a valuable tool in developing suitable models through the utilization of advanced features of data storage and management, interpretation, and display of spatial data. Integrating these models not only aids in quantifying soil loss but also provides sound knowledge about the spatial distribution of the eroded material. Thus, rendering a practically feasible solution for the assessment of soil degradation. Overall, the emphasis is to review the role of remote sensing in determining the extent of soil erosion and to highlight the lacuna associated with these techniques and recommendations for future applications so that these advanced techniques can be applied in a wide range of agro-climatic zones. Integrating GIS with empirical erosion models viz. RUSLE, not only estimates soil loss but also estimate the extent of the spatial distribution of erosion. GIS environment aids in generating erosion risk maps to facilitate areas with high erosion risks for prioritization (Kushwaha and Yousuf 2017). Using Remotely sensed data, the extent of erosion was enumerated to delineate the land cover changes and an algorithm was developed for long-term Universal Soil Loss Equation (USLE model) for parameter acquisition, calculation as well as validation based on remote sensing data (Ma et al 2003). Baban and Yusof (1999) assessed soil erosion using remotely sensed data (RUSLE model) and GIS and identified the spatial pattern and expanse of erosion and categorized different erosion risk areas in Ethiopia (Mekonnen and Melesse 2011). Prasad and Tiwari (2019) utilized USLE to measure soil disintegration in upper lake Bhopal, India. Soil loss was evaluated using RUSLE in the Southwestern part of India (Ganasri and Ramesh 2015). Ashiagbor et al (2013) depicted spatial circulation of soil disintegration using RUSLE and GIS gadgets and studied the relation between slope and Land use and Land Cover (LULC) in Ghana. Chang and Bayes (2013) used the RUSLE model to work out the most erodible territories in Ohio. GIS-based USLE approach was employed for spatial Conveyance of various erosion inclined regions in Bhopal (Prasad and Tiwari 2019). Waghmare and Suryawanshi (2017) mapped five soil erosion risk classes (very low, low, medium, medium-high, and high) based on RUSLE within the GIS environment. They explored relationships between soil erosion risk and LULC distribution. RUSLE model outstretches its application to different scenarios, including forest, rangeland, and disturbed areas (Renard et al 1997). New remote sensing technology estimates soil erosion and its spatial distribution from large areas (Waghmare and Suryawanshi 2017). Different approaches were used to assess soil erosion risk using different models (Bartsch et al 2002). A ranking method based on indicators viz. percentage of bare ground, organic carbon, aggregate stability, percent clay, and bulk density (Shakesby et al 2002), and qualitative erosion risk mapping based on the combination of five factors such as geology, soil, relief, climate, and vegetation (Vrieling et al 2002) play a crucial role in mapping soil erosion risk. Developed for the USA, RUSLE has proved to be crucial for delineating the extent of soil erosion in other regions of the world (Waghmare and Suryawanshi 2017). Morgan method, a much powerful method was used to solve the modeling problem of soil erosion. It is a quite easy and flexible method than the CREAMS method and fundamental than the USLE method. It was depicted that cover fraction (15%) by corn residues minimizes the soil runoff by 75% (Melesse and Jordan 2002). GIS software namely ILWIS and ERDAS Imagine were used to monitor the probable success of the Morgan method for soil erosion modeling (Ustun 2008). Integration of remote sensing with Geographic Information System (GIS), provides critical information on erosional dynamics and intensity over time and space, which is essential in providing major criteria for mapping soil erosion, control, and prediction (Sepuru and Dube 2018). Remote sensing acts as an indispensable tool in mapping land use/ land cover (LULC) and modelling soil erosion. Integrating GIS with the remotely sensed data, spatial distribution is the baseline step in assessing soil erosion vulnerable areas at basin and/ or regional scale (Krishna Bahadur 2009, Magliulo 2010, 2012, Chen et al 2011, Prasannakumar et al 2011, Mhangara et al 2012), is the most powerful and fundamental tool for land-use planning (Aydda et al 2014, Magliulo et al 2020), natural resources inventory for natural resources management (Lillesand and Kiefer 1994) and estimating soil erosion extent (Knight et al 2007, Sepuru and Dube 2018). With the furtherance of innovation and headway in the field of GIS and remote sensing, researchers have estimated extent of soil erosion throught the use of well-developed models (Prasad and Tiwari 2019).

Data source for soil erosion modelling: Highly advocated remotely sensed data for erosion modeling were multispectral sensors, viz. Landsat data imagery, while the use of high spectral resolution information was limited, predominantly due to the acquisition cost (Sepuru and Dube

2018). The data commonly utilized for RUSLE and preparation of erosion hazard map were obtained using various sources viz. topographic sheets (58 I/11, 12, 15, 16) and Landsat8 OLI/TIRS data using Earth Explorer and CARTO DEM (30m resolution) bhuvan website. The rainfall and soil data were obtained from IMSD data center, India and NBSS and land use planning centre, Tamilnadu, respectively. Processing of the data was done using maximum possibility classification algorithm and spatial analyst in ERDAS imagine and Arc GIS 10.1, respectively (Karthick et al 2017). To generate RUSLE factors, data was obtained from Landsat thematic mapper, digitized soil and topographic maps as well as the precipitation data (Millward and Mersey 1999). Landsar 8 imagery, Shuttle Radar Topography Mission (SRTM) imagery, Era-Interim integrated with soil database were utilized as a digital data source for preparing land use maps, digital elevation model (DEM), rainfall as well as soil data, respectively, to produce USLE (Universal Soil Loss Equation (USLE) variables (Ajibade et al 2020).

