ENSEMBLE
A bi-lingual peer reviewed academic journal

ISSN: 2582 - 0427 (Online)
Vol. 2, No. 2
September, 2020
http://www.ensembledrms.in

Article Type: Review Article
Article Ref. No.: 20073100297RF
https://doi.org/10.37948/ensemble-2021-0202-a016

REVISITING THE METHODOLOGICAL DEVELOPMENT IN SOIL EROSION RESEARCH

Tanmoy Sarkar[1]✉,Tapas Pal[2]

Abstract:

Soil erosion (by water) is a major land degradation process that may threat the Sustainable Development Goals (SDG) by its negative impact on environment and human well-being. Soil erosion research demands scientific methods, tools and techniques to assess soil erosion with more accuracy and reliability. Soil erosion research has had experienced crude field-based techniques in early twentieth century to model-based approaches since the 1970s and very recent machine learning and artificial intelligence models to predict soil erosion susceptibility and risk. The paper aims to review the trend in methodological development in soil erosion by water through time. The brief background of different approaches, their relative advantages and disadvantages are reviewed. Depending on the time of establishment and wide application the approaches are classified and represented as erosion plot/runoff approach, erosion pin technique followed by environmental tracer method and model approach in combination with Remote Sensing (RS) and Geographic Information System (GIS). Recent advancement in artificial intelligence and application of statistical techniques have a great potential to contribute in soil erosion research by identifying various degrees of susceptibility in large scale and also to quantify the erosion rate with high accuracy. The Remote sensing (RS) and Geographic Information System (GIS) contribute to develop regional scale data base with exploration of real time data and spatial analysis. The combination of RS & GIS and process-based models must be more effective than the traditional soil erosion model in the context of prediction with greater reliability and validity. The future research on soil erosion is better to focus on the theoretical analysis and development of erosion prediction model with more quantitative refinement and to model the future.

Article History: Submitted on 31 Jul 2020 | Accepted on 07 Feb 2021 | Published online on 05 Jun 2021

Keywords: Erosion, Runoff Plot, Environmental tracer, RS & GIS, Artificial intelligence

1.0 Introduction:

Soil erosion (by water) is a major land degradation process that may threat the Sustainable Development Goals (SDG) by its negative impact on environment and human well-being. It is a Global environmental concern and the greatest challenge for sustainable land management. Soil erosion research has had a very long history of methodological development. Soil erosion by water has a huge on-site and off-site impacts and costs for a wide range of dimension, from an individual farmer to the society as a whole (Phai et al., 2006). Scientific methods and models can provide effective information on soil erosion process, susceptibility and causative factors to guide conservation and management decisions.

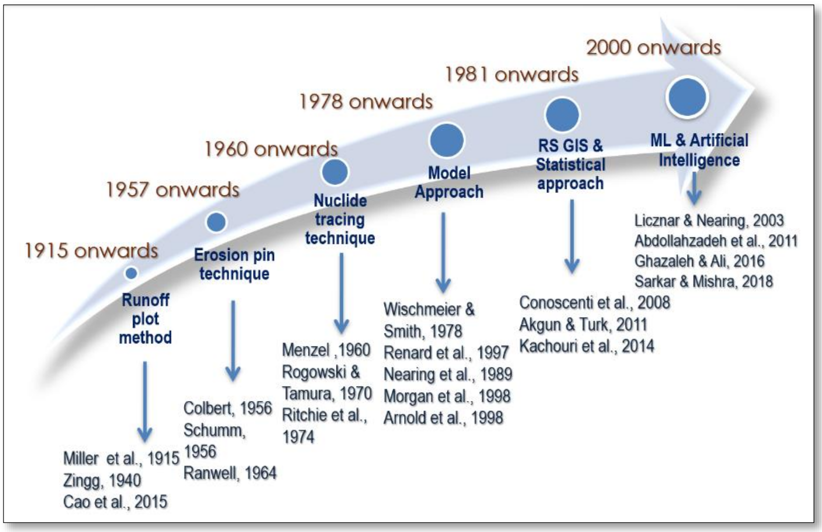
1 [Author] ✉ [Corresponding Author] Assistant Professor, Gazole Mahavidyalaya, Gazole, Malda, 732124, West Bengal, INDIA. E-mail: srkrtanmoy@gmail.com

2 [Author] Assistant Professor, Raiganj University, Uttar Dinajpur, 733134, West Bengal, INDIA

To review the research trends in a scientific domain is very necessary to make some generalisation of approaches and methods, to understand the progress, to explore the critical issues and finally to recommend the areas for future research. Previously, such review on soil erosion study, contemporary methods and models were contributed by Boardman (1986, 1996, 2006), Merritt et al. (2003), Brazier (2004), Vrieling (2006), Li et al. (2017), Igwe et al. (2017) et al.

Research on Soil erosion has had experienced a wider range of approaches, different methodologies and multiple tools and techniques through time. Throughout its history, confusions, contradictions and controversies regarding the scope, methods and dimensions of soil erosion study actually complemented towards its development. Research on soil erosion had experienced a change in its approach that was developed gradually from crude to precise and semi-quantitative to quantitative. These approaches also progressed from outdoor field based to laboratory monitoring forecast and simulation and from small-scale single-slope to large-scale regional comprehensive monitoring. The paper aims to review the trend in methodological development in soil erosion by water through time (Fig. 1). Present research status, brief background and the respective research gap and future direction of comprehensively classified methods are aimed to analyse.

Fig. 1: Methodological development in soil erosion study through time



(Source: Prepared by the authors)

2.0 Methodological development: Literature Review and Discussion:

2.1 Erosion Plot/Run off Plot:

2.1.1 Brief Description:

Field soil erosion research was started more than hundred years back in 1917 at Missouri Agricultural Experiment Station in Missouri by Miller and his associates (http://www.ars.usda.gov/Research/docs.htm?docid=18093). Numerous soil erosion and run off plots of varying size were prepared and used through times in various parts of the world. Measurement on erosion and runoff plots were used to provide quantitative data on runoff and soil loss from slope segments under different land use and land cover conditions. Such field scale monitoring units act as samples to study soil loss in broad and the data derived from field was used for model building, e.g., Universal Soil Loss Equation (USLE: Wischmeier and Smith, 1965, 1978).

Different types and description of erosion plots were used by researchers through time, like ‘experiment’ and ‘observation’ (Roels, 1985), ‘open plot’ (Bryan and Harvey, 1985), ‘small plot’ and ‘large scale plot’ (Ciesiolka and Freebairn, 1982; Millington, 1981). However, erosion plot data has had important application for providing information for particular land use, conservation practices and raindrop impact and sheet wash (inter rill) measures but the extrapolation of information to nature and to other localities needs considerable caution (Temple, 1972).

2.1.2 Critical Review:
The transferability of plot scale soil loss data to the larger landscape soil erosion study and modelling was the fundamental to soil erosion research. Non standardization of plot design, rarely tested assumptions about the typicality of chosen sites, variations in the time and length of study periods and variations in sampling technique were the critical issues examined and addressed in the same time by Sheng (1990), Wendt et al. (1986), Roels and Jonker (1983), The major advantages of this frequently applied method are its ease of installation or establishment, representing more or less a homogenous area and briefness in obtaining results (Fiener et al., 2019; Nearing et al., 1999; Sheng, 1990).

There are several disadvantages and lacunas in plot measurement techniques. It considers the runoff generation only caused by surface sealing ignoring the other latent process of runoff generation. Ephemeral gully erosion and erosion driven by relatively large rills are not considered. Furthermore, diversity in soil properties, variations in slope, diversity along the flow path are excluded (Fiener et al., 2019).

2.2 Erosion Pin Technique:
2.2.1 Brief Description:
Erosion pin is a widely popular and simple technique to measure soil erosion by temporal assessment of ground slope altitude. Colbert (1956) and Schumm (1956) used this technique for bad land erosion assessment in North America and the technique was followed by Ranwell, 1964, Clayton and Tinker, 1971, Lawler, 1993, Keay-Bright and Boardman, 2009; Boardman et al., 2015 in different studies. Erosion pin was applied in various environments with different objectives like gully erosion assessment by Harvey (1974), Vandekerckhove et al. (2001) and Sun et al. (2009),badland erosion study by Clarke and Rendell (2006), Hancock and Lowry (2015), river bank erosion assessment by Lawler (1978, 1993), bare soil study by Slaymaker (1972). A variety of erosion pins in their material and design have been employed over the years from wooden stakes (Colbert,1956; Schumm,1956), steel rod (Hadley and Schumn, 1961; Schumn and Lusby, 1963), iron nails with washer (Leopold et al., 1966; Emmett, 1974; Harvey, 1974) and iron pins with washer (Kirkby and Kirkby, 1974; Bridge and Harding, 1971) through time in combinations with movable contour plotting frame mounted on four modified erosion pins (Campbell, 1970; 1974) and portable contour plotting bar (Streeter, 1975).

2.2.2 Critical Review:
Hancock and Lowry (2015) compared the dataset derived from various erosion pin measurements with independent hillslope erosion study report and with regional scale erosion data and demonstrated that erosion pin technique can be considered as an important quick to measure tool to quantify erosion. It is less expensive, readily manageable and low maintenance technique in soil erosion assessment with adequate reliability. Their small size and minimal exposure over surface minimizes the potential influence on adjacent water and sediment movement unlike controlled runoff plot. Despite of its simplicity and ease of operation the issues like lower degree of automation, greater probability of human interferences in populated areas, requirement of close and minute contact observation must be considered. The subjectivity and human bias sometimes limit the accuracy of this technique.

2.3 Environmental Tracers Method:

2.3.1 Brief Description:

Traditional soil erosion assessment methods like runoff plot method and erosion pin technique are important to study the erosion rate at specific location and time. But to understand the process along with soil mass movement and sediment distribution at large, tracer method has a great potential (Stocking, 1987; Loughran, 1989; ZHU Ming-yong et al., 2010). The tracer elements are found in very well integration with soil particles and its solubility is limited. They are moved with soil at the same rate of soil particle movement without any interference to sediment transportation and most importantly the physicochemical characters of soil are not substantially altered with traces (Zhang *et al*. 2001, 2003; Stevens and Quinton 2008). These tracers are readily available in natural environment and found in aggregation with soil particles at relatively low level. There are number of radionuclides like Caesium-137 (^{137}Cs), lead (^{210}Pb) and Berrylium (^{7}Be) which are widely used in environmental radionuclide tracing method for soil erosion process and sediment migration study (Table 1). ZHU Ming-yong et al. (2010) advocated for the use of multiple tracers by which the bias of single tracer particle can be exceled and information regarding sediment redistribution will be more accurate.

