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Soil Erosion: A Review of Models and Applications

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***Abstract*— *Soil erosion is a global environmental problem influenced by both natural and human factors. Modeling provides a quantitative and consistent approach to estimate soil erosion and sediment yield under a wide range of conditions, and is needed to guide the comprehensive control of soil erosion. Over the years various soil erosion models have been developed. The application of these models is dependent on the soil type and climate of the given area because models differ in complexity and input requirements. This paper reviews various soil erosion models and their applications, focusing more on the most widely applied models which are: Universal Soil Loss Equation (USLE), Revised Universal Soil Loss Equation (RUSLE) and Water Erosion Prediction Project (WEPP). The method used for this research is a review of academic articles, bulletins, conference papers, textbooks, research reports and publicly available materials on soil erosion models and their applications. The results of this study revealed that most soil erosion models have been developed for the assessment of rill and interill erosion at plot or catchment scale on agricultural lands and watersheds in terms of estimating mostly soil loss, sediment yield, erodibility (K) values, rainfall factor (R) factors, runoff rates and forecasts of likely impacts. Again, the study indicated that most previous authors on soil erosion assessment used the empirical models due to their limited data and parameter inputs. Recommendations of this study include: (1) expansion of the USLE and RUSLE models for the simulation of gully erosion and sediment processes; (2) researchers should be encouraged through grants to develop empirical models (that make use of limited data) based on rainfall (R) factor and erodibility (K) factor that provide two opposing forces in soil erosion processes; and (3) management of soil erosion based on the indigenous knowledge of the affected people and land holders.*

Keywords*— Applications, Environmental Sustainability, Models, Review, Soil, Erosion, USLE.

I. INTRODUCTION

Soil erosion is one of the most serious environmental problems in the world today because it threatens agriculture and also the natural environment (Shougang, Na and Ruishe, 2014). Soil erosion has become one of the global environmental hazards that limits today's human survival and restricts global socio-economic sustainable development (Han, Ren, Zhang and Li, 2016). Land degradation due to erosion processes incurs substantial costs both for individual farmers and for society as a whole (Phai, Orange, Migraine, Toan and Vinh, 2006).

With growing pressure on natural resources and landscapes, there is an increasing need to predict the consequences of any changes to the environment (Shougang *et al*, 2014). They further stated that modelling plays an important role in this by helping our understanding of the environment and by forecasting likely impacts. Soil erosion models are useful to estimate soil loss and runoff rates from agricultural land, to plan land use strategies, to provide relative soil loss indices and to guide government policy and strategy on soil and water conservation (Smith, 1999). Effective modelling can provide information about current erosion, its trends and scenario analysis (Ganasri and Ramesh, 2016).

Soil erosion prediction technology began over 70 years ago, but it was in 1965 that the work expanded into the Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith, perhaps the foremost achievement in soil erosion prediction (Laflen and Flanagan, 2013). Since then several models have been developed to simulate soil erosion prediction process. They all consider slope steepness, slope length, vegetative cover, rainfall, soil properties and erosion control methods as parameters which influence erosion (Smith, 1999). Erosion models utilize the various factors that affect erosion to simulate erosion processes in order to predict the levels of erosion in a region (Anejionu, Nwilo and Ebinne, 2013). They opined that insights could be drawn from present and future trends of erosion impacts in a region with these models. Various studies on erosion models have clearly demonstrated that the dominant factor contributing to sediment discharge is the erosive power of rainfall (Phai *et al*, 2006).

Soil erosion models fall into three main categories, depending on the physical processes simulated by the model, the model algorithms describing these processes and the data dependence of the model: Empirical or Statistical; Conceptual; and Physics based models (Merrit, Letcher, and Jakeman, 2003). They further stated that empirical models are the simplest of all models as they can be implemented in situations with limited data and parameter inputs, and are particularly useful as a first step in identifying sources of sediment and nutrient generation. Examples of empirical models include the Universal Soil Loss Equation (USLE) and its derivates (Revised Universal Soil Loss Equation, RUSLE and Modified Universal Soil Loss Equation, MUSLE) (Tesfahunegn, 2011). In conceptual models, sediment producing factors such as rainfall and runoff are treated as inputs to the system and sediment yield is output (Chandromohan, Venkatesh, and Balchand, 2015). Agricultural Non-Point Source Pollution (AGNPS) developed in 1985 to evaluate potential problems on agricultural watersheds is an important example of conceptual models (Jaramilo, 2007). Physically-based models provide an understanding of fundamental sediment producing processes and have the capability to access the spatial and temporal variations of sediment entrainment, transport and deposition processes (Chandramohan *et al*, 2015). They described processes involved with the help of mathematical equations dealing with the laws of conservation of energy and mass (Morgan, 2005). An important and commonly used example of this model is the Water Erosion Prediction Project (WEPP). Most models predict soil erosion based on the major factors of soil erosion, these factors are: rainfall erosivity represented by R, soil erodibility represented by K, topography represented by LS, and land use and management represented by C and P (Lee and Lee, 2006) as shown in the equation:

$$A=RKLSCP$$

Models differ greatly in application, requirements, intended use and type of information they provide (Merritt *et al*, 2003). Therefore, this study is focused on a review of soil erosion models and applications.