Soil loss: Now-a-days, much of the global attention is towards soil erosion due to various ecological and environmental problems viz. land degradation, soil fertility loss, drainage and river siltation (Anees et al 2018, Wang et al 2018) leading to reduction in reservoir capacity thus, negatively impacting aquatic habitats, hydrologic systems as well as quality of water downstream as the sediments are usually combined with nutrients, toxic chemicals and metals (Kouli et al 2009, Zhang et al 2009, Kim 2014, Lamyaa et al 2018). Soil degradation relies upon both natural and anthropogenic elements. These elements are classified as quasi-static factors (morphology, infiltration and erodibility) and temporally variable factors (rainfall intensity, vegetation cover, land use and agricultural practices) (Roose & Lelong 1976, Boukheir et al 2006, Bouhadeb et al 2018, Ajibade et al 2020). Soil erosion is perceived as one of the most problematic and visible form of soil degradation (Boardman and Poesen 2006, EEA and JRC, 2010, Grimm et al 2002, Panagos et al 2016, Stolte et al 2016, Žížala et al 2019). Soil losses occur when erosion rates exceeds the deposition rates, resulting in soil loss which is the outcome of increasing surface erodibility, as well as rise in water or wind-erosive energy (Cerdà et al 2012, Shoshany et al 2013). In case of watershed, water erosion was found to be a critical problem causing soil loss ranging from zero in gentle slope of forest lands to 442.92 t ha^{-1} year^{-1} on very steep slope cultivated lands. Belayneh et al (2019) estimated the average soil erosion rate to be nearly 42.67 t ha^{-1} year^{-1}. A total of 9.68 mt of gross surface soil has been lost annually, of which 62.1% was generated from cultivated land area. According to the latest estimates, an area of about 120.72 Mha (million hectares) is affected by various forms of land degradation in India, out of which 82.57 Mha is solely as a result of water induced soil erosion (Maji et al 2010, Das and Poongathai 2018). The momentous effects of erosion includes degradation in soil productivity and water quality because of siltation, sedimentation and eutrophication of water bodies (Onyando et al 2005, Das et al 2020). Soil loss is enhanced by coalescence of various factors viz. climate change, slope length-steepness, land cover patterns and soil's intrinsic properties (Gelagay and Minale 2016). According to the report by the European Commission on 'Implementing Soil Thematic Strategy Protection' for Soil (European Commission 2012), soil erosion was observed to be an irreparable damage in Europe. When the soil loss is more than 1 t ha^{-1} year^{-1}, this causes an irretrievable damage to the soil (Verheijen et al 2009, Novotný et al 2016). Soil erosion exacerbates already existing land-related issues viz. landslides, drought, floods and other disasters (Munodawafa 2007, Rickson 2014, Zeng et al 2017).

Thus, remote sensing studies emphasize on exploring specific erosional processes concerned with overall soil losses. The fundamental methods involved in these studies includes a) direct methods, where indicators are explicitly linked to certain soil-erosion processes; b) indirect methods, where indicators can be linked implicitly to some specific processes of erosion and c) phenomenological methods describing the link between environmental parameters as well as actual soil loss (Shoshany et al 2013).

Remote Sensing Methods for Mapping Specific Soil Erosion Types

Direct method: These methods involves estimation through focus on studies related to properties like surface lowering (subsidence), change in soil roughness, etc. In surface lowering, changes in geomorphic surface are detected using temporal changes in interferometric coherence (Liu et al 1999, Smith et al 2002, Roering et al 2009, Zhao et al 2009) while radar backscattering and lidar mapping are used to evaluate changes in soil roughness (Fernández-Calviño et al 2010). For bare soil surfaces, radar backscatter is estimated by surface roughness and SM (Morgan 2005). Barber and Mahler (2010) reported High-resolution mapping of gullies, InSAR multi-temporal interferometric coherence change technique for analysing sheet, rill and gully erosion (Liu et al 1999, 2004). Roering et al (2009) further studied this approach by integrating air photographs and lidar data with InSAR for detecting erosional features. The methods aids in identification and delineation of individual erosion features (rills, gullies and sediment depositions) (Fadul et al 1999, Martínez-Casasnovas 2003), or eroded and accumulated areas (Alatorre and Beguería 2009, Žížala et al 2018)

Indirect method: Remote sensing plays a crucial role in erosion studies by acquiring input data for various erosion models or an indirect assessment of soil erosion through indirect method involves the analysis of vegetation cover. (Luleva 2013, Shoshany et al 2013, Vrieling 2007). These methods provide input data for erosion models. Reiche et al (2012) adopted vegetative cover typologies (satellite imagery and digital elevation model (DEM) data) for mapping the intensity of wind erosion in grazing areas of Inner Mongolia using Landsat Thematic Mapper (TM) and in Northern China (Yan et al 2005). Some of the indirect methods viz. NDVI time series method (Clark et al 2010), integration of NDVI in the Computational Environmental Management System (Smith and Leys 2009) in Australia and annual NDVI time series from MODIS correlated well with risk of wind-erosion in agricultural lands. Gully erosion can be detected using Landsat Enhanced Thematic Mapper (ETM) and Systéme Pour l'Observation de la Terre 5 (SPOT 5) in Sudan (Fadul et al 1999), Nigeria (Igbokwe et al 2008), the two-phase method combining classification (Landsat TM bands 3, 5, 7 and NDVI) in Spain (Martinez-Casasnovas and Zaragoza 1996), Landsat TM imagery (Barber and Mahler 2010), using simple supervised classification techniques (Torkashvand and Shadparvar 2011) and Advanced Spaceborne Thermal Emission and Reflection (ASTER) radiometer images (Bouaziz et al 2009).

Satellite remote sensing of soil erosion: Both Remote sensing and GIS are considered to be the fundamental tools for estimating soil loss and even for detecting the places that are under peril or encountering an alarming rate of soil erosion. Some studies focussed on quantitative estimation of soil erosion through satellite imagery (Tanser and Palmer 1999, Wessels et al 2004, 2007, Bai and Dent 2007, Thompson et al 2009, Bennett et al 2012). The data obtained through remote sensing is particularly useful for policy and decision-makers to preserve the environment and indulge in soil conservation measures to reduce soil loss as and where needed (Ahmed et al 2018). Remote sensing and GIS are constantly been used to estimate land use and change in land cover (Anees et al 2014, 2017), morphometric analysis (Ahmed et al 2010, Dinesh et al 2012), estimating soil loss (Ochoa-Cueva et al 2015, Markose and Jayappa 2016), sediment yield (Rawat et al 2014, Zhao et al 2017), watershed prioritisation; Malekian and Azarnivand 2016) and for various other hydrological models to work out input data (Anees et al 2018). Aerial photographs and satellite imagery are highly capable of quantifying and monitoring erosion at local, national and regional scales (Le Roux et al 2007, Sepuru and Dube 2018). Some Satellite-based spectral indices such as Normalized Difference Vegetation Index (NDVI), Normalized Difference Soil Index (NDSI), Tasselled Cap Transformation (TCT), along with Linear Spectral Unmixing Analysis (LSMA) are oftenly employed to assess soil erosion process (Singh et al 2004, Vrieling 2006), analyze soil exposure intensity (Xu 2014), estimate soil reflectance (Sayao et al 2018, Lobser and Cohen 2007), work out soil erosion status (Zhang et al 2014, Metternicht 1998) and evaluate different soil properties as well as bare soil fractions (Guerschman et al 2015). Unmanned Aerial Vehicle (UAV) imagery was used for small-scale monitoring of erosion thus providing very high spatial resolution imagery (Xu et al 2019). High resolution GeoEye-1 satellite data were obtained to extract information about soil, land cover and topography (Alexakis et al 2013). To work out land use/ cover data, high-resolution satellite imagery were used (Yuksel et al 2008). For estimating soil erosion, image obtained through Satellite (NDVI, SAVI and SARVI) was found to be the most simple, cheap and quick (Singh et al 2004, Gandhi et al 2015, Alhawiti and Mitsova 2016, Sonawane and Bhagat 2017, Sepuru and Dube 2018).

