Journal of Research in Forestry, Wildlife & Environment Vol. 13(1) March, 2021
E-mail: jrfwe2019@gmail.com; jfewr@yahoo.com
http://www.ajol.info/index.php/jrfwe
jfewr ©2020 - jfewr Publications
ISBN: 2141 – 1778
Abdulkareem et al., 2021

AN OVERVIEW OF SOIL EROSION MODELLING

Abdulkareem, J. H.[1*], Girei A. H.[2], Yamusa, A. M.[1] and Abdullahi, J.[3]

[1]Department of Soil Science, Institute for Agricultural Research Samaru, Faculty of Agriculture, Ahmadu Bello University, Zaria, Nigeria.
[2]Department of Soil Science, Faculty of Agriculture, Federal University, Dutse, Nigeria.
[3]National Agricultural Extension and Research Liaison Services (NAERLS), Ahmadu Bello University, Zaria, Nigeria
*__Corresponding Author:__ *abdulkareemjabir@yahoo.com*; +234 803 534 7950

ABSTRACT
Soil erosion is one of the most important environmental issues in natural and synthetic territories. It can lead to loss of fertility, slope instability, soil truncation; etc. which causes irreversible effects on the poorly renewable soil resource. Therefore, understanding the key parameters and factors to model soil erosion will enable the conservation of soil system goods, services and resources, and will avoid the damage outside of fields caused by transported and accumulated sediments and water. In view of this, a review was carried out on previous studies to examine the concept of soil erosion and review various soil models widely used in literature. It was found that several models are used for soil assessment and prediction and these models are classified into physical (e.g. WEPP), conceptual (SEDNET) and empirical (USLE). The Universal Soil Loss Equation (USLE) and its modifications were found to be the most commonly used soil erosion models due to its simplicity, ease of use and the ability to integrate the various ecosystem parameters successfully. Furthermore, it was found that one of the major limitations associated with the use of models is lack of data for validation especially in large areas where obtaining ground data is not feasible. Although some researchers have suggested the use of correlation between modeled erosion results with factors such as land cover and management factor and soil erodibility factor as well as results of land use change analyses as alternatives for validation purpose. Others correlate the predicted soil erosion results with that of sediment yield. Some validated their soil erosion data with results of land use change analyses, slope length and slope steepness factor, land cover and management factor and soil erodibility factor. However, there is still ambiguity in the knowledge of our understanding as to which soil erosion prediction model to use.

Keywords: soil erosion, model, validation, USLE, RUSLE

INTRODUCTION
Soil erosion is a process that occurs naturally aimed at preserving stability among diverse ecosystem functionaries. It is influenced by key factors such as land use changes, rainfall and slope steepness. Soil erosion is a known serious threat worldwide regarded as the greatest form of land degradation that serves as a precursor of irreversible effects on soil by causing loss of fertility, slope instability and soil truncation among others (Weifeng Bingfang, 2008; Buttafuoco *et al.*, 2012; Prasannakumar *et al.*, 2012). Soil erosion triggered by human activities mainly land use changes results to serious land degradation problems which has been a topic of growing concern for many years among researchers and policy

makers alike (Bathrellos *et al*., 2012; Bathrellos *et al*., 2013; Klein *et al*., 2013; Adhikary *et al*., 2014). Land use changes along with other factors such as rainfall, soil type, elevation, etc. may cause spatial variation in erosion from one location to another (Mallick *et al*., 2014; Mondal *et al*., 2017; Abdulkareem *et al*., 2017; Abdulkareem *et al*., 2018a; Abdulkareem et *al*., 2019). Soils are mostly subjected to the influence of erosion by human activities because of deforestation, poor agricultural practices, overgrazing, forest fires and rapid increase in urbanization. These are along with other improper land management practices are responsible for triggering erosion (Weifeng and Bingfang, 2008; Terranova *et al*., 2009; Buttafuoco *et al*., 2012).