1.1 Statement of the Problem

Fundamental difficulties in distributed erosion modelling arise from the natural complexity of landscape systems, from spatial heterogeneity and from lack of available data (Merritt *et al*, 2003). Much work has been done on soil erosion assessment at plot or catchment scale, however the quantitative assessment of spatially distributed soil erosion has not been adequately addressed and more work should be done on the soil erosion prediction (Han *et al*, 2016). The main problem in relation to erosion risk models is validation because of scarcely available data for comparing estimates of the models with actual soil loss (Ganasri and Ramesh, 2016).

Empirical models have constraints of applicability to regions and ecological conditions other than from which data were used in their development (Merritt *et al*, 2003). According to Smith (1999), empirical models are of great benefits in many situations given that they are to a large extent the only models that could be run with little available data. In his opinion, their disadvantages are that they: (1) are based on statistical analysis of important factors in the soil erosion process and yield only approximate and probable outcome; (2) are not practical for the prediction of soil loss on an event basis; (3) estimate soil erosion on single slope, instead of within catchments; (4) do not represent the process of sedimentation; (5) are restricted to sheet and/or rill erosion; and (6) soil losses and gains over neighbouring areas are not considered.

Physically based models are generally the most scientifically robust and flexible in both input and output and are based on an understanding of the physical processes that cause erosion and are therefore applicable to a wide range of soils, climatic and land use conditions (Lily, Grieve, Jordan, Baggaley, Birnie, Futter, Higgins, Hough, Jones, Noland, Stutter and Towers, 2009). They further asserted that this however, means that they are often difficult to parametise. Similarly, Ganasri and Ramesh (2016) agreed that physically-based models are data intensive and the amount of data needed is not readily available.

Conceptual models 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). Placed somewhere in between empirical and physically-based models, conceptual models reflect the physical processes governing the system but describe them with empirical relationships, e.g., Agricultural Non-Point Source (AGNPS) (Tesfahunegn, 2011). According to him, these models have the inherent limitations of the empirical models and also require relatively detailed data for calibration.

1.2 Objective

The objective of this study is to review various soil erosion models and their applications.

II. CONCEPTUAL FRAMEWORK: ENVIRONMENTAL SUSTAINABILITY

This research is based on the concept of environmental sustainability. Environmental sustainability could be defined as a condition of balance, resilience, and interconnectedness that allows human society to satisfy its needs while neither exceeding the capacity of its supporting ecosystems to continue to regenerate the services necessary to meet those needs nor by our actions diminishing biological diversity (Morelli, 2011).

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Environmental sustainability is the ability to maintain the qualities that are valued in the physical environment so as to ensure sustainable development (Sutton, 2014).

The World Conference on Environment and Development (WCED) (1987) defined sustainable development as development that meets the needs of the present without compromising the ability of future generations to meet their own needs. This research sets to review soil erosion models and their applications so as to make recommendations that will build sustainability into soil erosion management.

III. METHOD

The researchers were able to collect thirty-six (36) materials for this research but summarised the characteristics of ten (10) that were deemed to have addressed more soil erosion models and their applications for the review. This research made use of a review of academic articles, textbooks, bulletins, internet materials, news articles and publicly available materials on soil erosion models and their usefulness in predicting and managing soil erosion.

IV. LITERATURE REVIEW OF RELATED WORKS

Modelling is a useful tool for erosion scenario assessment that enables the adequate selection of erosion control measures (Moehansyah, Maheshwar and Armstrong, 2004). A wide range of models exists for use in simulating sediment transport and associated pollutant transport and these models differ in terms of complexity, processes considered and the data required for model calibration and model use (Merritt *et al*, 2003). They noted that choice of a suitable model structure relies heavily on the function that the model needs to serve.

Numerous erosion models such as Universal Soil Loss Equation (USLE), Revised Universal Soil Loss Equation (RUSLE), Coordination of Information on the Environment (CORINE), Water Erosion Prediction Project (WEPP), Pan-European Soil Erosion Risk Assessment (PESERA), Kinematic Runoff and Erosion Model (KINEROS), and Erosion Potential Model (EPM) have been developed and applied in various regions of the world (Anejionu *et al*, 2013). According to Smith (1999) the most widely applied soil loss models are the USLE, its improved version the Revised Universal Soil Loss Equation (RUSLE), and the Soil Loss Estimation model of Southern Africa (SLEMSA). Other widely applied models include: the Morgan, Morgan and Finney model (MMF), Agricultural Non-Point Source Pollution (AGNPS), Areal Nonpoint Source Watershed Environment Response Simulation (ANSWERS) and Chemicals, Runoff and Erosion from Agricultural Management Systems (CREAMS) (Jaramilo, 2007). ANSWERS and CREAMS are basically conceptual and event based models (Ganasri and Ramesh, 2016).