RUSLE–IDM (Information Diffusion Model) coupled model revealed soil erosion risk in different scenarios. It was observed that USLE algorithms do predict field erosion and are highly sensitive to slope gradients thus leading to overestimation of steep slopes (> 30%) (Liu et al 1994, Xu et al 2012). Figure 1 depicts methodology to depict various factors associated with soil erosion.

Mapping of soil eroded areas: Beguería (2006) adopted supervised classification procedure (multinomial logistic model) for mapping of soil eroded areas and hence used for developing a map of highly eroded areas in a mountain catchment. The ability of multi-temporal data (integration of

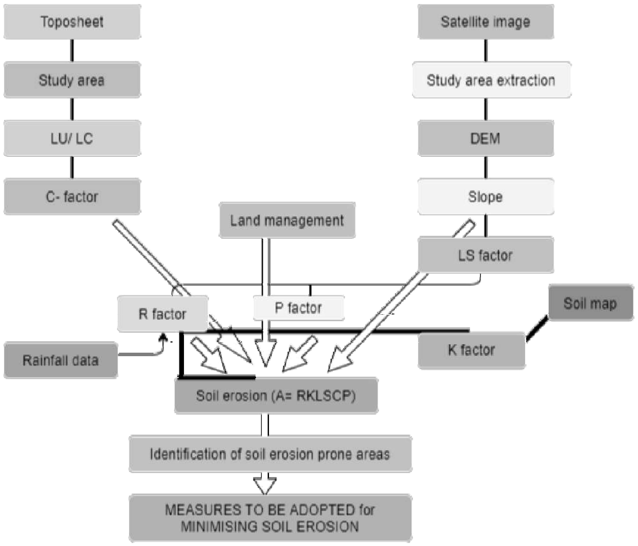

Fig. 1. Flow chart of methodology (Prasad and Tiwari 2019)

images from different seasons) was used for discriminating soil erosion features, and was compared to the use of single images (Beguería 2006, Dhakal et al 2002). Jensen (2005) further highlighted the use of Landsat TM (higher spectral resolution of seven bands) making it better suited for mapping the eroded landscapes. Dhakal et al (2002) used visible bands (Red, Green and Blue) in detecting eroded areas resulting from an extreme rainfall event. A remote-sensing based method was tested using a combination of time series of free access Sentinel-2 image data, airborne ortho images and ground truth data for detecting eroded areas. For identification of eroded areas, unsupervised classification ISODATA of the Sentinel-2A images has been performed (Žížala et al 2018) at the regional scale.

Available soil erosion modeling techniques: Several researchers (Lal 1994, Hudson 1995, Merritt et al 2003) applied different techniques viz. empirical, conceptual and physically based models. Empirical models, one of the simplest models depend upon field observation/ experiment, measurement reflecting observed facts and statistical techniques making prediction regarding future (Petter 1992). Conceptual models acts as an intermediate between empirical and physical models. These depict a true representation of reality by including general processes such as generation of sediment and runoff in the structure. These represent both qualitative as well as quantitative effects of land use without requirement of huge amount of spatial and temporal data (Merritt et al 2003). Some Physically based models include Soil and Water Assessment Tool (SWAT), Erosion Model for Mediterranean regions (SEMMED) (De Jong et al 1999) and the Water Erosion Prediction Project (WEPP) (Flanagan and Laflen 1997, Huang et al 1996, Laflen et al, 2004, Rosewell 2001, Brazier et al 2000, Sepuru and Dube 2018). In another classification models were categorized as Empirical and Deterministic models. Deterministic models illustrate the process of soil erosion with physical-mathematical relationships yielding accurate results (Hammond and McCullagh 1980). These models can be grouped into 'lumped' and 'distributed' models. 'Lumped' models (CREAMS) portrays average response of watershed because of spatial variation of erosion process (Beasley 1986) while the distributed model exacerbates the efficiency of stimulating simulation by using information of all the spatial variables. These models have the ability of depicting accurate information and presuming spatial distribution of the hydrological conditions (Beven 1985). Table 1 depicts various soil loss erosion equations and models (Kushwaha and Yousuf 2017).

Factors related to soil erosion estimation and delineation of soil conservation units: Factors such as fractional vegetation coverage, yellow leaf index, nitrogen reflectance index, bare soil index and slope are closely related to soil erosion. These can be derived through remote sensing imagery and rely upon related thematic indices or algorithms. Quantitatively, these represent vegetation density, soil exposure intensity, vegetation health status, and terrain steepness which are highly relevant to estimate soil erosion in forest (Xu et al 2019). Multi-criteria overlay analysis (using GIS) of different parameters such as soil erosion, soil depth, slope, land cover and surface texture was carried out for delineation of nine conservation units. Identification of conservation units was based on degree of erosion and site characteristics (slope, soil depth, and soil texture and land cover) (Srinivas et al 2002). Millward and

Table 1. Erosion and soil erosion models (Kushwaha and Yousuf 2017)