Land use change plays a crucial role in the most provocative decisions carried out by humans, as this can be evident in the rapid urbanization witnessed worldwide over the past decades (Glaeser and Kahn, 2004; Koomen *et al*., 2008; Brueckner, 2009; Abdulkareem *et al*., 2017; Abdulkareem *et al.*, 2018b*;* Abdulkareem *et al.,* 2019*).* Land transformation affect soil, water as well as the atmosphere, which has a direct influence on global environmental problems. Some examples of land use changes that exert great influence on soil degradation, biodiversity and materials needed for human survival are; rapid deforestation for agricultural purposes in tropical areas or the growing number of urban areas (Lambin, 2004; Koomen *et al*., 2008). Furthermore, land use change plays a major role in the regulation of hydrological activities in a catchment (Hörmann *et al*., 2005; Elfert and Bormann, 2010b; Nejadhashemi *et al*., 2011; Abdulkareem *et al*., 2017; Abdulkareem *et al*., 2018a; Abdulkareem *et al*., 2019). The hydrology of a watershed is influenced by its unique characteristics such as soil properties, topography and drainage area. Land use changes and climate are reported to cause variations on a short-term basis. Climate change has a profound effect on rainfall distribution, which in turn affects a watershed hydrologic processes such as surface runoff, streamflow, evapotranspiration and floods (Neupane and Kumar, 2015). Soils and vegetation cover serve as carbon sink by storing carbon dioxide produced by plants during photosynthesis. Long-term land use changes can result to emission of carbon dioxide along with other greenhouse gases (methane and nitrous oxide) which plays a vital in global warming. Furthermore, land use changes are also presumed to play a role in the hydrological dynamics of a watershed which when not controlled can result to significant land degradation problems such as soil erosion and sedimentation problem. For example, land use change influences soil erosion in areas with natural vegetation cover such as forest or grassland areas which when compared with arable lands record lower soil losses (Serpa *et al*., 2015; Abdulkareem *et al*., 2017).

Relatively little attention has been given to the modeling of soil transport across the landscape, in connection with soil, nutrient, and carbon delivery to stream and open waters. Whereas spatially- distributed sediment routing using transport and deposition laws may offer better perspectives to understand sediment delivery, such modeling approaches have been relatively simple (Van Rompaey *et al*. 2001) and need further improvement to fully account for the complexity of real landscapes. Mitigating and controlling erosion require advance-modeling tools to evaluate the appropriateness and efficiency of alternative approaches and methods. In view of this, a careful review of previous modelling studies in soil erosion becomes vital in order to fully understand the extent of studies carried out and type of models utilized.

Erosion and transport processes

The process of erosion can be described in three stages: detachment, transport and deposition. Detachment of sediment from the soil surface was originally considered to be exclusively the result of raindrop impact (e.g. Hudson, 1975), although the importance of overland flow as an erosive agent has now been recognized. Rainfall detachment is caused by the locally intense shear stresses generated at the soil surface by raindrop impact (Loch and Silburn, 1996; Merritt *et al*., 2003). Likewise, overland flow causes a shear stress to the soil surface, which if it exceeds the cohesive strength of the soil, termed the critical shear stress, results in sediment detachment. In different situations, the major processes leading to sediment detachment will differ (Merritt *et al*., 2003).

There are four main types of erosion processes: sheet, rill, gully and in-stream erosion. Sheet erosion refers to the uniform detachment and removal of soil, or sediment particles from the soil surface by overland flow or rain- drop impact evenly distributed across a slope (Hairsine and Rose, 1992; Merritt *et al.* 2003). Together with rill erosion, sheet erosion is often classified as 'overland flow' erosion, detaching sediment from the soil surface profile only. For purposes of simplification, the two processes are often considered together in erosion modelling (Merritt *et al*. 2003).