According to Merritt *et al* (2003) each model type serves a purpose, and a particular model type may not categorically be considered more appropriate than others in all situations. In their review of soil erosion and transport models, they summarised the various soil erosion models (Table 1).

Table.1: Erosion/sediment transport models

Model	Type	Scale	Input/output
Water quality AGNPS	Conceptual	Small Catchment	Input requirements: High Output: runoff volume; peak rates, SS, N, P, and COD concentrations.
ANSWERS	Physical	Small Catchment	Input requirements: High Output: sediment, nutrients
CREAMS	Physical	Field 40-400 ha	Input requirements: High Output: erosion; deposition
EMSS	Conceptual	Catchment	Input requirements: Low Output: runoff, sediment loads, nitrogen loads and phosphorus loads.
HSPF	Conceptual	Catchment	Input requirements: High Output: runoff, flow rate, sediment load, nutrient concentration.
IHACRES-WQ	Empirical/ Conceptual	Catchment	Input requirements: Low Output: runoff, sediment and nutrients.
IQQM	Conceptual	Catchment	Input requirements: Moderate Output: many pollutants including nutrients, sediments, dissolved oxygen, salt, algae.
LASCAM	Conceptual	Catchment	Input requirements: High Output: runoff, sediment, salt fluxes.
SWRRB	Conceptual		Input requirements: High Output: stream flow, sediment, nutrient and pesticide yields.
Erosion GUEST	Physical	Plot	Input: High Output: runoff, sediment concentration
LISEM	Physical	Small Catchment	Input: High Output: runoff; sediment yield.

Model	Type	Scale	Input/output
PERFECT	Physical	Field	Input: High Output: runoff, erosion, crop yield.
SEDNET	Empirical/ Conceptual	Catchment	Input requirements: Moderate Output: suspended sediment, relative contributions from overland flow, gully and bank erosion processes
TOPOG	Physical	Hillslope	Input: High Output: water logging, erosion hazard, solute transport.
USLE	Empirical	Hillslope	Input: High Output: erosion
WEPP	Physical	Hillslope/Catchment	Input: High Output: runoff, sediment characteristics; form of sediment loss.
In-stream transport MIKE-11	Physical	Catchment	Input: High Output: sediment yield, runoff

4.1 Universal Soil Loss Equation (USLE)

The USLE is an empirical soil model developed by Wischmeier and Smith, (1978). Originally, USLE was developed mainly for soil erosion estimation in croplands or gently sloping topography (Ganasri and Ramesh, 2016). The USLE quantifies soil erosion as the product of six factors representing rainfall and runoff erosivity (R), soil erodibility (K), slope length (L), slope steepness (S), cover and management practices (C), and supporting conservation practices (P) (Renard and Freimund, 1994). This empirical equation is based on the statistical analysis of more than 10,000 plot-years of data of sheet and rill erosion on plots and small watersheds (Roose, 1977). The equation is:

$$A = RKSLCP$$

in which erosion (A) is the estimated soil loss per unit area, R is the rainfall-runoff erosivity ∑factor, K is the soil erodibility factor, L is the slope length factor, S is the slope steepness factor, C is the cover management factor, and P is the supporting practices factor (Wischmeier and Smith, 1978).

The model predicts rainfall based on rainfall erosivity (R factor) and soil erodibilitty (K factor). Bols (1978) proposed a formular for calculating the R factor in Indonesia in a model:

$$R = \frac{2.5P^2}{100(0.073P+0.73)}$$

where P = Annual precipitation in millimetres and R is in $MJmmha^{-1}hr^{-1}yr^{-1}$

The soil erodibility index is calculated with the following equation (Roose, 1977):

$$K = \frac{A}{R \times SL \times 2.24}$$

where A is the erosion in tons per hectare, R is the rainfall erosivity index, SL is the topographic factor, and 2.24 the coefficient necessary to go from metric units (t/ha) to English units (t/acre).

Although the simplicity of this equation and the availability of parameter values have made this model relatively easy to use, there are a number of limitations to the USLE. As with most empirical models, the USLE is not event responsive, providing only an annual estimate of soil loss as 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 (Merritt *et al*, 2003). They asserted that the model is not event-based and as such cannot identify those events most likely to result in large-scale erosion. Applying the equation to purposes for which it was not intended, however, cannot be recommended (Wischmeier 1978). Since it was designed for interrill and rill erosion, it should not be used to estimate sediment yield from drainage basins or to predict gully or stream-bank erosion (Morgan, 2005). He reported that care should be taken in using it to estimate the contribution of hill slope erosion to basin sediment yield because it does not estimate deposition of material or incorporate a sediment delivery ratio. In his opinion, since the equation was developed to estimate long-term mean annual soil loss, it cannot be used to predict erosion from an individual storm.