	Model	References
USLE	Universal soil loss equation	Wischmeier and Smith (1978)
MUSLE	Modified universal soil loss equation	Williams (1975)
RUSLE	Revised universal soil loss equation	Renard et al (1991)
DUSLE	Differentiated universal soil loss equation	Flacke et al (1990)
CREAMS	Chemical runoff and erosion from agriculture management systems	Knisel (1980)
ANSWERS	Areal nonpoint source watershed environment response system	Beasley and Huggins (1982)
WEPP	Water erosion prediction project	Lane and Nearing 1989
OPUS	Advanced simulation model for nonpoint source pollution transport	Ferreira and Smith 1992
EROSION2D	Erosion-2D	Schimdt (1991)
PEPP	Process-oriented erosion prognosis program	Schramm (1994)
KINEROS	Kinematic erosion simulation	Woolhiser et al (1990)
EUROSEM	European soil erosion model	Morgan et al (1992)
LISEM	Limburg soil erosion model	De roo et al (1994)

Mersey (1999) predicted the soil loss quantitatively and it was then categorized into five classes. Five classes were observed for estimating soil erosion risk under Indian condition and these were Low (>5), Moderate (5-10), High (10-20), Very high (20-40) and Severe (40-80) (Karthick et al 2017). Soil loss was estimated using USLE coupled with GIS to priortise tehsils for conservation and delineation of soil units. Remote Sensing integrated with GIS techniques have proved to be of immense importance for land cover mapping (Srinivas et al 2002).

Rusle model: RUSLE is a highly influential and well pronounced model for qualitative and quantitative estimation of soil erosion with reasonably high accuracy (Mekonnen and Melesse 2011). RUSLE coupled with GIS was used for modeling the erosion potential for soil conservation planning in Mexico. Several researchers (Martinez R 1997, Millward and Mersey 1999) used raster-based GIS program i.e. IDRISI software package in Mexico. A combination of RS, GIS and RUSLE acts as a practically effective tool to estimate soil loss on cell-by-cell basis (Saini et al 2015). Slope length-gradient (LS) factor was predominantly an influential RUSLE factor followed by soil erodibility (K) (Gelagay and Minale 2016).

RUSLE is a revised version of USLE which can be employed with the assistance of computer program (Morgan et al 1998). USLE, an acknowledged equation is employed for categorizing in watershed management for large areas (Jain and Kothyari 2000). It predicts erosion rates of ungauged watersheds using watershed characteristics and local hydro-climatic conditions. It presents the spatial heterogeneity with practical viability as well as better accuracy in larger areas (Wishcheimer and Smith 1978]. The RUSLE model follows the equation (Kothyari 1996):

$$A = R * K * LS * C * P$$

where,

- A is the computed average soil loss over a period selected for R, usually on yearly basis (t ha^{-1} yr^{-1});
- The *R*-factor (rainfall-runoff erosivity factor; MJ mm ha^{-1} h^{-1} yr^{-1}) can be determined by the product (*EI*) of total storm energy (*E*) with the maximum 30-min intensity (*I*30) for all the storms over a long period of time (Brown and Foster 1987). *EI* computes raindrop impact and reflects the amount and runoff rate associated with the rain (Wischmeier and Smith 1978).
- K-factor (soil erodibility factor; t ha h ha^{-1} MJ^{-1} mm^{-1}) portrays the change in the soil per unit of applied external force of energy. It depends on the combined effect of rainfall, infiltration and runoff, thus influencing the soil properties on sloppy areas. This factor is highly applicable to tropical soils (Kaolinite dominant), but is less observed with Vertisols dominant soils (Roose 1977).
- The *LS*-factor (slope length and slope gradient factor; dimensionless) depicts the integrated effect of slope length and gradient on soil erosion. RUSLE model dispense conversion tables for evaluating *LS* on uniform slopes (Renard et al 1997). With the increment in soil steepness, an increase in soil loss was observed (McCool et al 1987).
- *C*-factor (cropping management factor; dimensionless; ranging between 0 and 1) determines the impact of all interrelated cover and management variables (Renard et al 1991). C values vary from near zero (well-protected soils) to 1.5 (finely tilled, ridged surfaces that are highly vulnerable to rill erosion) (Renard et al 1997).
- *P*-factor (supporting conservation practice factor; dimensionless; ranging between 0 and 1) is evaluated as the ratio of soil loss with specific support practice to soil loss with up and downslope tillage. *P*-factor extends from 0.2 (reverse-slope bench terraces) to 1.0 (no erosion control practices) (Wischmeier and Smith 1978, Angima et al 2003).

Integrating USLE with GIS aids in predicting soil erosion hazard (Xu and Shao 2006, Zhang et al 2007), hazard mapping (Youssef et al 2009, Qin et al 2009) and model potential soil erosion change for soil conservation planning (Millward and Mersey 1999, Huang 2018). ArcGIS and ERDAS software were utilized to produce desired amount of output using RUSLE equation (RKLSCP) (Srinivasan et al 2019). Using ArcGIS 10.1, inputs were digitized and thematic maps of different factors were generated. Later on, these were used to compute LS factor (Gelagay and Minale 2016). Schwab et al (1981) recommended use of relationship between soil texture and soil organic matter amount to figure out soil erodibility (K) (Stone and Hillborn 2000). An affiliation of soil slope on topography was observed under different conditions by some scientists (Yildirim 2012, Ozsoy et al 2012). Srinivasan et al 2019 estimated soil loss per annum on pixel-by-pixel basis and its spatial extent using an integrated combination of RUSLE and GIS.

By integrating RUSLE with remote sensing and GIS, the distribution and yearly mean value of soil erosion was computed (Ahmed et al 2018, Srinivasan et al 2019). Also, this exacerbates the appraisal of soil erosion, yielding better results and topographical analysis (Durigon et al 2014, Falcão et al 2020). Anees et al (2018) worked out soil erosion probability zones using pixel-based soil erosion analysis through RUSLE and sediment yield model. Soil erosion probability zones were also divided into five categories in which 20.1% and 17.8% represented very high and high probability zones respectively. Das and Poongothai (2018) computed RUSLE factors and presented them by raster layer in a GIS environment, then multiplied together to predict rates of soil erosion rates and for generating maps. The outcome obtained was then reclassified into varied erosion classes on basis of erosion intensity. Angima et al 2003 predicted annual soil loss using RUSLE (Version 1.06) to conclude erosion hazard areas and target locations for conservation measures. Erosion rates of ungauged catchments was also assessed using the understanding of catchment characteristics as well as local hydro-climatic conditions (Garde and Kathyari 1990).