Soil Erosion modeling

Soil loss prediction to determine environmental, social, and economic effects of soil prediction is essential at catchment level for carrying out sustainable conservation practices (Zhang *et al*., 2009; Demirci and Karaburun, 2012). A detailed knowledge of potential hazard and spatial distribution is of utmost importance in order to achieve sustainable soil conservation measures (Bewket and Teferi, 2009; Wang *et al*., 2009; Demirci and Karaburun, 2012). The use of models can be used to predict soil loss over a wide range of conditions. Several models are used for soil assessment and prediction. Soil erosion models are classified into physically based and empirical models (Bhattarai and Dutta, 2007). Table 1 shows a summary of characteristics of soil erosion models.

Table 1: Characteristics of soil erosion models (modified after Meritt *et el*., 2003)

Physically based model	Conceptual model	Empirical model
White box model or mechanistic WEPP, TREX	Grey box model or parametric, SEDNET	Black box model or metric USLE, MUSLE, RUSLE
Spatial distribution driven, assessment of parameters outlining physiographic feature	Involve reservoir modelling comprise semi-empirical equations that are physically based	Mathematical equations with values derived from time series
Initial model data required as well as watershed morphological features	Parameters are extracted from field data and calibration	Features and processes of the system are minimally considered
Complex model and not easy to use. Require skills and computational capability	Simple and easy to use in computer code	High degree of forecasting ability, low explanatory depth
Challenges with scale related problems	Large data sets required (hydrological and meteorological data)	Differ from one catchment to the other
Valid for several conditions	Curve fitting as part of the calibration process giving difficulties in physical interpretation	Valid within the boundary of a certain domain

Physically based soil erosion models

Soil erosion assessment by these models is done by combining individual elements of a watershed. Inadequate data to calibrate and validate these models is what limit their application to most watersheds even though their results provide adequate information on spatial and temporal situations of soil erosion (Bhattarai and Dutta, 2007). Example of these models include, Water Erosion Prediction Project (WEPP), European Soil Erosion Model (EUROSEM), Two-dimensional Runoff, Erosion, and Export (TREX), AGNPS, ANSWERS, SHETRAN, PERFECT, TOPOG, CREAMS etc. Physically based soil erosion models have been widely utilized in soil erosion prediction from around the word by many researchers e.g. Velleux *et al*. (2008), Bayley *et al*. (2010), Sukhanovskii (2010), Bathurst (2011) Alatorre *et al*. (2012) Shi *et al*. (2012), Mullan (2013), Khaleghpanah *et al*. (2017) etc.

Conceptual soil erosion models

Conceptual models are typically based on the representation of a catchment as a series of internal storages. They usually incorporate the underlying transfer mechanisms of sediment and runoff generation in their structure, representing flow paths in the catchment as a series of storages, each requiring some characterization of its dynamic behavior. Conceptual models tend to include a general description of catchment processes, without including the specific details of process interactions, which would require detailed catchment information (Sorooshian, 1991). This allows these models to provide an indication of the qualitative and quantitative effects of land use changes, without requiring large amounts of spatially and temporally distributed input data (Merritt *et al*. 2003).

Traditionally, conceptual models lump representative processes over the scale at which outputs are simulated (Wheater *et al*., 1993). Recently developed conceptual models have provided outputs in a spatially distributed manner. Alternatively, lumped conceptual models may be applied in a semi-distributed manner by disaggregating a catchment into linked sub catchments to which the model is applied (Merritt *et al*. 2003). Example of conceptual models include SEDNET.

Empirical soil erosion models

Empirical models are the most widely used class of erosion models due to their simplicity and limited data requirement at catchment scale. Example of such models include Universal Soil Loss Equation (USLE), Modified Universal Soil Loss Equation (MUSLE), and Revised Universal Soil Loss Equation (RUSLE) (Bhattarai and Dutta, 2007; Zhang *et al*., 2009; Demirci and Karaburun, 2012). Ever since various limitations to the use of USLE model were discovered, several revisions and modifications were offered to effectively suit the model under different climatic conditions.