4.2 The Revised Universal Soil Loss Equation (RUSLE)

The RUSLE has been revised to more accurately estimate soil loss from both crop and rangeland areas (McCool, Foster, Renard, Yoder, and Weesies, 1995). The RUSLE maintains the basic structure of the USLE but is a computerized version that incorporates the results of additional research and experience obtained since the 1978 publication of USLE by Wischmeier and Smith (Renard and Friedmund, 1994). The equation is:

$$A = R.K.L.S.C.P$$

where A is the computed soil loss, R is the rainfall-runoff erosivity factor plus a factor for any significant runoff from snow melt expressed in MJ mm $ha^{-1}h^{-1}yr^{-1}$; K is the soil erodibility factor – the soil-loss rate per erosion index unit for a specified soil as measured on a standard plot which is defined as a 72.6-ft (22.1m) length of uniform 9% slope in continuous clean-tilled fallow expressed in t

ha^{-1} MJ mm^{-1}; L is the slope length factor – the ratio of soil loss from the field slope length to soil loss from the field slope length to soil loss from a 72.6-ft length under identical conditions; S is the slope steepness factor – the ratio of soil loss from the field slope gradient to soil loss from a 9% slope under otherwise identical conditions; C is the cover management factor – the ratio of soil loss from an area with specified cover and management to soil loss from an identical area in tilled continuous fallow; and P is the supporting practices factor – the ratio of soil loss with a support practice like contouring, strip cropping, or terracing to soil loss with straight-row farming up and down the slope (Ganasri and Ramesh, 2016). The product of these factor values gave the expected soil loss in $tha^{-1}yr^{-1}$ (A), depending on the dimensions used in the climate and soil factor (Le Roux, 2005).

Like in the USLE, rainfall erosivity and soil erodibility are major factors in soil erosion prediction using the RUSLE model. Lee and Lee used the Toxopeus equation, which is well known for its superiority in Korea (Korea Institute of Construction Technology (KICT) (1992), was used to calculate rainfall erosivity factor, R as follows;

$$R = 38.5+0.35\times Pr$$

where, R is rainfall erosivity factor (in $MJmmha^{-1}yr^{-1}$) and Pr is the annual average rainfall (in $mmyr^{-1}$).

Le Roux (2005) in his study used the modified Fournier's Index developed by the FAO (Arnoldus, 1980) to estimate the R-factor values for each of the rainfall zone due to insufficient rainfall intensity data. The equation is given as:

$$R = 0.0302 \text{ x } (RI)^{1.9}$$

where RI = $\sum$ (MR)2/AR, MR is monthly rainfall in mm, and AR is annual rainfall in mm.

Normally nomograph is used to determine K factor for a soil, based on its texture, % silt plus very fine sand, % sand, % organic matter, soil structure, and permeability (Wischmeier and Smith, 1978). Ganasri and Ramesh (2016) used the equation developed by Wischmeier and Smith (1978), given as:

$$K = 27.66 \text{ x } m^{1.14} \text{ x } 10^{-8} \text{ x } (12 - a) + 0.0043 \text{ x } (b - 2) + 0.0033 \text{ x } (c - 3)$$

m = silt (in %) + very fine sand (in %) x (100 - clay (in %))

a = Organic matter (%)

b = structured code in which (1) is very structured or particulate, (2) is fairly structured, (3) is slightly structured, and (4) is solid

c = profile permeability code in which (1) is rapid, (2) is moderate to rapid, (3) is moderate, (4) is moderate to slow, (5) is slow and (6) is very slow.

Recent efforts have been made to incorporate other forms of erosion into the RUSLE equation such as the one developed in Indonesia (Penning de Vries *et al*, 1998) where the equation below was used to estimate the total annual yield Y in tonne. $ha^{-1}.yr^{-1}$ for a 130,000-ha watershed:

$$Y = A*SDR + Gl + Sb + Rs + L1$$

In this equation, A is the annual soil loss given by RUSLE in ton $ha^{-1}yr^{-1}$, SDR is a Sediment Delivery Ratio, and *Gl*, *Sb*, *Rs* and *L1* are gully, stream bank, road side and other forms of erosion respectively in ton $ha^{-1}yr^{-1}$ (Jaramilo, 2007). He reported that these last parameters are difficult to calculate and require complex measuring techniques and therefore it is uncertain if the addition of these sub-factors improves the accuracy of the soil loss estimates in a practical manner. An additional change incorporated in RUSLE is to account for rock fragments on and in the soil, a common occurrence on western US rangelands and croplands in many areas of the world (McCool *et al*, 1995). According to them rock fragments on the soil surface are treated like mulch in the C-factor, while K is adjusted for rock in the soil profile to account for effects on runoff.

With the RUSLE model, the average annual rate of soil loss for a site of interest can be predicted for any number of scenarios in association with cropping systems, management techniques, and erosion control practices (Lee and Lee, 2006). Being an empirical model, RUSLE does not take into account runoff or the processes of detachment, deposition or transport of sediment (Jaramilo, 2007). He opined that RUSLE is focused on determining erosion loss on landscapes where significant overland runoff occurs such as clear land, but was not originally designed for natural forested areas, where no overland runoff occurs or where it is limited and other types of erosion such as stream bank and gully erosion are not included.