Table 1: Soil erosion study with the application of environmental tracer method

Tracer Type	Reference	Description
^{137}Cs tracing method	Menzel (1960)	Study the relationship between soil erosion and radionuclide transportation and deposition
^{137}Cs tracing method	Rogowski and Tamura (1965, 1970)	Study to establish the exponential relationship between soil erosion and tracer particle by measuring 137Cs loss with runoff, and soil erosion. Soil erosion assessment by runoff measurement and migration and loss of 137Cs tracer particles
^{137}Cs tracing method	Ritchie et al. (1974)	established a quantitative relationship between the amount of soil erosion and the rate of 137Cs loss
^{137}Cs tracing method	Elliott et al. (1990)	Erosion estimation on non-tillage soil environment based on 137Cs loss model.
^{7}Be tracer method	Bai and Wan (1997)	Studied the seasonal variation of 7Be tracer distribution in karst environment and proposed the potential of usage of such tracer element to estimate soil erosion.
^{210}Pbex tracer	Walling and He (1999)	Soil erosion estimation in UK and proposed a quantitative model to predict soil erosion rate based on 210Pbex tracer method.
Combination of ^{137}Cs and 7Be tracer method	Walling et al. (1999)	Investigated the seasonal variation of soil erosion in agricultural land by 7Be tracer technique and 137Cs tracer was used to assess the impact of plough on soil erosion.
^{137}Cs tracing method	Collins et al. (2001)	Soil erosion estimation, tracer redistribution in commercial in communal farming in southern Jambia
^{7}Be tracer method	Blake et al. (2002)	Soil erosion study on slope with special emphasis on erosion rate, movement and redistribution of fine sediments
^{210}Pbex tracer	Zhang et al. (2003)	Investigated the distribution of traces in various soil profile depth in UK and China and proposed a stable-state model of erosion rates in agricultural land.
Combination of ^{7}Be and ^{210}Pbex tracer method	Matisoff et al. (2005)	Analysis of suspended sediment distribution and their age of deposition.
^{137}Cs tracing method	Othman and Ismail (2012)	Retrospective estimate and investigate medium-term soil erosion rates and soil redistribution in agricultural land

^{137}Cs tracing method	Alewell et al. (2014)	Soil erosion estimation in mountain grassland
Combination of ^{137}Cs and $^{210}Pb_{ex}$ tracer method	Bai et al. (2013)	Investigated the soil erosion in karst environment and explored the impacts of land use change on soil erosion.
Combination of ^{137}Cs and $^{210}Pb_{ex}$ tracer method	Porto et al. (2013)	River basin sediment analysis
^{7}Be tracer method	Zhang et al. (2014)	Rill erosion rate estimation and its relative contribution to total erosion. The study has contributed to the development of erosion prediction model with due consideration to erosion mechanism.

(Source: Prepared by the authors)

2.3.2 Critical Review:

Tracer element approach has a great potential to contribute information to build process-based model for soil erosion prediction as it indicates the soil movement, redistribution and deposition of soil particles to which they are tagged on. Several attempts have been carried out to distinguish between sheet and rill development and their relative contribution to soil erosion process (Song et al. 2003; Xue et al. 2004; Shen et al. 2007).

The complexity in sample processing and relative expensiveness are considered as the limitations of this very scientific method of soil erosion estimation. Moreover, in regions with high rainfall and leaching potential and in extreme erosion condition the tracer elements remain in the soil in very limited amount. It has some regional limits (Garcia-Ruiz et al. 2015). And most importantly there is a lack of complete database of the background values of various tracer elements in different regions with varying environment. The success of this method requires some assumptions including mixing of tracer element throughout soil profile by which tracer bonded soil particles are markedly changed in their physical properties from original. Polyakov *et al*. (2004) advocated against its reliable applications in natural areas or no-till fields as it does not reflect the erosion characteristics of original soil.The research progress with the application of this technique in the field of soil erosion study is relatively slow and the research by Walling (1999b), Matisoff (2005), Porto (2013) shows that single radionuclide tracing possesses some limitations to assess soil erosion process with high accuracy and reliability.

2.4 Model Approach:

Prediction is very important to visualize the future and scientific research always aims to make some predictive statement through modelling. Natural processes and the system components vary in time and space. So, it is difficult to set the initial conditions for model simulation, to replicate the process and to generate output as the natural system does. Moreover, to predict the natural processes shaped and reshaped with inevitable impact of anthropogenic activities seems more difficult. The development of soil erosion prediction model somehow started in late 1960s and early 1970s (Meyer & Wischmeier, 1969) and a wide range of empirical statistical models, physical process-based models, and distributed models came forward with their specific objectives and scale.

Review of field-scale and catchment scale model shows that the model complexity, consideration of input layers and model output are varied with scale. The important field-scale models are USLE (Wischmeier and Smith, 1978), WEPP (Flanagan and Nearing, 1995), CREAMS (Knisel, 1980), CSEP (Kirkby and Cox, 1995), EPIC (Williams, 1985) and the examples of catchment scale models are AGNPS (Young et al., 1989), ACRU (Schulze, 1989; New and Schulze, 1996), MEDRUSH (Kirkby, 1998) (Table 2).

2.4.1 Model Types:

2.4.1.1 Empirical Models:

The empirical models are based on identifying statistically significant relationships between assumed important variables where a reasonable data base exists. This is considered as the simplest model form that consider comparatively less computational data requirement. Merritt et al (2013) noted that parameter values are mainly calibrated and mostly they are obtained by calibration at experimental sites. Empirical models are criticised for the assumption of stationarity in the catchment and for ignoring the inherent non-linearities of the interacting components in a catchment system (Wheater et al., 1993). Despite of its limitations in some aspects empirical models are most widely applied in situations with limited data and parameter inputs and are particularly important as a primary step to identify sources of sediment generation (Merritt et al., 2013). Thewell-recognized empirical models are USLE (Wischmeier and Smith, 1978), RUSLE (Renard et al., 1997) SLEMSA (Soil Loss Estimator for Southern Africa; Elwell, 1978), The Morgan, Morgan and Finney Method (Morgan et al. 1984, 2001).

2.4.1.2 Physically Based Models:

Empirical models possess severe limitations with its inability to simulate the movement of water and sediment over the land or be used on scales ranging from individual fields to small catchments and they cannot be universally applied (Morgan 2013). To overcome such limitations and shortcomings a new generation, more physically based approach to soil erosion prediction modelling was developed. Such models are based on derivation of standard mathematical equations describing operating individual processes and the heterogeneity in a catchment is addressed by incorporating large number of parameters which are calibrated against observed data (Wheater et al., 1993). But this generates additional uncertainty in calibrated parameter value. Beven (1989) advocated that the equations used in physically based models are mostly derived from a small-scale controlled experiment and application of these in large scale real field condition with more complexity may contribute additional error. Widely applied and well recognized physically based models are WEPP (Water Erosion and Prediction Project; Nearing et al. 1989), GUEST (Griffith University Erosion System Template; Rose et al. 1998) and EUROSEM (European Soil Erosion Model; Morgan et al. 1998).

2.4.1.3 Conceptual Models:

Conceptual models are considered as an intermediary between empirical model and physical process-based model (Beck, 1987). This type of model generally provides a simple description of catchment processes without consideration of specific process interaction in catchment system (Merritt et al., 2013). Parameter values are mostly calibrated against observed data and identification of parameter value is a serious issue to be considered as there would be more than single 'possible best' option parameter sets available (Spear, 1995).

2.4.2 Review on Specific models:

USLE and Revised USLE (RUSLE) are the most widely used erosion prediction models during the history of soil erosion prediction research (Price 1993; Alewell et al., 2019) based on run-off plot data collected in the United States (USLE: Wischmeier and Smith, 1978; RUSLE: Renard et al. 1997). The USLE group of models are statistically calibrated models that combine erosion-controlling factors climatic (rainfall erosivity), edaphic (soil erodibility) and topographic (slope length and slope steepness) factors, as well as soil and vegetation management practices.

USLE was actually developed as a soil conservation planning tool that can estimate long term mean annual soil loss by rill and inter-rill erosion in field sized scale. Data accessibility, high degree of flexibility, extensive literature base, parsimonious parametrization, simplicity in model simulation and ease of output comparability are the major advantages and triggering points behind its worldwide application (Alewell et al., 2019).However, it was developed for US type of soil monitoring tool but the careful consideration of model parameters and proper scientific adaptation of site specific pedo-climatic, topographic and conservation and management factors would provide suitable condition for the model to be applied. The studies by Schwertmann et al. (1987), Kinnell (2010), Stolpe (2005), Yue et al. (2016) confirmed that the issue of uncertainty can be normalized with appropriate parameterization and the model can be applied in different site and regions.

It is not recommended to be used to estimate gully erosion or land sliding at stream bank and not suitable for sediment yield estimation from drainage basin (Morgan, 2005). The model cannot predict the sediment delivery ratio or it doesn't consider the sediment deposition factor (Trimble and Crosson, 2000). And for a large-scale erosion modelling, the limitation of this model to quantify gully erosion and stream bank erosion is widely criticized (Belyaev et al. 2005; Quinton, 2013; Evans and Boardman, 2016, 2016a). Jahun et al. (2015) recommended further scope of investigation to derive soil conservation and management factor consideration.