USLE and its Modifications

The USLE model is a straight forward empirical model developed by United States Department of Agriculture (USDA) in the 1970s for the prediction of long-term average annual soil loss in cultivated lands using factors such as rainfall, soil type, topography, cropping system as well as management practices (Zhou and Wu, 2008; Kouli, *et a*l. 2009; Demirci and Karaburun, 2012). The model was later applied to other parts of the world due to its ease of application (Bhattarai and Dutta, 2007; Demirci and Karaburun, 2012). There are various limitations associated with the use of USLE model. One of them is that, it cannot perform simulation on event bases, as such it does not have the capability to predict events that lead to extreme soil erosion (Merritt *et a*l., 2003). Another limitation is the fact that the model does not have the capability to detect large gullies as well as sediment yield deposition (Demirci and Karaburun, 2012; Merritt, *et al*., 2003).

Furthermore, the use of USLE in other parts of the world is impaired by unavailability of data needed to effectively simulate the model under new sets of conditions different from that of the United States (Merritt *et al*., 2003). For the USLE model to effectively adapt to a new set of environmental conditions, dedication in time and resources are necessary for the successful simulation of the model. Owing to rainfall variability from one part off the world to another. Evans *et al.* (1992) pointed out that at least 10 years data must be used for the USLE model to successfully run in mine spoils.

One of the modifications include MUSLE, which has the capability to predict soil loss better than USLE for short duration analysis. However, the MUSLE cannot offer proper estimates of spatial distribution of soil erosion (Wang *et al*., 2009). Zhang et al. (2009) incorporated the MUSLE into a GIS environment and produced a tool called ArcMUSLE, an extension of ArcGIS® software. The tool was developed to help conservation planners in soil loss prediction as well as mapping of hazard prone areas for soil erosion control measures. It can also be utilized in most watersheds for the prediction of curve number (CN) for runoff estimation, peak flow as well as soil loss for rainfall events if provided with the appropriate data.

The RUSLE model is the basic and modified version of MUSLE, which has some its factor values modified from those of USLE. The major modification in RUSLE is in the form of slope length factor (*L*) which permits the estimation of soil erosion based of Horton's forest biomass. Bagherzadeh (2014) utilized USLE model to predict soil loss caused by rill, splash and sheet erosion in an agriculture-dominated watershed. A good correlation was obtained between land use factors of dry farming and soil losses. The model was designed with some enhancements for the estimation of major factors related to soil erosion, specifically the topographic factor and the impacts of climate change on soil erosion have also been evaluated since long term average rainfall data are used in computing the rainfall erosivity (Lee, 2004; Pradhan *et al*., 2012; Segura *et al*., 2014; Correa *et al*., 2016; Mello *et al*., 2016; Abdulkareem *et al*. 2017). It is an empirical and parametric model that is built on the most appropriate water erosion process. Generally, erosion depends on the intensity and amount of rainfall as well as runoff, the cover given to the soil through land use change on the forces exerted by rainfall impact and that of surface runoff. In other words, the susceptibility of a soil to the influence of erosion is dependent upon soil properties, the manner in which land use modified the soil properties, and the topography of the landscape which is defined by slope length, steepness, and shape (Lee, 2004). Even with its limitations, the RUSLE can give an insight of the methodological changes connected to the topographic factor estimates and the use of map algebra tool to overlay the layers of the equation in a geographic information system (GIS) environment.

USLE model inputs, outputs and structure

Input data requirements are low compared with most other models. The input requirement include nnual rainfall, an estimate of soil erodibility, land cover information and topographic information is required. The typical output from the USLE is an annual estimate of soil erosion from hillslopes. The basic USLE is an empirical overland flow or sheet-rill erosion regression equation based primarily on observations. Model outputs are both spatially and temporally lumped. As with most empirical models, the USLE is not event responsive, providing only an annual estimate of soil loss. It ignores the processes of rainfall- runoff, and how these processes affect erosion, as well as the heterogeneities in inputs such as vegetation cover and soil types. USLE model is represented by following equation;

$A = R \times K \times LS \times C \times P$ ….. (1)

where A is the soil erosion rate (ton ha^{-1} yr^{-1}), R defined as rainfall runoff erosive factor (MJ mm ha^{-1} yr^{-1}), K means soil erodibility factor (t ha MJ^{-1} mm^{-1}), LS as terrain factors represent the slope length (L) and slope steepness (S) (dimensionless), C indicates land cover and management factor (dimensionless) and P stands for conservation practices factor (dimensionless).