4.3 The Soil Loss Estimator for Southern Africa (SLEMSA)

SLEMSA is similar in structure to that of the RUSLE using similar parameters (Le Roux, 2005). SLEMSA was developed largely from data from the Zimbabwe Highveld to evaluate the erosion resulting from different farming systems so that appropriate conservation measures could be recommended, the technique has since been adopted throughout the countries of Southern Africa (Morgan, 2005). The equation is (Elwell 1978):

$$Z = K \text{ x } X \text{ x } C$$

where Z is predicted mean annual soil loss (t $ha^{-1}yr^{-1}$), K is mean annual soil loss (t $ha^{-1}yr^{-1}$) from a standard field plot, 30m long, 10m wide, at 2.5° slope for a soil of known erodibility (F) under a weed-free bare fallow, X is a dimensionless combined slope length and steepness factor and C is a dimensionless crop management factor.

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The factor K accounts for soil erodibility (F) and rainfall energy (E). The erodibility value F was modified according to management practices that influence soil properties. Using the F values, values of K are derived from the equation (Elwell, 1976):

$$\ln K = b \ln E + a$$

where a = 2.884 – 8.1209 F; and b = 0.74026 – 0.09436 a; and

$$E = 9.28\ P - 8.838$$

where E is mean annual rainfall energy in Jm^{-2}, and P is mean annual precipitation in mm.

Although SLEMSA uses similar parameters to the RUSLE a notable difference between these two models is the definition of K as the rate of soil loss per unit of erosivity (Morgan, 2005). He reported that in SLEMSA the K-factor is dependent on rainfall energy, to which it is exponentially rather than linearly related, as well as the dimensionless soil erodibility index F. He further stated that SLEMSA treats the soil erosion factors as separate entities and this is an advantage over the RUSLE where interactions between model components can cause complications.

4.4 The Agricultural Non-Point Source model (AGNPS)

It is a non-point source pollution model developed by the US Department of Agriculture, Agricultural Research Service (USDA-ARS) in cooperation with the Minnesota Pollution Control Agency and the Soil Conservation Service (SCS) in the USA (Young, Onstad, Bosch and Anderson, 1989). They reported that it is an event based model that simulates runoff, sediment and nutrient transport from agricultural watersheds. The model was developed to predict and analyse the water quality of runoff from rural catchments ranging from a few to over 20 000 hectares (Merritt *et al*, 2003). They noted that the model utilises components of existing models in its structure including the RUSLE for predicting soil loss in grid cells.

The Agricultural Non-Point Sources Pollution (AGNPS) model is a mathematical model based on the functional relationships between the influential factors in the drainage basin (Nugroho, 2003). The AGNPS model can simulate surface runoff and sediment and nutrient transport in a drainage basin dominated by agricultural activity (Young, Onstad, Bosch and Anderson, 1995). Runoff in a catchment is simulated using the SCS curve number method, an empirical rainfall-runoff modelling technique developed in the United States by the Soil Conservation Service (SCS) (1972).

The AGNPS model can be applied in the planning stage of drainage basin management, so that environmental degradation and critical land can be identified and analysed (Nugroho. 2003). The greater data requirements and computational complexity of AGNPS compared with empirical models must be weighed against the added modelling capabilities of the model (Merrit *et al*, 2003).

4.5 Water Erosion Prediction Project

The Watershed Erosion Prediction Project (WEPP) is a physics-based model developed in the United States in an initiative between the Agricultural Research Service, the Soil Conservation Service, the Forest Service in the Department of Agriculture and the Bureau of Land Management in the US Department of the Interior (Natural Science and Engineering Research Laboratory (NSERL) (1995). The overall package contains three computer models: a profile (hillslope) version, a watershed version and a grid model (Morgan, 2005). The hillslope version of WEPP contains nine components: weather generation, winter processes, irrigation, surface hydrology and water balance, subsurface hydrology, soils, plant growth, residue decomposition, overland-flow hydraulics, and erosion (Pieri, Bitelli, Wu, Dun, Flanagan, Pisa, Ventura and Salvatorelli, 2006). They reported that the WEPP model requires four input files: topography, climate, soil and management. The erosion model within WEPP applies the continuity equation for sediment transport down slope in the form (Foster & Meyer 1972):

$$\frac{dQs}{dx} = D_i + D_f$$

where Qs is the sediment load per unit width per unit time, x is the distance downslope, D_i is the delivery rate of particles detached by interrill erosion to rill flow and D_f is the rate of detachment or deposition by rill flow.

The basic output contains the runoff and erosion summary on a storm-by-storm, monthly, annual and average annual basis (Merritt *et al*, 2003). One difference between the WEPP model and other models is that the sediment continuity equation is applied within rills rather than using uniform flow hydraulics (Han *et al*, 2016). They reported that further study on the spatial variability of soil and vegetative cover is needed to successfully model larger areas.