Polykretis et al 2020a analysed the temporal variations among the two RUSLE factors viz. rainfall erosivity (R) and cover management (C) using high temporal resolution. While the rest three factors namely soil erodibility (K), slope length and steepness (LS) and support practice (P) characterized by the data of soil, topography and land cover. Headway in the field of remote sensing have facilitated soil erosion modeling thus enabling quantitative estimation and spatial extent of soil erosion.

The average rainfall erosivity is then estimated according to:

$$\mathrm{R}=\frac{1}{n}\sum_{i=1}^{n}\sum_{k=1}^{mj}(7.5R_{10}-150D_{10})k,j$$

where R_{10} is the total rainfall within a month (mm) and only for the days with rainfall ≥10 mm (otherwise, set to zero), D10 is the number of days with rainfall ≥10 mm, n is the number of days covered by the rainfall data, k is the individual erosive events of each month j, and mj is the total number of erosive events of this month. The R-factor was estimated at point (rainfall station) level. The estimated values were extrapolated to island level by applying ordinary kriging-based interpolation (Grillakis et al 2020) in the ArcGIS environment.

The approach developed by Williams and Renard (1983) was applied to estimate the K-factor. It is expressed as follows:

$$\mathbf{K}=0.2+0.3\mathrm{e}^{(0.0256\times \mathrm{SAN}\times(1-\frac{SIL}{100}))}\times\left(\frac{SIL}{CLA+SIL}\right)^{0.3}\times\left(1-\frac{0.25\times C}{C+e^{(3.72-2.95\times C)}}\right)\times\left(1-\frac{0.7SN}{SN+e^{(-5.51+22.9\times SN)}}\right)$$

where SAN is the sand content (%), SIL is the silt content (%), CLA is the clay content (%), C is the organic carbon content (%), and SN = 1 - (SAN/100). The soil properties included in "WISE30sec" database were linked to the six different soil types of study area from the "ESDB v2.0" within the ArcGIS environment. The K values for the different soil types were then calculated by Equation (3) in order to obtain the spatial distribution of K-factor in the study area.

The LS-factor was created using a hydrology module provided by SAGA GIS (v2.3.2) software package. The module was selected to incorporate the SRTM DEM derivative of slope gradient as S and the approach proposed by Desmet and Govers (1996) for L estimation. This approach is defined as:

$$\mathbf{L}=\frac{((A_{i.j.-in}+D^{2}))^{m+1}-A_{i,j-in}^{m+1}}{D^{m+2}\times x_{i,j}^{m}\times 22.13^{m}}$$

where $A_{i,j,-in}$ is the contributing area (m^2) at the inlet of grid pixel (i,j), D is the grid pixel size (m), xi,j is the summation of the sine and cosine of aspect direction (αi,j) of grid pixel (xi,j = sinαi,j + cosαi,j), and m is a ratio of the rill to interill erosion ranging from 0 to 1.

The C-factor was generated monthly for each time frame (2016 and 2019) by handling the respective Sentinel-2 imagery data. Afterwards, the Normalized Difference Vegetation Index (NDVI) was calculated in the ArcGIS environment by the following Equation (Polykretis et al 2020b):

$$\mathbf{NDVI}=\frac{(\rho NIR-\rho RED)}{(\rho NIR+\rho RED)}$$

where ρNIR and αβρRED are the reflectance values at NIR and Red spectral bands, respectively. As an indicator of the energy reflected from the earth's surface, NDVI has been widely used to represent the various vegetation coverage conditions of several regions (Baiamonte et al 2019, Maury et al 2019). Its values range between -1 and 1 indicating a lack of vegetation or dense vegetation, respectively. The approach proposed by Van der Knijff et al 1999 was eventually followed to estimate the C-factor as follows:

$$\mathbf{C}=\exp[-\alpha(\frac{NDVI}{\beta-NDVI})]$$

where α and β are constants with value 2 and 1, respectively. All the negative C-factor values were set to 0, and the values higher than 1 were set to 1.

Its estimation in the ArcGIS environment had the form of the product of the (sub) P-factors of these practices (Panagos et al 2015):

$$P=P_{cf}\times P_{sw}\times P_{gm}$$

where P_{cf}, P_{sw}, and P_{gm} are the P-factor values for contour farming, stone walls, and grass margins, respectively.

Although RUSLE is considered as a leading model in soil erosion assessment, the data availability for generating some of its factors remains a major limitation for maximizing the model accuracy (Karamage et al 2017).

Evaluation of different morphometric characteristics, land use/ land cover and USLE was carried out using ArcGIS and

ArcSWAT. SWAT model proved to be an indispensable tool for pinpointing and characterizing erosion vulnerable areas (Ghafari et al 2017). To estimate the extent of erosion, Raja et al (2015) utilized Sediment Yield Index (SYI) as the method for prioritizing watershed (Shivhare et al 2017).

There's been a considerable shift from the empirical models viz. USLE and SLEMSA (Stocking 1981), towards highly analytical and deterministic models eg. CREAMS (Knisel 1980) and ANSWERS (Beasley and Huggins 1982, de Roo et al 1989). Several modifications were observed from empirical model (USLE) (Warren et al 1989, Flacke et al 1990), and to watershed models which acts as non-point source of pollution e.g., AGNPS or ANSWERS (de Roo et al 1989, Rewerts and Engel 1991, Srinivasan and Engel 1991, Mitasova et al 1996). Using WEPP, erosion rate as well as sediment yield were analysed on the basis of erosion factors for diverse time periods (Yuksel et al 2008)

Comparison between RUSLE and AHP method: RUSLE model estimates the soil loss potential without considering the interdependency of soil erosion factors while AHP (Analytical Hierarchy Process) permits interrelationship between the decision factors (Nekhay et al 2009). RUSLE analyzes rill erosion but not gully or stream-channel erosion (Karydas et al 2009). Point allocation and multi-attribute utility theory, flexibility, minimizes biasedness in making decisions by evaluating geometric mean of the individual pairwise comparisons (Zahir 1999), ability to check inconsistencies and appeal to decision makers prove supremacy of AHP method over RUSLE methodology (Ramanathan 2001). RUSLE estimates absolute value of soil loss potential whereas AHP assesses and constructs soil erosion risk map (Alexakis et al 2013).