Rainfall Erosive Factor (R)

The rainfall erosivity factor is a major factor used to define the type of erosion caused by rainfall and runoff on soil surface of a specific location. This factor depends on the intensity and volume of rainfall for its development. Therefore, a direct relationship exists between rainfall and erosivity factor in a way that if one increase the other one increases (Pradhan *et al*., 2011; Demirci and Karaburun, 2012; Khosrokhani and Pradhan, 2013; Bagherzadeh, 2014). There exists a multitude of equations for the calculation of *R* factor namely; Wischmeier-Smith (WS), Fournier index (MFI), Sicily, Morocco and Arnoldus equation (Kouli *et al*., 2008; Khosrokhani and Pradhan, 2013).

Soil Erodibility Factor (*K*)

The susceptibility of soil to erosion is dependent upon its soil erodibility factor, which defines its ability to resist detachment and transport by falling raindrops and runoff alike. Different soils differ in their ability to be vulnerable to erosion more than others do. Soil erodibility is subject to soil inherent properties like texture, permeability, structure, organic matter content and cohesiveness.

Land cover and Management Factor (*C*)

The land cover and management is the most crucial factor in soil erosion prediction. Soil erosion can be controlled in an area by reforestation (Lee, 2004; Kouli et al., 2009).

Conservation Practice Factor (*P*)

Conservation practice factor is used to designate changes in practices such as; sediment basins, concave slopes, terraces, contouring, strip cropping, among others.

Previous studies on soil erosion prediction using USLE

Demirci and Karaburun (2012) carried out a study at Buyukcekmece Lake, Turkey using RUSLE to predict spatial soil loss. The result of the prediction provides an in depth of soil degradation as well mapping of areas of erosion priority. It was also found that about 50% of the study area is in need of efficient soil conservation practices to be implemented to control erosion.

CONCLUSIONS

One of the major limitations associated with the use of soil erosion prediction models, is lack of data for validation especially in large watersheds where obtaining ground data is not feasible. Although some researchers have suggested the use of correlation between modeled erosion results with factors such as land cover and management factor and soil erodibility factor (Bagherzadeh, 2014) as well as results of LULC analyses as alternatives for validation purpose. Others like Teh, (2011) correlate the predicted soil erosion results with that of sediment yield while Rizeei et al. (2016) validated their soil erosion results with results of LULC analyses, slope length and slope steepness factor, land cover and management factor and soil erodibility factor. Khosrokhani and Pradhan, (2014) utilizes results of LULC analyses, slope length and slope steepness factor, cover and management factor and soil erodibility factor for validating USLE results. Pradhan *et al*., 2011 validated their soil erosion results obtained from USLE by correlating with landslide events. However, there is still ambiguity in the knowledge of our understanding as to how soil erosion validation should be carried out.

REFERENCES

Abdulkareem, J. H., Pradhan, B., Sulaiman, W. N. A and Jamil, N. R. (2017). Prediction of Spatial Soil Loss Impacted by Long-term Land-use/Land-cover Change in a Tropical Watershed. Published by Geoscience Frontiers.

Abdulkareem, J. H., Pradhan, B., Sulaiman, W. N. A and Jamil, N. R. (2018a). Long-term runoff dynamics as influenced by land use/cover changes (LULC) in a tropical complex catchment. Published by Environmental System and Decisions.

Abdulkareem, J. H., Pradhan, B., Sulaiman, W. N. A and Jamil, N. R. (2018b). Quantification of runoff as influenced by morphometric characteristics in a rural catchment. Published by Earth System and Environment. https://doi.org/10.1007/s41748-018-0043-0

Abdulkareem, J. H., Pradhan, B., Sulaiman, W. N. A and Jamil, N. R. (2019). Development of lag time and time of concentration for a tropical complex catchment under the influence of long-term land use/land cover (LULC) changes. Arabian Journal of Geoscience (2019) 1:101.