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Table.2: Summary of some of the Studies that Described Soil Erosion Models and their Applications

S/N	Author(s)	Title	Model Developed/ Applied	Result(s)	Recommendation(s)	Conclusion
1	Ganasri and Ramesh (2016)	Assesment of Soil Erosion by RUSLE model using Remote Sensing and GIS – A case study of Nethravathi Basin	Applied RUSLE model	It is found that the soil loss of 473,339t per estimated by RUSLE model using land use-land cover of 2003 was almost matching with the measured sediment load of 441,870t during 2002-2003.	The results obtained from this study should be used in developing management scenarios and provide options to policy makers for managing soil erosion hazards in the most efficient manner.	GIS is a valuable tool in assessing soil erosion and estimation of erosion loss as the model result reasonably matched with observed data.
2	Han et al (2016)	The WEPP Model Application in a Small Watershed in the Loess Plateau	Applied WEPP model	By comparing the measured and simulated values of runoff and soil erosion under different vegetation cover amounts, the results showed that the WEPP-simulated runoff and sediment yield predictions are relatively consistent with the measured values at slope scale but at watershed scale both the simulated values of runoff and erosion were higher than the measured.	The model can simulate erosion distribution due to different soil and land use types, which can be used to plan vegetation establishment, and then reduce erosion through planting vegetation in the areas with the greatest erosion.	Although the WEPP stimulated erosion and runoff values at the watershed scale were greater than observed values, the simulated erosion trends after returning farmland clearly showed the benefit of replacing croplands with a perennial forage crop. So it can be used to guide the restoration of Loess Plateau and establish a reasonable vegetation layout mode.
3	Lee and Lee (2006)	Scaling Effect for Estimating Soil Loss in the RUSLE Model using Remotely Sensed Geospatial Data in Korea	Applied RUSLE model	Because there is large discrepancy (157% overestimated) between the observed and the estimated, the simulated soil loss by RUSLE is not acceptable.	The spatial resolution is very sensitive to the estimation of soil loss in the RUSLE model. It implies that caution needs to be taken in selecting the grid size for estimating soil loss using numerical modeling approach.	The optimum resolution for soil loss comes out to be 125m in this study but it might be dependent on the selection of model, the quality of geospatial data, and the basin characteristics.

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S/N	Author(s)	Title	Model Developed/ Applied	Result(s)	Recommendation(s)	Conclusion
4	Le Roux (2005)	Soil Erosion Prediction under Changing Land Use on Mauritius	Applied RUSLE and SLEMSA models	The RUSLE predicted a total of 4229 tons of soil to be relocated by soil erosion under present land cover conditions in the RDAC. SLEMSA predicted the total to be 10 times higher at 46316 tons. These totals depend on the surface area covered by each land use. Within both models, soil loss results for identical cropping systems deviated greatly.	Intensive cultivation of the upper catchment area, might lead to accelerated rates of erosion. Therefore, the upper catchment area should be regarded as highly sensitive, which renders it unsuitable for cultivation without proper conservational measures.	RUSLE soil loss results were much lower compared to SLEMSA results, SLEMSA results were three to ten times higher compared to RUSLE predictions. Soil loss results predicted by SLEMSA were excessively high for scrub growing on the upper area of the catchment.
5	Nugroho (2003)	Application of the Agricultural Non-Point Source Pollution (AGNPS) Model for Sediment Yield and Nutrient Loss Prediction in the Dumpul Sub-watershed, Central Java, Indonesia	Applied AGNPS model	The results of simulation in the Dumpul sub-drainage basin show that the absence of soil and water conservation activities has the effect of increasing runoff volume, peak discharge, sediment yield, and nutrient loss (N, P, COD)	The AGNPS model can be applied in the planning stage of drainage basin management, so that environmental degradation and critical land can be identified and analysed. By using the AGNPS model, soil and water conservation practices can be adjusted to the bio-geophysical conditions in the drainage basin.	Soil and water conservation practices, 2such as contouring ridges, in all cropland will reduce runoff volume, peak discharge, sediment yield, and nutrient loss.
6	Pieri et al (2006)	Using the Water Erosion Prediction Project (WEPP)	Applied WEPP model	Results indicated that WEPP could adequately simulate the water balance for the model plot.	Future WEPP application efforts may involve a thorough assessment and appropriate calibration of the erodibility	WEPP proved to be a useful tool for evaluating the impact of cropping systems and management practices on water