The Morgan, Morgan and Finney (MMF) model was developed by Morgan (1984) and revised by Morgan (2001) to estimate annual soil loss from field-sized areas on the hillslopes. This is a process-based model (Ande et al. 2009) that retains the simplicity of USLE in combination with its stronger physical consideration. The model considers two different phases of soil erosion process: water phase and a sediment phase. The water phase determines the runoff volume and the available energy of rainfall used to detach the soil particles. In the sediment phase of the model, the detachment of the soil particles is taken as a function of the soil erodibility, energy of rainfall and the interception of rainfall that is affected by vegetation (Mondal et al. 2016). MMF considers the impact of landcover change in erosion and with its proper application the source areas of sediment and the deposition sites can be predicted. Hence, it is able to provide information regarding sediment delivery ratio (Morgan, 2001). The model is not preferable to consider for soil loss estimation from single storm event or from gully erosion (Morgan, 2005). The model was further modified and revised as the Revised MMF (Morgan, 2001) and the Modified MMF (Morgan and Duzant, 2007) to consider the impact of vegetation cover in soil erosion and to enable the model to incorporate particle-size selectivity analysis in the process of soil erosion, transport and deposition.

Watershed Erosion Prediction Project (WEPP) was developed by Lane and Nearing (1989), Nearing et al. (1989) and Flanagan and Nearing (1995) as a continuous simulation model on hillslope profile. The model was supported by USDA and is a very well documented programme that predicts net soil erosion or net soil deposition on a two-dimensional hillslope. The model was widely applied (Bjorneberg et al. 1999; Cochrane and Flanagan, 2003; Covert et al., 2005; Issa et al., 2011) to simulate soil erosion in both at the watershed and slope scales. Han et al. (2016) advocated the applicability of the model as a reasonable vegetation restoration model. WEPP is a distinct model as it considers the sediment continuity equation that is applied within rills rather than utilizing uniform flow hydraulics (Han et al.,2016). However, spatial variability of vegetation cover and soil must be considered for simulation in larger scale (Igwe et al. 2017). The lack of input data file outside the U.S. demands experimental parameter determination.

Griffith University Erosion System Template (GUEST) (Mishra and Rose, 1990) was another model developed in the same time to determine the non-dimensional soil erodibility parameter β by analysing runoff plot data. Soil erodibility factor (β) is more precisely described for the runoff plot slope segment where flow-driven erosion process is dominant over rainfall impact. However, the hypothesized requirement of constant slope of experimental plot was greatly criticized (Rose, 2014). The soil erodibility factor is widely varied across world and within same soil with different conservation and management initiatives, and also varied with degree and duration of soil erosion process (Rose et al., 1997).

The Agricultural Non-Point Source model (AGNPS) is a non-point source event-driven model developed by USDA, Agricultural Research Service (USDA-ARS) in cooperation with the Soil Conservation Service (SCS) and the Minnesota Pollution Control Agency in the USA. The advantage of this model is the ability of spatial assessment of soil erosion along with its impact on soil quality and nutrient loss in catchment scale. However large number of input parameters and complex modelling process for simulation are considered as the disadvantages of this model. AnnAGNPS is the modified version of AGNPS developed by USDA with the improved consideration of daily step simulated results of surface runoff, sediment, soil nutrients and impact of pesticides (Shen et al., 2016) in larger watershed scale.

European Soil Erosion Model (EUROSEM) (Morgan et al., 1998 was developed to predict soil erosion, sediment transport and deposition for single storm events and in single slope segments. Some features of WEPP, like sediment concentration assessment, were also considered in this model. Consideration of concentrated overland flow, effects of soil and vegetation treatment differs it from other process-based erosion models (Quinton, 1997). Moreover, the simulation of impacts of conservation measures by describing micro-topography, soil and vegetation is an important strength of this model.

The **Soil and Water Assessment Tool** (**SWAT)** method (Arnold et al., 1998) was developed to simulate watershed management of soil erosion and the deposition effect and to predict the impact of land management practices on water, sediment, and agricultural chemical yields in large and complex watersheds with varying soils, land use, and management conditions over long periods of time (Gassman et al., 2007). Besides its obvious advantage as a hydrological modelling tool that includes modularity, computational efficiency, ability to predict long-term impacts as a continuous model along with its ability to use readily available global datasets, availability of a reliable user and developer support have contributed to its acceptance as one of the most widely adopted and applied hydrological model worldwide (Gassman et al., 2010; Tibebe and Bewket 2011;). Despite its ability to incorporate multi-disciplinary coverage of processes representing the hydrology, soil science, erosion/sediment transport, crop growth, in-stream water quality and the agricultural management, the model suffers for lack of validation for a spatially distributed process and the parameters of the distributed model need to be evaluated (Griensven et al. 2012).

Table 2: Soil erosion and water quality prediction models

Model	Reference	Model Input	Model Output	Remark
USLE (Universal Soil Loss Equation)	Wischmeier and Smith (1978)	High	Soil erosion rate	Hillslope scale, empirical erosion model
SLEMSA (The Soil Loss Estimator for Southern Africa)	Elwell, 1978	High	Soil erosion	Field plot scale, empirical erosion prediction model

ANSWERS (Areal Nonpoint Source Watershed Environment Response Simulation)	Beasley et al. (1980)	High,	sediment, nutrients	Catchment scale, physically based water quality assessment model
CREAMS (Chemical Runoff and Erosion from Agricultural Management Systems)	Knisel (1980)	High	Soil erosion, sediment deposition	Field scale model for water quality assessment
AGNPS (The Agricultural Non-Point Source model)	Young et al. (1987)	High	Erosion, its impact on soil quality, nutrient loss	Small catchment scale, conceptual model for water quality assessment
WEPP (Watershed Erosion Prediction Project)	Laflen et al. (1991)	High	Soil loss, runoff; sediment deposition, form of sediment loss	Applicable in both hillslope and catchment scale, physically based model for soil erosion prediction
TOPOG	TOPOG Homepage; Gutteridge Haskins and Davey (1991)	High	Sediment, water flux and solute transfer	Catchment scale, physically based model for erosion prediction
PERFECT (Productivity, Erosion and Runoff, Functions to Evaluate Conservation Techniques)	Littleboy et al. (1992)	High	Erosion, Runoff and crop yield	Field scale physically based model for water balance and runoff prediction, erosion and crop yield estimation
EUROSEM (European Soil Erosion Model)	Morgan, 1994	High	Soil erosion, sediment transport and deposition, protection measure	Individual event-based erosion prediction from single slope. Combine some features of GUEST and WEPP
GUEST (Griffith University Erosion System Template)	Yu et al. (1997)	High	Runoff, sediment concentration	Plot scale erosion model for soil erodibility assessment
SWAT (Soil and Water Assessment Tool)	Arnold et al. (1998)	High	Assess the Quality and quantity of ground and surface water, predict the possible impact of climate change, land use and land management practices	Hydrological water balance simulation, simulation of sediment dynamics using runoff Applicable in large watershed
LASCAM	Viney and Sivalapan (1999)	High	runoff, sediment	Catchment scale, conceptual model, water quality assessment model
SEDENT	Prosser et al. (2001)	Modera te	Suspended sediment, relative contributions from overland flow, gully and bank erosion processes	Catchment scale, Empirical/Conceptual model for soil erosion prediction

(Source: Prepared by the authors)

2.5 Applications of Remote Sensing and GIS:

2.5.1 Brief Description:

Remote Sensing & Geographic Information Systems (GIS) have emerged as a powerful decision support tool for handling spatially geo-referenced information for preparation and visualization of input and output in a wide range of scale from small field plot to regional scale soil and water conservation and for interaction with models (Renschler and Harbor, 2002). Satellite data has had been widely applied to directly detect erosion or to detect erosion consequences (Table 3). GIS enables the integration of the spatial analytical functionality of parameters that are spatially distributed. The application of GIS to soil degradation assessment has been in the areas of analysis and display of relevant attribute data, model parameterization for simulation and representation of interrelations of model parameters to make decision as per model objective.

Surface soil features differentiation and detection over a wide range of wavelength, repetitive coverage, wide scale monitoring with high resolution of polar orbiting satellites provide a broad scope of monitoring soil erosion and degradation through time. Soil surface differentiation from canopy coverage by spectral separation (Huete, 1989), usage of aerial photo for erosion feature identification (Frazier and Hooper, 1983), erosion phase determination (Bergsma, 1974), different erosion class separation by colour composite image interpretation (Raina et al., 1993) are the examples of RS application around 1980s-1990s. Land use landcover classification and change detection, hydrological modelling using Digital Elevation Model (DEM), derivation of vegetation and mineral indices, small to large scale digital soil mapping are the potential areas to contribute soil erosion research.

In the 1990s, the soil erosion model was integrated with GIS to monitor global and regional soil erosion, to understand the impacts of soil erosion, and to analyse soil erosion dynamics. Remote sensing provides detailed and easily-available high-quality data over large regions for a wide spectral range with regular overpasses and can therefore bears a huge potential to regional scale soil erosion assessment (e.g. Zinck *et al.*, 2001; Haboudane*et al.*, 2002; King *et al.*, 2005). Multicriteria decision making model in combination with RS & GIS contributed new dimension in geo-hydrological parameter modelling, thematic mapping and in applied morphometric analysis (Arabameri, 2014; Arabameri et al. 2018; Arabameri et al. 2019).

Table 3: Application of RS & GIS in soil erosion monitoring

Area of Contribution	References
Detection of erosion features and eroded areas	Langran, 1983; Millington and Townshend, 1984; Vrieling and Rodrigues 2004; Dwivedi and Ramana, 2003; Sujatha et al., 2000; Servenay and Prat 2003 et al.
Detection of erosion consequences	Khan and Islam 2003; Goel and Jain, 1996; Goel et al., 2002; Liu et al. 2003 et al.
Erosion controlling factors assessment	Mannaerts and Saavedra 2003; McBratney et al., 2003; Wang et al. 2003; Dwivedi, 2001 et al.
Erosion models	Fenton, 1982; Fraser et al., 1995; Lee, 2004; Millward and Mersey, 1999; Reusing et al., 2000 at al.
Qualitative methods	Jain and Goel, 2002; Shrimali et al., 2001; Vrieling et al., 2002 et al.
Validation	Reusing et al., 2000; Zhang et al., 2002; Millward and Mersey, 1999 et al.