Adhikary, P. P., Tiwari, S. P., Mandal, D., Lakaria, B. L., and Madhu, M. (2014). Geospatial comparison of four models to predict soil erodibility in a semi-arid region of Central India. *Environmental Earth Sciences*, *72*(12), 5049–5062.

Alatorre, L. C., Beguería, S., Lana-Renault, N., Navas, A., and García-Ruiz, J. M. (2012). Soil erosion and sediment delivery in a mountain catchment under scenarios of land use change using a spatially distributed numerical model. *Hydrology and Earth System Sciences*, 16(5), 1321.

Bagherzadeh, A. (2014). Estimation of soil losses by USLE model using GIS at Mashhad plain, Northeast of Iran. *Arabian Journal of Geosciences*, *7*(1), 211–220.

Bathrellos, G. D., Gaki-Papanastassiou, K., Skilodimou, H. D., Papanastassiou, D., and Chousianitis, K. G. (2012). Potential suitability for urban planning and industry development using natural hazard maps and geologicalgeomorphological parameters. *Environmental Earth Sciences*, *66*(2), 537–548.

Bathrellos, G. D., Gaki-Papanastassiou, K., Skilodimou, H. D., Skianis, G. A., and Chousianitis, K. G. (2013). Assessment of rural community and agricultural development using geomorphological-geological factors and GIS in the Trikala prefecture (Central Greece). Stochastic *Environmental Research and Risk Assessment*, *27*(2), 573–588.

Bathurst, J. C. (2011). Predicting impacts of land use and climate change on erosion and sediment yield in river basins using SHETRAN. In *Handbook of Erosion Modelling* (pp. 263–288). School of Civil Engineering and Geosciences, Newcastle University, New castle upon Tyne NE17RU, United Kingdom. http://doi.org/10.1002/9781444328455.ch14

Bayley, T., Elliot, W., Nearing, M. A., Guertin, D. P., Johnson, T., Goodrich, D., and Flanagan, D. (2010). Modeling erosion under future climates with the WEPP model. *In*: *Hydrology and sedimentation for a changing future: Existing and emerging issues; Proceedings of the 2nd Joint Federal Interagency Conference [9th Federal* *interagency sedimentation conference and 4th Federal interagency hydrologic modeling conference]; 27 June-1 July; Las Vegas, NV. 12 p.*

Bewket, W., and Teferi, E. (2009). Assessment of soil erosion hazard and prioritization for treatment at the watershed level: Case study in the Chemoga watershed, Blue Nile basin, Ethiopia. *Land Degradation and Development*, *20*(6), 609–622.

Bhattarai, R., and Dutta, D. (2007). Estimation of Soil Erosion and Sediment Yield Using GIS at Catchment Scale. *Water Resources Management*, *21*(10), 1635–1647.

Brueckner, J. K. (2009). *International Regional Science Review*.

Buttafuoco, G., Conforti, M., Aucelli, P. P. C., Robustelli, G., and Scarciglia, F. (2012). Assessing spatial uncertainty in mapping soil erodibility factor using geostatistical stochastic simulation. *Environmental Earth Sciences*, *66*(4), 1111–1125.

Correa, S. W., Mello, C. R., Chou, S. C., Curi, N., and Norton, L. D. (2016). Soil erosion risk associated with climate change at Mantaro River basin, Peruvian Andes. *Catena*, *147*, 110–124.

Demirci, A., and Karaburun, A. (2012). Estimation of soil erosion using RUSLE in a GIS framework: A case study in the Buyukcekmece Lake watershed, northwest Turkey. *Environmental Earth Sciences*, *66*(3), 903–913.