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S/N	Author(s)	Title	Model Developed/ Applied	Result(s)	Recommendation(s)	Conclusion
		Model to Simulate Field-observed Runoff and Erosion in the Appenines Mountain Range, Italy		Comparison between WEPP-simulated and field measured sediment yields suggested that WEPP tends to under-predict sediment yield.	parameters in order to improve erosion prediction for the study site.	balance and soil erosion.
7	Renard and Freimund (1994)	Using Monthly Precipitation to Estimate R-Factor in the Revised USLE.	Developed RUSLE model	When all 155 stations were considered, neither average annual precipitation nor the modified Fournier index correlated well with R-values (r^2 = 0.041 and 0.29 respectively).	Similar to the relations developed using mean annual precipitation, a composite relation could provide the best fit over the range of modified index values.	While the estimated values could be considerably in error, and the predicted soil loss may be far from exact, they may be the best available for at least assessing the erosion potential or relative erosion rates from different conditions (such as management or crop) or soils.
8	Roose (1977)	Use of the Universal Soil Loss Equation to Predict Erosion in West Africa.	Applied USLE model	It predicts sheet and rill erosion on hilly slopes and neither approaches neither the problem of flow nor that of transport in solution and neglects the qualitative aspect of eroded materials.	The erosivity index accurately takes into account the interactions of amount, intensity, and duration of rainfall on solid transport. However, a soil moisture index could be added to it expressing this condition before the rain.	To be of maximum use in West Africa, data is needed to modify the Wischmeier-Smith equation for soils with swelling clays; for mountainous regions of recent origin, where gully erosion predominates; and Mediterranean zones, where unusually intense rains are important. However, this equation seems to be well adapted to the majority of cultivated soils in West Africa and to the moderate slopes on ferrallitic and ferruginous tropical soils in particular.

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S/N	Author(s)	Title	Model Developed/ Applied	Result(s)	Recommendation(s)	Conclusion
9	Young et al (1989)	AGNPS: A Nonpoint Source Pollution Model for Evaluating Agricultural Watersheds.	Developed AGNPS model	Sediment yield estimates from the model compared favourably with the measured values from the three watersheds. Also, the performance of the model in estimating runoff and sediment yield compared favourably with that of several other current models when tested on three different types of watershed in Mississippi.	Accuracy of results can be increased by reducing the cell size, but this increases the time and labour required to run the model.	General land use and topographic factors for the whole area contributed to high sediment yields.
10	Wischmeier and Smith (1978)	Predicting Rainfall Erosion Losses- A Guide to Conserving Planning,	Developed USLE model	Soil loss equations are substantially less accurate for prediction of specific events than for the prediction of long time averages.	Since it was designed for interrill and rill erosion, applying the equation to purposes for which it was not intended was not recommended	The USLE is designed to predict long-time average soil losses for specified conditions. 90% of erosion on the steeply rolling wheat land was estimated to derive from runoff.

Source: Researchers' design, 2017.

V. RESULTS AND DISCUSSION

As a result of problems arising from soil erosion and land degradation, various models have been developed for estimation and simulation of soil erosion. Based on the review of previous studies on soil erosion modes and applications, the following results were obtained as summarised in Table 2. Although simple to apply, USLE and RUSLE are empirical models and therefore cannot be used to simulate erosion on an event basis. Roose (1977) reported that USLE predicts sheet and rill erosion on hilly slopes and approaches neither the problem of flow nor that of transport in solution and neglects the qualitative aspect of eroded materials. Present USLE soil loss equations are substantially less accurate for prediction of specific events than for the prediction of long time averages (Wischmeier and Smith, 1978). Similarly, Renard and Frerimund (1994) agreed that the most accurate estimate of R-values for both USLE and RUSLE can only be obtained from long-term rainfall intensity data. In the opinion of Ganasri and Ramesh (2016), RUSLE is sensitive to land use - land cover as result obtained matched reasonably with observed data.

In their application of the WEPP model, Han *et al.* (2016) observed that the WEPP-simulated runoff and sediment yield predictions were relatively consistent with the measured values at slope scale but at watershed scale both the simulated values of runoff and erosion were higher than the measured. Pieri *et al.* (2006) held the same view that WEPP could adequately simulate the water balance for the model plot but further stated that comparison between WEPP-simulated and field measured sediment yields suggested that WEPP tends to under-predict sediment yield. Chandramohan *et al.* (2015) noted that the model under-predicted soil loss because of the large data requirement and many number of model parameters related to soil and crop management which is impractical to collect or measure in studies of large scale. Its major advantage over empirical models is that being a physically-based model, it takes into account processes/events that influence erosion. Therefore, the limitations of the models both in coverage and applications call for development of more models that will estimate and simulate soil loss/sediment yield for rill, interrill, and gully erosion based on the factors that trigger them, particularly the rainfall (R) factor and erodibility (K) factor which are two opposing forces in rain splash-sheet-rill-gully erosion processes.