(Source: Prepared by the Authors)

2.5.2 Critical Review:

All the techniques in remote sensing cannot be easily transferred to all environmental conditions. In extremely humid environment satellite applications and use of spectral classes are limited. The extreme complex erosion process, different environmental settings, scale dependency are the most important hindrances to develop a standardized operational soil erosion prediction system using satellite data (Vrieling A, 2006). Before using satellite data researchers, modellers must identify the observables that can be extracted and developed with satellite imagery with required resolution for the region and scale required. Vrieling A (2006) recommended for the promising fields in remote sensing for erosion study to be explored includes SAR interferometric decorrelation, soil erodibility analysis using geo-statistics, C-factor mapping and soil and vegetation condition assessment by spectral unmixing of optical data. However, GIS can be used as a decision support tool for big data capture, store analysis and spatial representation in combination with model simulation. Satellite derived data and model output must be validated by field data to get operational erosion monitoring system for particular study area.

2.6 Statistical Modelling, Machine Learning (ML) and Artificial Intelligence (AI):

2.6.1 Brief Description:

Recent research on the application of statistical techniques in soil erosion susceptibility analysis and mapping in GIS platform has contributed a new dimension in the methodological advancement. Susceptibility mapping considers the geo environmental causative factors and actual affected status of land in response to the erosion process, to determine the various degree of spatial probability of erosion occurrence (Conoscenti et al., 2008). Statistical modelling explores the quantitative relationship between spatial distribution of soil erosion and the spatial distribution of conditioning variables. There are wide range of advanced statistical methods in soil erosion studies including logistic regression (Akgün and Türk , 2011; Yalcin A et a., 2011; Kachouri et al., 2014; Varouchakis et al., 2016; Sarkar and Mishra, 2018), multivariate statistical analysis (Conoscenti et al., 2008; Conoscenti et al., 2013; Kachouri et al., 2014), the analytical hierarchy process(AHP) (Yalcin A et a., 2011; Svoray et al. 2012; Kachouri et al., 2014; Arabameri et al. 2018), random forest model(Blanko et al., 2018; Arabameri et al. 2019), frequency ratio method (Yalcin A et a., 2011; Sar N et al., 2016; Zabihi et al.2018), Weight of Evidence (WoE) analysis (Dube et al. 2014; Gayen and Saha, 2017; Hembram T K et al., 2019), Multivariate adaptive regression spline method (MARS) (Conoscenti et al. 2018; Shepherd and Walsh, 2002;), classification and regression tree models (CART) (Shepherd and Walsh, 2002; Tittonell et al. 2008; Gayen and Pourghasemi 2019) etc.

Machine Learning (ML) is an emerging field in scientific research including soil science. It can contribute in data handling, empirical and process-based model building and simulations of soil processes (Rossiter, 2018). Artificial intelligence and neural network model are being widely used in soil science, mainly for digital soil mapping and estimation and spatial distribution of soil properties (Behrens et al. 2005; Calderano Filho et al. 2014; Sarmadian and Taghizadeh Mehrjardi 2008;Zhao et al. 2010; Erzin et al.2010), soil texture analysis (Zhao et al. 2009)and soil erosion assessment (Kimand Gilley 2008; Abdollahzadeh et al. 2011). Licznar and Nearing (2003) applied neural network method for soil erosion and runoff prediction and advocated the potential of this method as a complementary tool in soil erosion research in the future. Ghazaleh and Ali (2016) extended this approach using ImpelERO model that combines neural network and decision trees for soil erosion study. Sarkar and Mishra (2018) applied Artificial Neural Network (ANN) and Logistic regression technique for soil erosion susceptibility analysis and mapping.

2.6.2 Critical Review:

It is obvious that ML and AI is emerging as more advanced and powerful method in comparison to traditional models for prediction. However, Padarian et al. (2019) mentioned that some researches with advanced ML models are criticised for low interpretability. It is extremely important to apply complex model in accordance to the objectives of the research and with proper consideration of complexities in the research problem.

3.0 Conclusion and Future Direction:

Consideration of input spatial layers with limited field data, over assumption and available spatial data with coarse resolution must be reviewed and should be exempted to get better result with greater reliability. Future research may focus on strengthen field investigation and monitoring to develop validation data bank in large scale. Use of real time high resolution spatial data in Remote Sensing & GIS platform in coupling process-based models has a great potential to contribute in large scale erosion prediction. RS has a wide scope to supplement and contribute to model building and to provide information not otherwise available to researchers, modellers and soil scientists. Model simplicity and incorporation of available data layers are very important for wide application of a model but must not be in cost of accuracy and reliability. However individual model has its own assumptions and conditions for applications. Researchers, modelers and stakeholders must be aware of model component definitions, underlying model concepts and parameters. Validation of model output must be done by long term intensive field measurement and monitoring. There is no confusions and contradiction in development and adoption of different methods through time. Rather the emergence and application of RS &GIS and statistical techniques complemented the model development and provides more accuracy and reliability invalidation of model output.

There is a large scope for future soil erosion science research in application of statistical models and artificial intelligence to explore the hidden inter-variables and intra-variable relationship to address the erosion process in large scale. The importance and scope of ML is considered by the capability to learn and deal with complex non linearities in data. The review may advocate the better performance of machine learning and artificial intelligence on prediction of continuous component properties and classes. ML and ANN have an enormous capability to consider wide range parameters in comparison to traditional empirical and physically based models where it is limited. Soil erosion is a natural process but human induced erosion process has become a hazard. The nature is very complex in itself and human interventions and interactions make the natural process more complex. Field observation is extremely important and inevitable to understand the ongoing process and to derive the explanation. The challenge is to make necessity simplifications of real observations and to predict the future.

References:

Abdollahzadeh, A., Mukhlisin, M., & El Shafie, A. (2011). Predict soil erosion with artificial neural network in Tanakami (Japan). WSEAS Trans Comput, 10, 51–60.

Akgu¨n, A., & Tu¨rk, N. (2011). Mapping erosion susceptibility by a multivariate statistical method: a case studyfrom the Ayvalık region, NW Turkey. Comput Geosci, 37, 1515–1524.

Alewell, C., Borrelli, P., Meusburger, K., & Panagos, P. (2013). Using the USLE: Chances, challenges and limitations of soil erosion modelling. International Soil and Water Conservation Research, 7 (2019), 203-225. https://doi.org/10.1016/j.iswcr.2019.05.004

Alewell, C., Meusburger, K., Juretzko, G, Mabit, L., & Ketterer, M.E. (2014). Suitability of 239+240PU and Cs-137 as tracers for soil erosion assessment in mountain grasslands. Chemosphere, 103, 274-280.

Ande, O.T., Alaga, Y., Oluwatosin, G.A. (2009). Soil erosion prediction using MMF model on highly dissected hilly terrain of Ekiti environs in southwestern Nigeria. International Journal of Physical Sciences, 4(2), 53–57.

Arabameri, A., Pradha, B., & Rezaei, K. (2019). Gully erosion zonation mapping using integrated geographically weighted regression with certainty factor and random forest models in GIS. J Environ Manag, 232,928–942.

Arabameri, A., Rezaei, K., Pourghasemi, H.R., Lee, S., & Yamani, M. (2018). GIS-based gully erosion susceptibility mapping: a comparison among three data-driven models and AHP knowledge-based technique. Environ Earth Sci., 77, 628.

Arabameri, A. (2014). Application of the Analytic Hierarchy Process (AHP) for locating fire stations: Case Study Maku City. Merit Res. J. Arts Soc. Sci. Humanit, 2,1–10.

Arabameri, A., Pradhan, B., Pourghasemi, H.R., & Rezaei, K. (2018). Identification of erosion-prone areas using different multi-criteria decision-making techniques and GIS. Geomat. Nat. Hazards Risk, 9,1129–1155.

Arabameri, A., Rezaei, K., Cerda, A., Conoscenti, C., & Kalantari, Z. (2019). A comparison of statistical methods and multi-criteria decision making to map flood hazard susceptibility in Northern Iran. Sci. Total Environ. 660,443–458.

Arnold, J. G., Srinivasan, R., Muttiah, R. S., & Williams, J. R. (1998). Large area hydrologic modeling and assesment Part I: Model development. JAWRA Journal of the American Water Resources Association, 34(1),73-89.

Bai, X.Y., Zhang, X.B., Long, Y., Liu, X.M., & Zhang S.Y. (2013). Use of 137Cs and 210Pbex measurements on deposits in a karst depression to study the erosional response of a small karst catchment in Southwest China to land-use change. HYDROL PROCESS 27(6), 822-829.

Bai, Z.G., & Wan, X. (1997). Geochemical Speciation of 7Be, 137Cs, 226Ra and 228Ra in soils of the Karst region, South-western China and their erosion trace. ACTA Scientiae Circumstantiae 17(4), 407-411.

Beasley, D.B., Huggins, L.F., & Monke, E.J. (1980). ANSWERS: A model for watershed planning. Transactions, American Society of Agricultural Engineers, 23.

Beck, M.B. (1987). Water quality modelling: a review of uncertainty. Water Resources Research, 23 (8), 1393–1442.

Behrens, T., Förster, H., Scholten, T., Steinrücken, U., Spies, E.D., Goldschmitt, M. (2005). Digital soil mapping using artificial neural networks. J Plant Nutr Soil Sci., 168,21–33.

Belyaev, V. R., Wallbrink, P. J., Golosov, V. N., Murray, A. S., & Sidorchuk, A. Y. (2005). A comparison of methods for evaluating soil redistribution in the severely eroded Stavropol region, southern European Russia. Geomorphology, 65(3-4),173-193.

Bergsma, E. (1974). Soil erosion sequences on aerial photographs. ITC Jour., 3, 342-376.

Beven, K. (1989). Changing ideas in hydrology—the case of physically based models. Journal of Hydrology, 105, 157–172.

Bjorneberg, D.L., Trout, T., Sojka, R., Aase, J. (1999). Evaluating WEPP- predicted infiltration, runoff, and soil erosion for furrow irrigation. Transactions of the ASAE, 42(6), 1733–1741.

Blake, W.H., Walling, D.E., & He, Q. (2002). Using cosmogenic beeryllium-7 as a tracer in sediment budget investigations. Geografiska Annaler, 84(2), 89-102.