Elfert, S., and Bormann, H. (2010b). Simulated impact of past and possible future land use changes on the hydrological response of the Northern German lowland "Hunte" catchment. *Journal of Hydrology*, *383*(3–4), 245–255.

Evans, K.G., Loch, R.J., Aspinall, T.O., Bell, L.C., 1992. Spoil pile erosion prediction—How far have we advanced? In: Third Large Open Pit Mining Conference, Mackay, Queensland, . 201–205.

Glaeser, E. L., and Kahn, M. E. (2004). Sprawl and urban growth. In T. J. Henderson V (Ed.), *Handbook of regional and urban economics*: cities and geography, handbooks in economics. Elsevier, Amsterdan.

Hairsine, P., Rose, C. (1992). Modelling water erosion due to overland flow using physical principles: 2. Rill flow. Water Resources Research 28(1): 245–250.

Hörmann, G., Horn, A., and Fohrer, N. (2005). The evaluation of land-use options in mesoscale catchments: Prospects and limitations of eco-hydrological models. *Ecological Modelling*, 187: 3–14.

Hudson, N. W., 1975. The factors determining the extent of soil erosion. In: Greemland, R. (Ed.), Soil Conservation and Management in the Humid Tropics. John Wiley and Sons.

Khaleghpanah, N., Shorafa, M., Asadi, H., Gorji, M., and Davari, M. (2017). Corrigendum to "Modeling soil loss at plot scale with EUROSEM and RUSLE at stony soils of Khamesan watershed, Iran". *Catena*, *151*, 259.

Khosrokhani, M., and Pradhan, B. (2013). Spatio-temporal assessment of soil erosion at Kuala Lumpur metropolitan city using remote sensing data and GIS. *Geomatics, Natural Hazards and Risk*, *5705* (December), 1–19.

Klein, J., Jarva, J., Frank-Kamenetsky, D., and Bogatyrev, I. (2013). Integrated geological risk mapping: A qualitative methodology applied in St. Petersburg, Russia. *Environmental Earth Sciences*, *70*(4), 1629–1645Koomen, E., Rietveld, P., and Nijs, T. (2008). Modelling land-use change for spatial planning support.

The Annals of Regional Science, 42(1), 1–10.

Kouli, M., Soupios, P., and Vallianatos, F. (2009). Soil erosion prediction using the Revised Universal Soil Loss Equation (RUSLE) in a GIS framework, Chania, Northwestern Crete, Greece. *Environmental Geology, 57*(3), 483–497.

Lambin, E. F. (2004). Linking socioeconomic and remote sensing data at the community or at the household level. In *People and the Environment* (pp. 223–240). Springer, Boston, MA.

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.

Loch, R.J., Silburn, D.M., 1996. Constraints to sustainability—soil erosion. In: Clarke, L., Wylie, P.B. (Eds.), Sustainable Crop Pro- duction in the Sub-tropics: an Australian Perspective. QDPI.

Mallick, J., Alashker, Y., Mohammad, S. A.-D., Ahmed, M., and Hasan, M. A. (2014). Risk assessment of soil erosion in semi-arid mountainous watershed in Saudi Arabia by RUSLE model coupled with remote sensing and GIS. *Geocarto International, 29*(8), 915–940.

Mello, C. R. De, Norton, L. D., Pinto, L. C., Beskow, S., and Curi, N. (2016). Agricultural watershed modeling: a review for hydrology and soil erosion processes. *Ciência Agrotecnologia,* 40(1), 7-25.

Merritt, W. S., Letcher, R. A., Jakeman, A. J. (2003). A review of erosion and sediment transport models. *Environmental Modelling and Software,* 18 (2003) 761–799

Mondal, A., Khare, D., Kundu, S., Mukherjee, S., Mukhopadhyay, A., and Mondal, S. (2017). Uncertainty of soil erosion modelling using open source high resolution and aggregated DEMs. *Geoscience Frontiers,* 8(3), 425–436.

Mullan, D. (2013). Soil erosion under the impacts of future climate change: Assessing the statistical significance of future changes and the potential on-site and offsite problems. *Catena, 109*, 234–246.