Pan-European soil erosion risk assessment (pesera) model: This model runs over a stipulated time period of 20 years duration assessing both monthly and annual soil loss for nearly 12 land use/ land cover types with the input of 128 variables computed from climate, soil, land use/ land cover and topographic data. It focussed around one-dimension hydrological balance that segregates precipitation among evapotranspiration, subsurface flow, overland flow and groundwater recharge. Factors augmenting soil erosion were decline in soil organic carbon, meagre and scattered vegetation cover and varying climatic conditions. This model was developed for large scales concerning mainly rill and sheet erosion and index of soil erosion risk at the regional scale (Kirkby et al 2008). SVAT (Soil-Vegetation-Atmosphere Transfer) deviates from PESERA by considering water and sidestepping energy balance utilizing potential evapotranspiration as the major input variable.

The model integrates the impacts of soil, climate, vegetation, topography and soil erosion (E; t ha^{-1} yr^{-1}) in the PESERA model is determined by:

$E=k\Delta\Omega$

where k represents erodibility based on vegetation cover, soil parameters and land use, Δ represents the prospective topography based on a digital elevation model (DEM) and Ω represents the prospective vegetation/ climate and runoff soil erosion based on a plant growth model, vegetation cover and gridded climate data (Kirkby et al 2008).

According to PESERA model, forests, pastures and grasslands are at minimum risk while degraded natural vegetation and scrublands are highly susceptible to erosion (Berberoglu *et al.* 2020). PESERA acts as a diagnostic tool for estimating erosion rate of different soils and topographical characteristics (Kirkby et al 2008, Licciardello et al 2009, Karamesouti et al 2016).

Comparison between RUSLE and PESERA model: RUSLE is an empirical model (Renard et al 1991) whereas PESERA is run-off based mechanistic model for estimating soil erosion (Kirkby et al 2004). RUSLE model yields extremely high values i.e. prediction values with extreme peaks. The outcome was filtered to prevent fallacious results. Contrarily, PESERA portrayed smoother behaviour. RUSLE model was observed to be highly sensitive to C factor (Karaburun 2009), particularly when erosion was analysed after a fire events (Larsen and MacDonald 2007). Post-fire incident erosion rate varied from 1.7 to 113.2 t ha^{-1} yr^{-1} in Mexico (Miller et al 2003). PESERA offers its applications in wide scenarios as the output was obtained with reasonable spatial distribution (Esteves et al 2012). RUSLE anticipated remarkably higher erosion for areas with slope more than 60%. Its outcome is highly sensitive to rainfall erosivity and rainfall. PESERA depicted high vulnerability to vegetation coverage and characteristics of soil (Karamesouti et al 2016).

Answers model: It is a distributed parameter model for mapping soil erosion as well as surface runoff (Beasley and Huggins 1982). This model is constructed to simulate the watershed characteristics. Variables for each characteristic are slope, aspect, crop variables (interception capacity, coverage and USLE C/P factor), soil variables (porosity, field capacity, moisture content, erodibility factor, infiltration capacity), surface variables (surface retention and surface retention) and channel variables (roughness and width). The original version of the model permitted only 20 soils as well as land use/ land cover types for simulation with the hypothesis that they were spatially homogenous. With further advancements and modifications in the model, soil and land use types were limited by the square elements. This model cannot be utilized without integration with GIS at optimal spatial resolution. The supremacy of ANSWERS in comparison to USLE relies on the following heads viz. high accuracy for prognosticating runoff as well as erosion, physically-based mathematical relationships; integrating recently developed relationships, spatial variability. While ANSWERS model lag behind due to certain theoretical weaknesses (eg. subsurface flow, gully erosion, and infiltration), acquisition cost, highly sensitive to certain variables such as soil moisture, infiltration and soil roughness, quantity as well as quality of required input information.

Primarily, use of USLE model was limited to agricultural fields alone and its use for modeling erosion in the landscape was considered quite inappropriate (Foster and Wischmeier 1974, Moore and Wilson 1992). Complete integration of GIS with the topographic data alongwith three-dimensional visualization yields an efficacious environment for evaluation of different approaches to erosion risk analysis for applications to landscape.

A number of studies were conducted primarily focussed on field data, laboratory analysis and satellite remote sensing thus analyzing post-fire effect on different soil properties, processes and functions (Varela et al 2010, Shakesby 2011, Esteves et al 2012, de Vente et al 2013). In the current scenario, two commonly used models are RUSLE (Wischmeier and Smith 1978, van der Knijff et al 2000) and PESERA (Kirkby et al 2003). Initially, both these models were developed for analysing average annual sheet, rill and inter-rill water erosion in the agricultural fields (Kinnell 2010). Several studies (Miller et al 2003, Larsen and MacDonald 2007, Deog Park et al 2012, Esteves et al 2012, Karamesouti et al 2016) notably contributed to post-fire erosion estimation in forest using RUSLE and PESERA models.

Corine model: Coupling CORINE model with remote sensing and GIS plays an indispensable role in mapping erosion risk in Turkey. The digitized input data of various factors viz. topography, soil type and climate was generated by using ArcGIS v9.2 software and these were integrated to produce erosion risk maps (Yuksel et al 2008). Based on CooRdination of Information on the Environment (CORINE) model, soil erosion risk map were generated. Nearly, 2.47% of the study area was observed to be under high risk of soil erosion, while moderate soil risk was in 22.18% and low in 75.35% of the study area (Barakat et al 2015). Ustun (2008) adopted Morgan method for soil erosion modelling as this method. A diverse number of studies were carried out for soil erosion modeling by integrating remote sensing and GIS (Millward and Mersey 1999, Jong et al 1999, Yuksel et al 2008). This aids in soil loss as well as spatial extent of erosion (Okalp 2005), land degradation and mapping erosion (Sazbo et al 1998), erosion surveys and estimating risks (Yuksel et al 2008).