Blanco, C. M. G., Gomez, V. M. B., Crespo, P., & Ließ, M. (2018). Spatial prediction of soil water retention in a Páramo landscape: Methodological insight into machine learning using random forest, Geoderma, 316, 100–114.

Boardman, J. (2006). Soil erosion science: Reflections on the limitations of current approaches. Catena, 68, 73 – 86. doi:10.1016/j.catena.2006.03.007

Boardman, J., Favis-Mortlock, D.T., & Foster, I.D.L. (2015). A 13-year record of erosion on badland sites in the

Karoo, South Africa. Earth Surface Processes and Landforms. DOI: 10.1002/esp.3775.

Boardman, J. (1986). The context of soil erosion. SEESOIL, 3, 2 –13.

Boardman, J. (1996). Soil erosion by water: problems and prospects for research. In Anderson, M.G., Brooks, S.M. (Eds.), Advances in Hillslope Processes, (vol. 1. pp. 489–505) Wiley, Chichester, UK.

Brazier, R. (2004). Quantifying soil erosion by water in the UK: a review of monitoring and modelling approaches. Progress in Physical Geography, 28(3), 40–365.

Bridges, E.M., Harding, & D.M. (1971). Micro-erosion processes and factors affecting slope development in the Lower Swansea Valley. In Slopes Form and Process, Brunsden D. (ed). Institute of British Geographers: London, 65-79.

Bryan, R.B., & Harvey, L.E. (1985). Observations on the geomorphic significance of tunnel erosion in a semi-arid ephemeral drainage system. Geografiska Annaler, 67A, 257-72.

Calderano, F.B., Polivanov, H., da Silva Chagas, C., de Carvalho Júnior, W., Barroso, E.V., José, A., Guerra, T., & Calderano, S.B. (2014). Artificial neural networks applied for soil class prediction in mountainous landscape of the Serra do Mar. Rev Bras Ciênc Solo, 38, 1681–1693.

Campbell, I. A. (1974). Measurements of erosion on badlands surfaces. Z. Geomorph. Suppl. bd 21, 127-137.

Campbell, I.A. (1970). Micro-relief measurements on unvegetated shale slopes. Prof. Geog., 22,215 220.

Cao, L.X., Liang, Y., Wang, Y., Lu, H.Z. (2015). Runoff and soil loss from Pinus massoniana forest in Southern China after simulated rainfall. Catena, 129,1-8.

Ciesiolka, C.A.A., & Freebairn, D.M. (1982). The influence of scale of runoff and erosion. The Institution of Engineers, Australia, National Conference Publication, 82/8, 203-206.

Clarke, M.L., Rendell, H.M. (2006). Process-form realtionships in southern Italian badlands: erosion rates and implications for landform evolution. Earth Surface Processes and Landforms, 31, 15-29.

Clayton, L., Tinker, J.R. (1971). Rates of hillslope lowering in the Badlands of North Dakota. North Dakota University Water Resources Research Institute, Report W1-221-012-71. W73.09121.N.T.I.S. PB 220 355, 1-36.

Cochrane, T. A., & Flanagan, D.C. (2003). Representative hillslope methods for applying the WEPP model with DEMs and GIS. Trans. ASAE, 46(4), 1041-1049.

Colbert, E.H. (1956). Rates of erosion in the Chinle formation. Plateau, 28(4), 73–76.

Collins, A. L., Walling, D.E., Sichingabula H.M., & Leeks, G.J L. (2001). Using 137Cs measurements to quantify soil erosion and redistribution rates for areas under different land use in the Upper Kaleya River basin, southern Zambia. Geoderma, 104, 299–323.

Conoscenti, C., Agnesi, V., Angileri, S., Cappadonia, C., Rotigliano, E., & Ma¨rker, M. (2013). A GIS-based approachfor gully erosion susceptibility modelling: a test in Sicily, Italy. Environ Earth Sci., 70(3), 1179–1195.

Conoscenti, C., Agnesi, V., Cama, M., Caraballo-Arias, N.A., Rotigliano, E. (2018). Assessment of gully erosion susceptibility using multivariate adaptive regression splines and accounting for terrain connectivity. Land Degrad Dev., 29, 724–736.

Conoscenti, C., Di Maggio, C., & Rotigliano, E. (2008). Soil erosion susceptibility assessment and validation usinga geostatistical multivariate approach: a test in Southern Sicily. Nat Hazard, 46, 287–305.

Covert, S., Robichaud, P., Elliot, W., & Link, T. (2005). Evaluation of runoff prediction from WEPP-based erosion models for harvested and burned forest watersheds. Transactions of the ASAE., 48, (3), 1091–1100.

Covert, S.A., Robichaud, P.R., Elliot, W.J., & Link, T.E. (2005). Evaluation of runoff prediction from WEPP-based erosion models for harvested and burned forestwatersheds. Trans. ASAE 48, 1091–1100.

Dube, F., Nhapi, I., Murwira, A., Gumindoga, W., Goldin, J., & Mashauri, D.A. (2014). Potential of weight of evidence modelling for gully erosion hazard assessment in Mbire District–Zimbabwe. Physics and Chemistry of theEarth, Parts A/B/C 67, 145–152.

Dwivedi, R. & Ramana, K. (2003). The delineation of reclamative groups of ravines in the Indo-Gangetic alluvial plains using IRS-ID LISS-III data. International Journal of Remote Sensing. 24. 4347-4355. 10.1080/0143116031000116994.

Dwivedi, R.S. (2001). Soil resources mapping: a remote sensing perspective. Remote Sensing Reviews, 20, 89–122.

Elliott, G.L., Campbell, B.L., & Loughran, R.J. (1990). Correlation of erosion measurements and soil Caesium-137 content. APPL. RADIAT. ISOTOPES, 41(8), 713-717.

Elwell, H.A. (1978). Modeling soil losses in southern Africa. Journal of Agricultural Engineering Research, 23:117-127.

Emmett, W.W. (1974). Channel aggradation in western United States as indicated by observations at Vigil Network sites: Zeitschrift fur Geomorphologie, 2 (3-5), 53.

Erzin, Y., Hanumantha, Rao, B., Patel, A., Gumaste, S.D., & Singh, D.N. (2010). Artificial neural network models for predicting electrical resistivity of soils from their thermal resistivity. Int J Therm Sci., 49, 118–130.

Evans, R., & Boardman, J. (2016). The new assessment of soil loss by water erosion in Europe. Panagos P. et al., 2015 Environmental Science & Policy 54, 438-447-A response. Environmental Science & Policy, 58, 11-15.

Evans, R., & Boardman, J. (2016a). A reply to panagos et al., 2016 (Environmental science & policy 59 (2016) 53-57. Environmental Science & Policy, 60, 63-68.

Fenton, T.E. (1982). Estimating soil erosion by remote sensing techniques. In Johannsen, C.J., Sanders, J.L. (Eds.), Remote Sensing for Resource Management. Soil Conservation Society of America, Ankeny, IA,pp. 217– 231.

Fiener, P., Wilken, F., & Auerswald, K. (2019). Filling the gap between plot and landscape scale – eight years of soil erosion monitoring in 14 adjacent watersheds under soil conservation at Scheyern, Southern Germany. Adv. Geosci., 48, 31–48. https://doi.org/10.5194/adgeo-48-31-2019.

Flanagan, D.C., & Nearing, M.A. (1995). USDA Water Erosion Prediction Project: Hillslope Profile and Watershed Model Documentation. NSERL Report No. 10, USDA-ARS National Soil Erosion Research Laboratory, West Lafayette, IN, USA.

Fraser, R.H., Warren, M.V., & Barten, P.K. (1995). Comparative evaluation of land cover data sources for soil erosion prediction. Water Resources Bulletin 31 (6), 991– 1000.

Frazier, B.E., Hooper, G.K. (1983). Use of chromogenic film for aerial photography of erosio features. Photogramm. Eng. Remote Sens., 49, 1211-1217.

Garcia-Ruiz, J.M., Begueria, S., Nadal-Romero, E., Gonzalez-Hidalgo, J.C., Lana-Renault, N., & Sanjuan, Y. (2015). A meta-analysis of soil erosion rates across the world. GEOMORPHOLOGY 239, 160-173.

Gassman, P.W., Arnold, J.G., Srinivasan, R., & Reyes, M. (2010). The worldwide use of the SWAT model: Technological drivers, networking impacts, and simulation trends. In Proc. 21st Century Watershed Technology: Improving Water Quality and Environment. ASABE Publication No. 701P0210cd. St. Joseph, Mich.: ASABE

Gassman, P.W., Reyes, M., Green, C. H., & Arnold, J. G. (2007). The Soil and Water Assessment Tool: Historical development, applications, and future directions. Trans. ASABE, 50(4), 1211-1250.

Gayen, A., Pourghasemi, H.R. (2019). Spatial modeling of gully erosion: a new ensemble of CART and GLM data-mining algorithms. In: Spatial modeling in GIS and R for earth and environmental science, pp 653–669.

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. Modeling Earth Systems and Environment 3(3), 1123–1139.

Ghazaleh, R., Ali, B. (2016). Assessment of soil erosion by neural networkbased IMPELERO model using GIS in Neyshabour plain, northeast of Iran. Indian J Fundam Appl Life Sci 6(S1):8–15 Centre for Info Bio Technology (CIBTech).

Goel, M.K., Jain, S.K. (1996). Evaluation of reservoir sedimentation using multi-temporal IRS-1A LISS-II data. Asian-Pacific Remote Sensing and GIS Journal, 8 (2), 39– 43.

Goel, M.K., Jain, S.K., Agarwal, P.K. (2002). Assessment of sediment deposition rate in Bargi Reservoir using digital image processing. Hydrological Sciences Journal 47, S81–S92 (Special Issue: Towards Integrated Water Resources Management for Sustainable Development).

Gutteridge, Haskins & Davey, (1991). Integrated Quantity/Quality Modelling—Stage 3, Gutteridge Haskins and Davey, for Department of Water Resources, Sydney, pp. 102.

Haboudane, D., Bonn, F., Royer, A., Sommer, S., Mehl, W. (2002). Land degradation and erosion risk mapping by fusion of spectrally-based information and digital geomorphometric attributes. International Journal of Remote Sensing 23 (18), 3795–3820.