Nejadhashemi, A. P., Wardynski, B. J., and Munoz, J. D. (2011). Evaluating the impacts of land use changes on hydrologic responses in the agricultural regions of Michigan and Wisconsin. *Hydrology and Earth System Sciences Discussions, 8*(2), 3421–3468.

Neupane, R. P., and Kumar, S. (2015). Estimating the effects of potential climate and land use changes on hydrologic processes of a large agriculture dominated watershed. *Journal of Hydrology,* 529(AUGUST), 418–429.

Pradhan, B., and Youssef, A. M. (2011). A 100-year maximum flood susceptibility mapping using integrated hydrological and hydrodynamic models: Kelantan River Corridor, Malaysia. *Journal of Flood Risk Management, 4*(3), 189–202.

Pradhan, B., and Buchroithner, M. (Eds.). (2012). Terrigenous Mass Movements: Detection, Modelling, Early Warning and Mitigation Using Geoinformation Technology. Springer Science and Business Media.

Prasannakumar, V., Vijith, H., Abinod, S., and Geetha, N. (2012). Estimation of soil erosion risk within a small mountainous sub-watershed in

Kerala, India, using Revised Universal Soil Loss Equation (RUSLE) and geo-information technology. *Geoscience Frontiers, 3*(2), 209–215.

Segura, C., Sun, G., McNulty, S., and Zhang, Y. (2014). Potential impacts of climate change on soil erosion vulnerability across the conterminous United States. *Journal of Soil and Water Conservation, 69*(2), 171–181.

Serpa, D., Nunes, J. P., Santos, J., Sampaio, E., Jacinto, R., Veiga, S., … and Abrantes, N. (2015). Impacts of climate and land use changes on the hydrological and erosion processes of two contrasting Mediterranean catchments. *Science of the Total Environment, 538*, 64–77.

Sorooshian, S., (1991). and model validation: conceptual type models. In: Bowles, D.S., O'Connell, P.E. (Eds.), Recent Advances in the Modelling of Hydrological Systems. Kluwer Academic, pp. 443– 467.

Sukhanovskii, Y. P. (2010). Rainfall Erosion Model. *Eurasian Soil Science, 43*(9), 1036–1046.

Terranova, O., Antronico, L., Coscarelli, R., and Iaquinta, P. (2009). Soil erosion risk scenarios in the Mediterranean environment using RUSLE and GIS: An application model for Calabria (southern Italy). *Geomorphology,* 112(3–4), 228–245.

Van Rompaey, A. J. .J., Verstraeten, G., Van Oost, K., Govers, G., Poesen, J., 2001. Modelling mean annual sediment yield using a dis- tributed approach. Earth Surface Processes and Landforms 26, 1221e1236.

Velleux, M. L., England, J. F., and Julien, P. Y. (2008). TREX: Spatially distributed model to assess watershed contaminant transport and fate. *Science of the Total Environment, 404*(1), 113–128.

Wang, G., Hapuarachchi, P., Ishidaira, H., Kiem, A. S., and Takeuchi, K. (2009). Estimation of soil erosion and sediment yield during individual rainstorms at catchment scale. *Water Resources Management,* 23(8), 1447–1465. Weifeng, Z. H. O. U., and Bingfang, W. U. (2008). Assessment of soil erosion and sediment delivery ratio using remote sensing and GIS: a case study of upstream Chaobaihe River catchment, north China. *International Journal of Sediment Research*, 23(2), 167-173.

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

Zhang, Y., Degroote, J., Wolter, C., and Sugumaran, R. (2009). Integration of modified universal soil loss equation (MUSLE) into a GIS framework to assess soil erosion risk. *Land Degradation and Development*, 20(1), 84–91.

Zhou, W. and Wu, B. (2008). Assessment of soil erosion and sediment delivery ratio using remote sensing and GIS: a case study of upstream Chaobaihe River catchment, north China. *International Journal of Sediment Research*, 23 (2008) 167-173.