CORINE model, a renowned methodology for presuming soil erosion risk by coupling two parameters i.e. potential erosion risk (function of soil erosivity, erodibility and topography) and vegetation cover data (as the intensity of vegetation cover impacts rate of erosion (Lal 1994, Evrendilek et al 2007). In accordance with CORINE (1992) and Soil Survey Division Staff (1993), distinguishing parameters observed were soil erosivity, erodibility, slope and land use/ land cover. Soil erodibilty was estimated by contemplating soil depth, texture (slightly, moderately and highly erodible) and stoniness. Soil erodibility index was found to be dependent on soil depth, texture and stoniness (CORINE 1992, Yuksel et al 2008).

Soil Erodibility Index = Texture Class x Depth Class x Stoniness Class

Soil erodibility maps were prepared by using “Raster Calculator” tool using ArcGIS v9.2 (Editions of ESRI 2004). To estimate potential soil erosion risk, soil erosivity, erodibility and topography layers were imbricated by using “Raster Calculator” tool of ArcGIS v9.2 to estimate potential soil erosion risk (Yuksel et al 2008)

Potential Soil Erosion Risk Index = Soil Erodibility Index x Erosivity Index x Slope index

Figure 2 depicts flow diagram of CORINE method (Modified from CORINE 1992).

Spot and landsat tm imagery for soil erosion modelling: Multispectral Landsat series and SPOT data or high-resolution data, such as IKONOS and QuickBird are the most widely used satellite data in soil erosion research (Luleva et al 2012, Sepuru and Dube 2018, Vrieling 2006). Landsat-8 and Sentinel-2 are newly launched satellites with their improved spectral, radiometric as well as spatial characteristics provide freely available multi-temporal data suitable for soil erosion mapping (Žížala et al 2018). Even though Landsat data is taking over in soil erosion modelling, it is therefore encouraged to compare its effectiveness with other remote sensing data sets. Dwivedi et al 1997 also found that SPOT image improved the classification of eroded lands as compared to Landsat TM bands. Although SPOT image has proven better at mapping soil eroded areas, its low spectral sampling (4 bands) has shown to be a limitation in mapping gullies (Servenay and Prat 2003). Serveney and Prat (2003) reported that SPOT was unable to identify outcropping eroded areas even it possess unique spectral signatures. While there is an insufficient literature available about SPOT and Landsat TM comparison for mapping gullies, it is depicted that Landsat TM prove to be better at mapping gullies due to higher spectral, spatial resolution and on spectral sampling capabilities of the sensor (Luleva et al 2012). Soil erosion model was integrated with NDVI as well

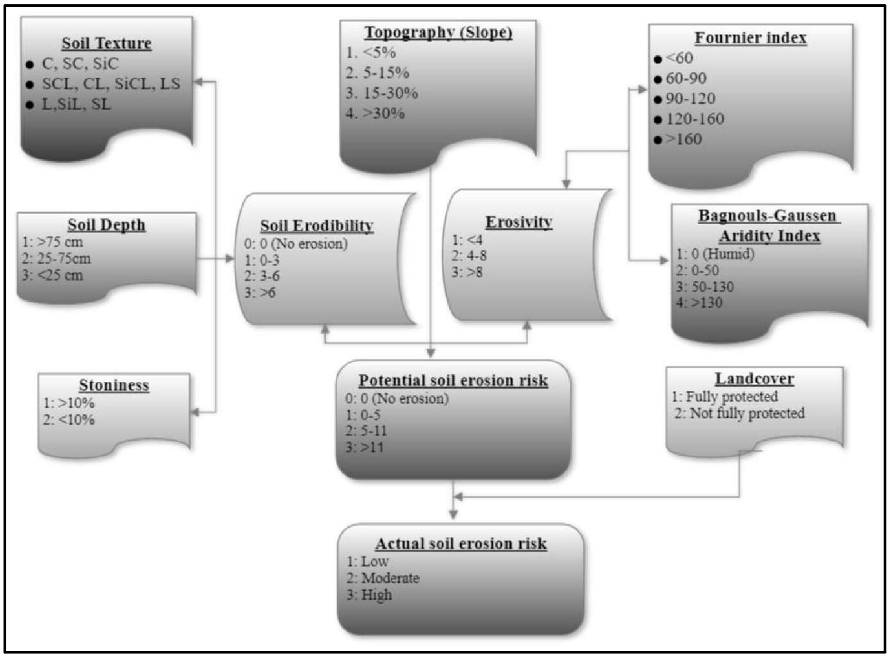

Fig. 2. Flow diagram of CORINE method (Modified from CORINE 1992)

as slope for analysing soil erosion rate per annum (Hazarika and Honda 2001). Landsat data imagery was predominantly used for soil erosion monitoring (Luleva et al 2012). Beguería (2006) distinguished soil erosion on bare soil using supervised classification procedure (multinomial logistic model) over three Landsat thematic mapper (TM). Fulajtar (2001) identified soil erosion patterns using high spatial resolution SPOT PAN Image and procured finest results in contrast with conventional field survey method (Sepuru and Dube 2018). Landsat and SPOT satellite images with very high spatial resolution thus aids in recognizing both medium and large sized landforms (Millington and Townshend 1984), for efficacious analysis of the extent of wide erosion prone areas (Vrieling 2006, Luleva et al 2012, Conforti et al 2013, Sepuru and Dube 2018, Magliulo et al 2020). SPOT-I dominated in mapping accuracy (94%) as compared to 92% in LANDSAT-D (average accuracy) and 89% in TM 2, 3, 5 combinations. Both satellite and airborne images were highly renowned for mapping soil erosion and routine erosion monitoring (Cihlar 1987). Gully erosion was mapped in Northern France by estimating NDVI, brightness index and masked out effect of vegetation using SPOT imagery (Mathieu et al 1997, Sepuru and Dube 2018).

Delineation of soil erosion types: Hochschild et al (2003) delineated various types of soil erosion which can be ranged from slight rill to deep gullies of which rill to inter-rill erosion and deep linear erosion (gully erosion) are predominant in the Mbuluzi catchment using Landsat satellite data. In Nsikazi, Mpumalanga Province of South Africa, Wentzel (2002) adopted Indian Remote Sensing satellite (IRS) data to derive bare soil index for soil erosion mapping. Delineated gully and sheet erosion areas were delineated using Landsat TM images in Olifants River catchment, South Africa to explore whether gullies could be mapped more accurately (Randall 1993). Correspondingly, Liggitt (1988) portrayed remotely sensed data to assess soil erosion in Mfolozi and comprehended orthophotos as well as aerial photographs at different times and scales to analyse the spatial extent of both gully and sheet erosion..