Hadley, R.F., Schumm, S.A. (1961). Sediment sources and drainage basin characteristics in upper Cheyenne River Basin. USGS Wat er Supply Paper1531-B.

Han, F., Ren, L., Zhang, X., & Li, Zhanbin. (2016). The WEPP Model Application in a Small Watershed in the Loess Plateau. PLOS ONE. 11. e0148445. 10.1371/journal.pone.0148445.

Hancock, G.R., & Lowry, J.B.C. (2015). Hillslope erosion measurement – a simple approach to a complex process. Hydrological Processes 29, 4809-4816.

Harvey, A.M. (1974). Gully erosion and sediment yield in the Howgills, Westmorland. In Gregory, K.J. and Walling, D.E., (eds) Fluvial processes in instrumented watersheds. IBG Special Publication No. 6, 45–58.

Hembram, T.K., Paul, G.C., & Saha, S. (2019). Comparative Analysis between Morphometry and Geo Environmental Factor Based Soil Erosion Risk Assessment Using Weight of Evidence Model: a Study on Jainti River Basin, Eastern India. Environmental Processes. https://doi.org/10.1007/s40710-019-00388-5

Huete, A.R. (1989). Soil influences in remotely sensed vegetation canopu spectra. p 107-141. In G Asrar (ed.) Theory and Applications of Optical Remote Sensing. Wiley Series of Remote Sens., J Wiley & Sons, New York, NY.

Igwe, P.U.; Onuigbo, A.A.; Chinedu, O.C.; Ezeaku, I.I.; & Muoneke, M.M. (2017) Soil Erosion: A Review of Models and Applications. International Journal of Advanced Engineering Research and Science (IJAERS), 4(12):138-150. https://dx.doi.org/10.22161/ijaers.4.12.22

Issa, A., Azzedine, H., & Isam, S. (2011). WEPP and ANN models for simulating soil loss and runoff in a semi-arid mediterranean region. Environment Monitoring and Assessment, 180, 537–556.

Jahun, B.G., Ibrahim, R., Dlamini, N.S., & Musa, S.M. (2015). Review of Soil Erosion Assessment using RUSLE Model and GIS. Journal of Biology, Agriculture and Healthcare, 5(9), 36-47.

Jain, S.K., & Goel, M.K. (2002). Assessing the vulnerability to soil erosion of the Ukai Dam catchments using remote sensing and GIS. Hydrological Sciences Journal, 47(1), 31–40.

Kachouri, S., Achour, H., Abida, H., & Bouaziz, S. (2014). Soil erosion hazard mapping using analytic hierarchy process and logistic regression: a case study of Haffouz watershed, central Tunisia. Saudi Society for Geosciences. Arab J Geosci. https://doi.org/10.1007/s12517-014-1464-1

Keay-Bright, J., & Boardman, J. (2009). Evidence from field-based studies of rates of erosion on degraded land in the central Karoo, South Africa. Geomorphology, 103, 455-465.

Khan, N.I., & Islam, A. (2003). Quantification of erosion patterns in the Brahmaputra-Jamuna River using geographical information system and remote sensing techniques. Hydrological Processes, 17(5), 959–966.

Kim, M., & Gilley, J.E. (2008). Artificial neural network estimation of soil erosion and nutrient concentrations in runoff from land application areas. Comput Electron Agric, 64, 268–275.

King, J.A., Dampney, P.M.R., Lark, R.M., Wheeler, H.C., Bradley, R.I., & Mayr, T.R. (2005). Mapping potential crop management zones within fields: Use of yield-map series and patterns of soil physical properties identified by electromagnetic induction sensing. Precision Agriculture 6, 167–181.

Kinnell, P. I. A. (2010). Event soil loss, runoff and the universal soil loss equation family of models: A review. Journal of Hydrology, 385(1-4), 384-397.

Kirkby A.V.T., & Kirkby, M.J. (1974). Surface wash at the semi-arid break in slope. Zeitschrift fur Geomorphologie Suppl., 21, 151-176.

Kirkby, M.J. (1998). Modelling across scales: the MEDALUS family of models. In Boardman, J., Favis-Mort- lock, D.T. (Eds.), Modelling Soil Erosion by Water. NATO ASI Series I-55, Springer, Berlin, pp. 161–174.

Kirkby, M.J., & Cox, N.J. (1995). A climatic index for soil erosion potential (CSEP) including seasonal and vegetation factors. Catena, 25 (1–4), 333–352.

Knisel, W.G. (1980). CREAMS. A Field Scale Model for Chemicals, Runoff and Erosion from Agricultural Management Systems. U.S. Dept Agric., Conserv. Res. Rep. No. 26

Vandekerckhove, L., Poesen, J., Oostwoud Wijdenes, D., & Gyssels, G. (2001). Short term bank gully retreat rates in Mediterranean environments. Catena 44, 133-161.

Laflen, J.M., Elliot, W.J., Simanton, J.R., Holzhey, C.S. & Kohl, K.D. (1991). WEPP: Soil Erodibility Experiments for Rangeland and Cropland Soils. Journal of Soil and Water Conservation. 46.

Lane, L.J., & Nearing, M.A. (Eds) (1989) USDA Water erosion Prediction Project: Hillslope Profile Model Documentation NSERL Report No 2. National Soil Erosion Laboratory, USDA-ARS, W. Lafayette, IN.

Langran, K.J. (1983), Potential for monitoring soil erosion features and soil erosion modelling components from remotely sensed data. In Proceedings of IGARSS'83,31August–2 September 1983, San Francisco, California (Piscataway, NJ: IEEE), pp.2.1–2.4

Lawler, D.M. (1978). The use of erosion pins in river banks. Swansea Geographer, 16, 9-18.

Lawler, D.M. (1993). The measurement of river bank erosion and lateral channel change: a review. Earth Surface Processes and Landforms, 18, 777-821.

Lee, S. (2004). Soil erosion assessment and its verification using the Universal Soil Loss Equation and Geographic Information System: a case study at Boun, Korea. Environmental Geology, 45 (4), 457–465.

Leopold, L.B., Emmett, W.W., & Myrick, R.M. (1966). Channel and hillslope processes in a semiarid area, New Mexico. USGS Prof. Pap. 352-G

Li, Y., Bai, X., Tian Y., & Luo G. (2017). Review and Future Research Directions about Major Monitoring Method of Soil Erosion. IOP Conf. Series: Earth and Environmental Science 63 (2017) 012042. doi :10.1088/1755-1315/63/1/012042

Licznar, P., & Nearing, M.A. (2003). Artificial neural networks of soil erosion and runoff prediction at the plot scale. Catena, 51, 89–114.

Littleboy, M., Silburn, M.D., Freebairn, D.M., Woodruff, D.R., Hammer, G.L., Leslie, J.K., (1992). Impact of soil erosion on production in cropping systems. I. Development and validation of a simulation model. Australian Journal of Soil Research 30, 757–774

Liu, Y., Islam, M.A., Gao, J. (2003). Quantification of shallow water quality parameters by means of remote sensing. Progress in Physical Geography, 27 (1), 24–43.

Loughran, R. J. (1989). The measurement of soil erosion. Progress in Physical Geography, 13, 216–233.

Mannaerts, C.M., & Saavedra, C.P. (2003) Regional Scale Erosion Modeling and Monitoring Using Remotely Sensed Data: Some Spatial Data Scale Issues. In: Gabriels D, Cornelis W (eds.), Proceedings of the International Symposium on 25 Years of Assessment of Erosion. pp 433-440. Ghent University, Ghent, Belgium.

Matisoff, G., Wilson, C.G., Whiting, P.J. (2005). The 7Be/210Pbxs ratio as an indicator of suspended sediment age or fraction new sediment in suspension. Earth Surface Processes and Landforms, 30(9), 1191–1201.

McBratney, A.B., Santos, M.L.M., & Minasny, B. (2003). On Digital Soil Mapping. Geoderma, 117(1-2), 3-52. DOI: 10.1016/S0016-7061 (03)00223-4

Menzel, R.G. (1960). Transport of strontium-90 in runoff. Science (Washington, DC), 131, 499-500

Merritt, W.S., Letcher, R.A., & Jakeman, A.J. (2003). A Review of Erosion and Sediment Transport Models. Environmental Modelling and Software, 18(8), 761-799.

Meyer, L.D., & Wischmeier, W.H. (1969). Mathematical simulation of the process of soil erosion by water. Transactions of the American Society of Agricultural Engineers, 12, 754–758.

Miller, M.F. (1915). Waste through soil erosion. Journal Am. Soc. Agron, 18, 153-160.

Millington, A.C. & Townshend, J.R.G. (1984). Remote sensing applications in African erosion and sedimentation studies, Challenges in African Hydrology and Water Resources (Proceedings of the Harare

Symposium, July 1984). IAHS Publ. no. 144.

Millington, A.C. (1981). Relationship between three scales of erosion measurement on two small basins in Sierra Leone. Symposium on Erosion and Sediment Transport Measurement, Florence. International Association of Hydrological Sciences Publication, 133, 485-92.

Millward, A.A., Mersey, J.E. (1999). Adapting the RUSLE to model soil erosion potential in a mountainous tropical watershed. Catena, 38 (2),109– 129.

Mishra, R.K., & Rose, C.W. (1990) Manual for use of program GUEST. Division of Australian Environmental Studies Report. Griffith University, Nathan Campus, Brisbane, Australia.

Mondal, A., Khare, D., & Kundu, S. (2016). A comparative study of soil erosion modelling by MMF, USLE and RUSLE. Geocarto International, 33, 1-25. 10.1080/10106049.2016.1232313.

Morgan, R.P.C, Duzant, J.H. (2007). Modified MMF (Morgan–Morgan–Finney) model for evaluating effects of crops and vegetation cover on soil erosion. Earth Surf. Process. Landforms, 32, 90–106 (2008)

Morgan, R.P.C., Morgan, D.D.V., Finney, H.J. (1984). A predictive model for the assessment of soil erosion risk. Journal of Agricultural Engineering Research, 30 (1984), 245-253 https://doi.org/10.1016/S0021-8634(84)80025-6. https://www.sciencedirect.com/science/article/pii/S0021863484800256

Morgan, R.P.C. (2005). Soil Erosion and Conservation. Third edition. Blackwell Publishing, Malden, U.S.A.

Morgan, R.P.C., Quinton, J.N., Smith, R.E., Govers, G., Poesen, J.W.A., Auerswald, K., Chisci, G., Torri, D., & Styczen, M.E. (1998). The European Soil Erosion Model (EUROSEM): a dynamic approach for predicting sediment transport from fields and small catchments. Earth Surf. Process. Landforms, 23, 527-544. https://doi.org/10.1002/(SICI)1096-9837(199806)23:6<527::AID-ESP868>3.0.CO;2-5

Morgan, R.P.C. (1994). The European soil erosion model: An update on its structure and research base. In RJ Rickson (ed.). Conserving Soil Resources, European Perspectives. CAB International, Wallingford. 428 pp.

Morgan, R.P.C. (2001). A simple approach to soil loss prediction: a revised Morgan Morgan-Finney model. Catena, 44, 305-22.

Nearing, M.A, Foster, G.R, Lane, L.J, & Finckner, S.C. (1989). A process-based soil erosion model for USDA-Water Erosion Prediction Project Technology. Trans. ASAE. 32, 1587-1593.

Nearing, M.A., Govers, G., & Norton, D. L. (1999). Variability in soil erosion data from replicated plots, Soil Sci. Soc. Am. J., 63, 1829–1835.

Nearing, M.A., Foster, G.R., Lane, L.J. & Finckner, S.C. (1989). A process-based soil erosion model for USDAWater Erosion Prediction Project technology. Transactions of the American Society of Agricultural Engineers, 32, 1587–93.

New, M.G., & Schulze, R.E. (1996). Hydrologic sensitivity to climate change in the Langrivier catchment, Stellenbosch, South Africa and some implications for geomorphic processes. Zeitschrift fur Geomorphologie Supplementband 107, 11–34.

Othman, Z., Ismail, W.R. (2012). Using environmental radionuclide, 137Cs to investigate soil re–distribution in an agricultural plot in Kalumpang, Selangor, Malaysia. Kajian Malaysia, Vol. 30, No.2, 2012, 45–70. Penerbit Universiti Sains Malaysia.

Padarian,J., Minasny, B., & McBratney, A.B. (2019) Using deep learning for digital soil mapping. SOIL, 5, 79–89. https://doi.org/10.5194/soil-5-79-2019

Phai, D.D., Orange, D., Migraine, J.B., Toan, T.D., & Vinh, N.C. (2006). Applying GIS-Assisted Modelling to Predict Soil Erosion for a Small Agricultural Watershed within Sloping Lands in Northern Vietnam. International Conference on Sustainable Sloping Lands and Watershed Management, Pp. 312-328.

Polyakov, V.O., Nearing, M.A., Shipitalo, M.J. (2004). Tracking sediment redistribution in a small watershed: Implications for agro-landscape evolution. Earth Surface Processes and Landforms, 29, 1275-1291.

Porto, P., Walling, D.E., Callegari, G. (2013). Using 137Cs and 210Pbex measurements to investigate the sediment budget of a small forested catchment in southern Italy. HYDROL. PROCESS 27(6), 795-806.

Prosser, I.P., Young, B., Rustomji, P., Hughes, A., & Moran, C. (2001). A model of river sediment budgets as an element of river health assessment. In: Proceedings of the International Congress on Modelling and Simulation (MODSIM'2001), December 10–13, pp.861–866.

Quinton, J.N. (1997). Reducing predictive uncertainty in model simulations: a comparison of two methods using the European Soil Erosion Model (EUROSEM). Catena, 30, 101-117.

Quinton, J. (2013). Erosion and sediment transport. In J. Wainwright, & M. Mulligan (Eds.), Environmental modelling: Finding simplicity in complexity (pp. 187-196). John Wiley & Sons, Ltd.

Raina, P, Joshi D.C., & Kolarkar, A.S. (1993) Mapping of soil degradation by using remote sensing on alluvial plain, Rajasthan, India. Arid Soil Res. Rehab., 7, 145-161.

Ranwell, D.S. (1964). Spartina salt marshes in southern England 11: Rate and seasonal pattern of sediment accretion. Journal of Ecology, 52, 79-94.

Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D., & Yoder, D. (1997). Predicting soil erosion by water: a guide to conservation planning with the revised universal soil loss equation (RUSLE). Agriculture Handbook No. 703. U.S. Department of Agriculture, Washington DC.

Renschler, C.S., & Harbor, J. (2002). Soil erosion assess-ment tools from point to regional scales—The role of geomorphologists in land management research andimplementation. Geomorphology, 47, 189–209.

Reusing, M., Schneider, T., & Ammer, U. (2000). Modelling soil loss rates in the Ethiopian Highlands by integration of high resolution MOMS- 02/D2-stereo-data in a GIS. International Journal of Remote Sensing 21(9), 1885–1896.

Ritchie, J.C., Spraberr, J. A., & McHenry, J. R. (1974). Estimating soil erosion from redistribution of fallout Cs-137. Soil Science Society of America Journal, 38(1), 137–139.

Roels, J.M. (1985). Estimation of soil loss at a regional scale based on plot measurements - some critical considerations. Earth Surface Processes and Landforms, 10, 587-95.

Roels, J.M., & Jonker, P.J. (1983). Probability Sampling Techniques for Estimating Soil Erosion. Soil Science Society of America Journal, 47, 1224-1228. https://doi.org/10.2136/sssaj1983.03615995004700060032x

Rogowski, A.S., & Tamura, T. (1965). Movement of 137CS by run011; erosion and infiltration on the alluvial Captina silt loam. Health Phys. 11:1333-1340

Rogowski, A.S., & Tamura, T. (1970). Environmental mobility of cesium-137. Radiat. Bot. 10:35-45.

Rose C.W., Coughlan K.J., & Fentie B. (1998) Griffith University Erosion System Template (GUEST). In

Boardman J., Favis-Mortlock D. (eds) Modelling Soil Erosion by Water. NATO ASI Series (Series I: Global Environmental Change), vol 55. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-58913-3_30

Rose, C.W. (2014). Modelling Erosion by Water and Wind. In R Lal et al. (ed) Methods for assessment soil degradation. CRC Press.

Rose, C.W., Coughlan, K.J., Ciesiolka, L.A.A., & Fentie, B. (1997). Program GUEST (Griffith University Erosion System Template), a new soil conservation methodology and application to cropping systems in tropical steeplands. ACIAR Technical Reports, 40, 34–58.

Rossiter, D.G. (2018). Past, present & future of information technology in pedometrics, Geoderma, 324, 131–137.

Sar, N., Khan, A., Chatterjee, S., Das, A., & Mipun, B.S. (2016). WITHDRAWN: coupling of analytical hierarchy process and frequency ratio based spatial prediction of soil erosion susceptibility in Keleghai river basin, India. Int Soil Water Conserv Res. https://doi.org/10.1016/j.iswcr.2016.09.004

Sarkar,T., & Mishra, M. (2018). Soil Erosion Susceptibility Mapping with the Application of Logistic Regression and Artificial Neural Network. Journal of Geovisualization and Spatial Analysis (2018) 2, 8. https://doi.org/10.1007/s41651-018-0015-9

Sarmadian, F., & Taghizadeh, M.R. (2008). Modeling of some soil properties using artificial neural network and multivariate regression in Gorgan Province, North of Iran. Glob J Environ Res., 2, 30–35.

Schulze, R. (1989). ACRU: background, concepts and theory. Report 35, Agricultural Catchments Research Unit, Department of Agricultural Engineering, University of Natal, Pietermaritzburg, South Africa.

Schumm, S. (1956). Evolution of drainage systems and slopes in badland at Perth Amboy. NJ Bull Geol Soc Am., 67, 597–646.

Schumm, S.A., & Lusby, G.C. (1963). Seasonal variation of infiltration capacity and runoff on hillslopes in western Colorado. J. Geophys. Res., 68, 3655–3666.

Schwertmann, U., Vogl, W., & Kainz, M. (1987). Bodenerosion durch Wasser - vorhersage des Abtrags und Bewertung von Gegenmaßnahmen. Stuttgart: Verlag Eugen Ulmer.

Servenay, A., & Prat, C. (2003). Erosion extension of indurated volcanic soils of Mexico by aerial photographs and remote sensing analysis. Geoderma, 117 (3–4), 367–375. http://dx.doi.org/10.1016/S0016-7061(03)00134-4.

Shen, Z.Z., Liu, P.L., Xie, Y.S., Yang, M.Y., Li, M., & Lian, Z.L. (2007). Transformation of erosion types on Loess slope by REE tracking. Journal of Rare Earths, 25, 67-73.

Shen, D., Jia, Y., Altinakar, M., & Bingner, R. (2016). GIS-based channel flow and sediment transport simulation using CCHE1D coupled with AnnAGNPS. Journal of Hydraulic Research, 54, 1-8. 10.1080/00221686.2016.1168883.

Shen, Z., Liao, Q., Hong, Q., & Gong, Y. (2012). An overview of research on agricultural non-point source pollution modelling in China. Separation and Purification Technology, Elsevier. 84, 104–111.

Sheng, T.C. (1990). Runoff plots and erosion phenomena on tropical steeplands. In Research Needs and Applications to Reduce Erosion and Sedimentation in Tropical SteepEands (Proceedings of the Fiji Symposium, June 1990): IAHS-AISH Publ. No.192,1990 pp. 154-161

Shepherd, K.D., & Walsh, M.G. (2002). Development of reflectance spectral libraries for characterization of soil properties. Soil Sci. Soc. Am. J. 66,988–998

Shrimali, S.S., Aggarwal, S.P., & Samra, J.S. (2001). Prioritizing erosion-prone areas in hills using remote sensing and GIS—a case study of the Sukhna Lake catchment, Northern India. International Journal of Applied Earth Observation and Geoinformation, 3 (1), 54– 60.

Slaymaker, H.O. (1972). Patterns of present sub-aerial erosion and landforms in mid-Wales. Transactions of the Institute of British Geographers, 55, 47-68.