Mapping soil erosion using spectral signature: Alatorre and Begueria (2009) demonstrated use of classification algorithms for obtaining digital information dependent on spectral or structural patterns for recognizing and estimation of soil erosion Different approaches for classification includes supervised, unsupervised and hybrid (i.e. combination of supervised and unsupervised classification) methods (Vrieling 2006, Sepuru and Dube 2018). There lies a direct relationship between the soil and spectral reflectance that permits identification of disturbed soils (Price 1993). Each and every feature on this earth possesses a different spectral signature. Spectral reflectance differs with surface features viz. water body, vegetation cover, cultivated lands, etc (De Asis and Omasa 2007). Spectral signature of bare soil was mainly governed by the texture, moisture content, mineral composition as well as the organic matter of soil (Barnes and Baker 2000, Sujatha et al 2000). Predominantly used NDVI modifications in soil erosion study were Soil Adjusted Vegetation Index (SAVI, Huete 1988), and Soil and

Atmospherically Resistant Vegetation Index (SARVI; Huete and Liu 1994) (Kwanele and Njoya 2017). Remote sensing was profoundly used for assessing soil erosion which include Normalized Difference Water Index (NDWI) (Dasgupta et al 2007), Modified Temperature - Vegetation Dryness Index (MTVDI) (Kimura 2007), Land Surface Temperature (LST), Leaf Area Index (LAI), Normalized Soil Moisture Index (NSMI) (Haubrock et al 2008, Luleva et al 2012, Sepuru and Dube 2018). Spectral reflectance differs with different soil properties viz. organic matter, particle size, iron oxides, moisture content, type and amount of minerals (Magliulo et al 2020).

Mapping soil degradation using aerial data: Progression in space technology led to development of new possibilities in the field of soil science. Using airborne as well as spaceborne data for mapping bear greater accuracy, economy and efficiency as compared to conventional methods. The efficacy of soil mapping in case of computer techniques, interpretation of aerial photos and conventional method is in the ratio of 1:5:10. At both semi-detailed and reconnaissance levels, aerial photointerpretation techniques were adopted (Srinivasan 1972, Ahuja and Manchanda 1980). Govindarajan and Mouttapa (1967) reported for the first-time use of photo-interpretation techniques for mapping soil degradation. Kamphrost and Iyer (1972) carried out study on aerial photos and classified ravine areas based on width and depth of ravines into four major classes in the Northern part of India. While scrutinizing saline soils of Haryana and Punjab, three levels of soil salinity were observed and analysed through photo interpretation studies (Shanwal et al 1980, Bhargava and Sharma 1980). Some peculiar and advanced techniques such as band stretching, enhancement, ratioing, computer aided statistical functions and clustering techniques in decoding digital data proved highly useful in soil mapping. Image enhancement technique was effective in differentiating shallow red soils from the deeper ones that portrayed same spectral response (Karale et al 1983).

Limitations in use of satellite imagery: Although higher spatial resolution imagery such as SPOT 5, IKONOS, Quikbird, etc. offers high grade data for potential use in soil erosion mapping (Taruvinga 2009) but they are not utilized. The high-resolution data (IKONOS and QuickBird) are quite costly to be used for mapping erosion in wide area (Vrieling et al 2008) and not affordable for the developing countries. According to Sepuru et al (2018), high spectral resolution information remained limited mainly due to high acquisition cost. Another reason behind the limited use is knowledge gap which can limit the regular use of these advance methods for the quantification of eroded soils. Some other factors involved are indispensability of precise atmospheric corrections, masking of the clouds and their shadows, heterogeneity of environmental factors especially soil cover structure (occurrence of different soil types and parent material, historical human-induced disturbances (Zádorová et al 2018, Žížala et al 2018). The stumbling block in RUSLE model are extrapolation, spatial scale effects as well as the complexity of entire procedure of soil erosion (Xu et al 2012); restriction in understanding process involved mainly in spatial distribution of eroded areas (Croke and Mockler 2001), depending on small scale application (Nigel and Rughooputh 2010). In current generation satellite data, spatial resolution and stereoscopic coverage inhibit effective soil mapping at both the meium as well as large scale (Karale et al 1983).

Future prospects: Integrating remote sensing with GIS has given ways to a number of opportunities in the field of mapping soil erosion. Remote sensing has opened new ideas for characterization and monitoring of degraded lands (Tesfamichael 2004). Le Roux (2007) recommended that remote sensing approach for soil erosion modelling must be expanded to a regional scale. Future studies should involve use of 2D hydrological modelling for rainfall–runoff relationships and to determine the accuracy of RUSLE and sediment yield models with high resolution remote sensing data such as SPOT 5 (2.5 m resolution) and LIDAR based DEM (2.5 m resolution). Sediment yield models should also be correlated with in situ sediment yield data through hydrological modelling. (Anees et al 2018). Both Future generation satellite and Microwave sensing are valuble tools for developing an efficient and reliable system for soil studies. As the shorter wavelength radar system estimates vegetation parameters whereas the longer wavelength radar system analyse subsurface soil conditions also (Karale et al 1983). Inspite of the drawbacks involved Satellite remote sensing sensors are leading way forward to solve the environmental problems (Morgan, 2005, Le Roux et al 2008, Seutloali et al 2016, Sepuru and Dube 2018).

CONCLUSION

Soil erosion has constantly been a threatening problem for agricultural production today. Due to human intervention, its condition is worsening so proper remedial measures needs to be taken in action. Immediate intervention is needed for better conservation planning for identifying the soil priority classes and hotspot areas. Now a days, Geographic Information System (GIS) and remote Sensing are emerging as most effective tools for estimating spatial information in a vast area. The use of the USLE model integrated to GIS and RS are quite efficient for assessing the soil loss vulnerability in a basin's scale. This is useful for decision making to establish appropriate strategies for soil and water conservation.

CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

AUTHOR CONTRIBUTION

Garima Dahiya: Conceptualization; writing - original draft; writing-review & editing. Hardeep Singh Sheoran: Conceptualization; writing - original draft; supervision, writing-review & editing. Isha Ahlawat: Conceptualization; writing-review & editing. Roohi: Conceptualization; writing-review & editing.

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