Song, W., Liu, P.L., Yang, M.Y, & Xue, Y.Z. (2003). Using REE tracers to measure sheet erosion changing to rill erosion. Journal of Rare Earths, 21, 587-590.

Spear, R.C. (1995). Large simulation models: Calibration, uniqueness and goodness of fit. In: International Congress on Modelling and Simulation Proceedings, (Agriculture, Catchment Hydrology and Industry), 1, pp. 8–15.

Stevens, C.J., & Quinton, J.N. (2008). Investigating source areas of eroded sediments transported in concentrated overland flow using rare earth element tracers. Catena, 74, 31-36.

Stocking, M. A. (1987). Measuring land degradation. In Land degradation and society, eds. P. Blaikie and H. Brookfield, 49–63. London: Methuen.

Stolpe, N. B. (2005). A comparison of the RUSLE, EPIC and WEPP erosion models as calibrated to climate and soil of south-central Chile. Acta Agriculturae Scandinavica Section B Soil and Plant Science, 55(1), 2-8.

Streeter, D.T. (1975). Preliminary observations on rates of erosion on chalk downland footpaths. Environmental Impact on Recreational Areas Symp., Inst. of British Geographers, Annual Conference, Oxford: 8 pp., illustr. (mimeogr.)

Sujatha, G., Dwivedi, R.S., Sreenivas, K., & Venkataratnam, L. (2000). Mapping and monitoring of degraded lands in part of Jaunpur district of Uttar Padresh using temporal spaceborne multispectral data. International Journal of Remote Sensing, 21 (3),519–531. http://dx.doi.org/10.1080/014311600210722.

Sun, Y.H., Wang, T., Zhao, C.C., et al. (2009). Contributing ratio of impact factor on gully erosion in Loess hilly and gully area of Qinghai province. Ecology and Environmental Sciences, 18(4), 1402-1406.

Svoray, T., Michailov, E., Cohen, A., Rokah, L., & Sturm, A. (2012). Predicting gully initiation: comparing data mining techniques, analytical hierarchy processes and the topographic threshold. Earth Surf Process Landf 37, 607–619.

Temple, P.H. (1972). Measurements of runoff and soil erosion at an erosion plot scale with particular reference to Tanzania. Geografiska Ann., 54-A, 203-220.

Tibebe, D., & Bewket, W. (2011). Surface runoff and soil erosion estimation using the SWAT model in the Keleta Watershed, Ethiopia. Land Degradation and Development, 22(6), 551-564.

Tittonell,P., Shepherd,K.D., Vanlauwe, B., & Giller, K.E. (2008) Unravelling the effects of soil and crop management on maize productivity in smallholder agricultural systems of western Kenya—An application of classification and regression tree analysis, Agriculture, Ecosystems & Environment, 123(1–3), 137-150. ISSN 0167-8809,https://doi.org/10.1016/j.agee.2007.05.005.

Trimble, S.W., & Crosson, P. (2000). U.S. Soil erosion rates–myth and reality. Science, 289(5477), 248-250.

Van Griensven, A., Ndomba, P., Yalew, S., & Kilonzo, F. (2012). Critical review of SWAT applications in the upper Nile basin countries. Hydrology and Earth System Sciences. https://doi.org/10.5194/hess-16-3371-2012

Varouchakis, E.A., Giannakis, G.V., Lilli, M.A., Ioannidou, E., Nikolaidis, N.P., & Karatzas, G.P. (2016). Development of a statistical tool for the estimation of riverbank erosion probability, Copernicus Publications on behalf of the European Geosciences Union, SOIL, 2, 1–11. https://doi.org/10.5194/soil-2-1-2016

Viney, N.R., & Sivapalan, M. (1999). A conceptual model of sediment transport: application to the Avon River Basin in Western Australia. Hydrological Processes, 13, 727–743.

Vrieling, A. (2006). Satellite remote sensing for water erosion assessment: A review. Catena, 65 (2006), 2 – 18.

Vrieling, A., & Rodrigues, S.C. (2004), Erosion assessment in the Brazilian Cerrados usingmulti-temporal SAR imagery. In Proc. of the 2004 Envisat & ERS Symposium, Salzburg, Austria 6-10 September 2004 (ESA SP-572, April 2005)

Vrieling, A., Sterk, G., & Beaulieu, N. (2002). Erosion risk mapping: a methodological case study in the Colombian Eastern Plains. Journal of Soil and Water Conservation, 57(3), 158– 163.

Walling, D.E., & He, Q. (1999). Using of fallout lead-210 measurements to estimate soil erosion on cultivated land. Soil Sci. Am. J., 63, 1404-1412.

Walling, D.E, He, Q.P., & Blake, W. (1999). Use of 7Be and 137Cs measurements to document short and medium term rates of water induced soil erosion agricultural land. WATER RESOUR.RES, 35(12), 3865-3874.

Wang, G., Gertner, G., Fang, S., & Anderson, A.B. (2003). Mapping multiple variables for predicting soil loss by geostatistical methods with TM images and a slope map. Photogrammetric Engineering and Remote Sensing, 69(8), 889–898.

Wendt, R.C., Alberts, E.E., & Hjelmfelt, A.T. Jr. (1986). Variability of runoff and soil loss from fallow experimental plots. Soil Sci. Soc Am. J., 50, 730–736.

Wheater, H.S., Jakeman, A.J., & Beven, K.J. (1993). Progress and directions in rainfall-runoff modelling. In: Jakeman, A.J., Beck, M.B., McAleer, M.J. (Eds.), Modelling Change in Environmental Systems. John Wiley and Sons, Chichester, pp. 101–132.

Williams, J.R. (1985). The physical components of the EPIC model. In: El-Swaify, S.A., Moldenhauer, W.C., Lo, A. (Eds.)., Soil Erosion and Conservation. Soil Conservation Society of America, Ankeny, IA, pp. 272–284.

Wischmeier, W.H., & Smith, D.D. (1978). Predicting Soil Erosion Losses: A Guide to Conservation Planning. USDA Agricultural Handbook No. 537, 58 pp. US Dept Agric., Washington, DC.

Wischmeier,W.C., & Smith, D.D. (1965). Predicting rainfall erosion losses from cropland east of the Rocky Mountains. Agricultural Handbook No. 282. US Dept Agric.,Washington, DC.

Xue, Y.Z., Liu, P.L, Yang, M.Y., & Ju, T.J. (2004). Study of spatial and temporal process of soil erosion on sloping land using rare earth elements as tracers. Journal of Rare Earths, 22, 707-713.

Yalcin, A., Reis, S., Aydinoglu, A.C., & Yomralioglu, T. (2011). A GIS-based comparative study of frequency ratio, analytical hierarchy process, bivariate statistics and logistics regression methods for soil erosion susceptibility mapping in Trabzon, NE Turkey. Catena, 85(3), 274–287. doi: 10.1016/j.catena.2011.01.014

Young, R.A., Onstad, C.A., Bosch, D.D., & Anderson, W.P. (1987). AGNPS, Agricultural Non-PointSource Pollution Model - A Watershed Analysis Tool. United States Department of Agriculture, Conservation Research Report 35: 80 p

Young, R.A., Onstad, C.A., Bosch, D.D., & Anderson, W.P. (1989). AGNPS: a nonpoint-source pollution model for evaluating agricultural watersheds. Journal of Soil and Water Conservation, 44(2), 168–173.

Yu, B., Rose, C.W., Cielsiolka, C.A.A., Coughlan, K.J., & Fentie, B. (1997). Towards a framework for runoff and soil loss prediction using GUEST technology. Australian Journal of Soil Research, 35, 1191–1212.

Yue, Y., Ni, J. R., Ciais, P., Piao, S. L., Wang, T., Huang, M. T., et al. (2016). Lateral transport of soil carbon and land-atmosphere CO2 flux induced by water erosion in China. Proceedings of the National Academy of Sciences of the United States of America, 113(24), 6617-6622

Zabihi, M., Mirchooli, F., Motevalli, A., Darvishan, A.K., Pourghasemi, H.R., Zakeri, M.A., Sadighi, F. (2018). Spatial modelling of gully erosion in Mazandaran Province, northern Iran. Catena, 161, 1–13.

Zhang, Q.W., Dong, Y.Q., Li, F., Zhang, A.P., Lei, T.W. (2014). Quantifying detachment rate of eroding rill or ephemeral gully for WEPP with flume experiments. J. HYDROL., 519, 2012-2019.

Zhang, X.C., Friedrich, J.M., Nearing, M.A., Norton, L.D. (2001). Potential use of rare earth oxides as tracers for soil erosion and aggregation studies. Soil Science Society of America Journal, 65, 1508-1515.

Zhang, X.C., Nearing, M.A., Polyakov, V.O., & Friedrich, J.M. (2003). Using rare-earth oxide tracers for studying soil erosion dynamics. Soil Science Society of America Journal, 67, 279-288.

Zhang, X., Drake, N., Wainwright, J., 2002. Scaling land surface parameters for global-scale soil erosion estimation. Water Resources Research, 38 (9), 19(1)– 19(9).

Zhao, Z., Chow, T.L., Rees, H.W., Yang, Q., Xing, Z., & Meng, F-R. (2009). Predict soil texture distributions using an artificial neural network model. Comput Electron Agric.

Zhao, Z., Yang, Q., Benoy, G., Chow, T.L., Xing, Z., Rees, H.W., & Meng, F.R. (2010). Using artificial neural network models to produce soil organic carbon content distributionmaps across landscapes. Can J Soil Sci., 90, 75–87.

Zhu, Ming-yong, Tan, Shu-duan, Liu Wen-zhi, & Zhang Quan-fa (2010). A Review of REE Tracer Method Used in Soil Erosion Studies. Agricultural Sciences in China, 9(8), 1167-1174.

Zinck, J. A. (2001). Monitoring salinity from remote sensing data. In R.Goossens, & B. M. De Vliegher (Eds.), Proceedings of the 1st Workshop of the EARSeL Special Interest Group on Remote Sensing for Developing Countries (pp. 359 – 368). Belgium: Ghent University.

Zingg, A.W. (1940). Degree and length of land slope as it affects soil loss in runoff. Agricultural Engineering, 21, 59-64.