VI. RECOMMENDATIONS

From the results of literature review of soil erosion models and application, the following recommendations are hereby made:

1. USLE and RUSLE models should be expanded to incorporate physical processes and also parameters should be included that will enable them simulate gully erosion and sediment processes.
2. The WEPP model has only been successfully used in predicting sediment yield for small catchment areas and therefore parameters used in the model should be adjusted and made more practical to facilitate soil erosion prediction in large areas and watersheds.
3. Researchers should be encouraged through grants by governments donor agencies and non-governmental organizations (NGOs) to develop empirical models for the quantitative computation of soil loss based on rainfall (R) factor and erodibility (K) factor that provide the two opposing forces in soil erosion processes.
4. Management of soil erosion that will be based on the indigenous knowledge of the affected people and landholders as adaptive techniques are desirable. This will help to reduce occurrences of soil erosion.

VII. CONCLUSION

This paper discussed soil erosion models and their applications by reviewing the previous works done on soil erosion models. Previous authors agreed that USLE is the simplest model to apply and can be applied in various land areas but cannot be used to simulate stream bank and gully erosion because it was not originally made for naturally forested areas. They also agreed that topographic factors and general land use contributes to high erosion and sediment yield. Authors that studied the WEPP model concurred that it has a high level of prediction accuracy but cannot be used for large scale erosion prediction. Based on the review and results of this study, it is therefore concluded that given the limitations of the existing soil erosion models and their applications, more research is needed to develop robust models that will fill the gaps. Additionally, management of soil erosion should be driven by the affected people and landholders who are capable of identifying rill erosion at its early stage and could be encouraged through grants to stem it from developing into gully erosion through some adaptive measures based on their indigenous knowledge.

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REFERENCES

[1] Anejionu, O.C.D., Nwilo, P.C., and Ebinne, E.S. (2013). Long Term Assessment and Mapping of Erosion Hotspots in South East Nigeria. TSO 3B – Remote Sensing for Land use and Planning – 6448, *FIG Working Week*, 2013.

[2] Arnoldus, H. M. J. (1980) An Approximation of the Rainfall Factor in the Universal Soil Loss Equation, FAO, Rome.

[3] Chandramohan, T., Venkatesh, B., and Balchand, A.N. (2015). Evaluation of Three Soil Erosion Models for Small Watershed. *International Conference on Water Resources, Coastal and Ocean Engineering (ICWRCOE) Aquatic Procedia*, 4:1227-1234.

[4] Elwell, H. A., 1976: Natal Agricultural Research Bulletin No 7, Soil Loss Estimator for Southern Africa, Department of Agricultural Technical Services, Natal.

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

[6] Foster, G.R., and Meyer, L.D. (1972). A Closed Form Soil Erosion Equation for Upland Erosion. In: Shen, H.W. (Ed.), Sedimentation. Colorado State University, Ft Collins, Colorado, 12.

[7] Ganasri, B.P., and Ramesh, H. (2016). Assessment of Soil Erosion by RUSLE Model Using Rmote Sensing and GIS – A Case Study of Nethravathi. *Basin Geoscience Frontiers*, 7:953-961.

[8] Han, F., Ren, L., Zhang, X., and Li, Z. (2016). The WEPP Model Application in a Small Watershed in Loess Plateau. *PLoS ONE*, 11(3):1-11.

[9] Jaramillo, F. (2007). Estimating and Modelling Soil Loss and Sediment Yield in the Maracas-St. Joseph River Catchment with Empirical Models (RUSLE and MUSLE) and a Physically Based Model (Erosion 3D). M.Sc. Thesis, McGill University, Montreal.

[10] Korea Institute of Construction Technology (KICT) (1992). The Development of Selection Standard for Calculation Method of Unit Sediment Yield in River, KICT 89-WR-113 Research Paper (in Korean), 1992.

[11] Laflen, J.M., and Flanagan, D.C., (2013). The Development of U.S Soil Erosion Prediction and Modelling. *International Soil and Water Conservation Research*, 1(2):1-11.

[12] Lee, G.S., and Lee, K.H. (2006). Scaling Effect for Estimating Soil Loss in the RUSLE Model using Remotely Sensed Geospatial Data in Korea. *Hydrology and Earth System Sciences*, 3:135-157.

[13] Le Roux, J. J. (2005). Soil Erosion Prediction under Changing Land Use on Mauritius. M.Sc. Thesis, University of Pretoria.

[14] Lilly, A., Grieve, I.C., Jordan, C., Baggaley, N.J., Birnie, R.V., Futter, M.N., Higgins, A., Hough, R., Jones, M., Noland, A.J., Stutter, M.I., and Towers, W. (2009). Climate Change, Land Management and Erosion in the Organic and Organo-Mineral Soils in Scotland and Northern Ireland. Scottish Natural Heritage Commissioned Report No. 325, pp. 53-103.

[15] McCool, D.K., Foster G.R., Renard, K.G., Yoder, D.C., and Weeisies, G.A. (1995). The Revised Universal Soil Loss Equation. Department of Defense/Interagency Workshop on Technologies to Address Soil Erosion on Department of Defense Lands San Antonio, TX, June 11-15, 1995.

[16] Merrritt, W.S., Letcher, R.A., and Jakeman, A.J. (2003). A Review of Erosion and Sediment Transport Model. *Environmental Modelling and Software*, 18:761-799.

[17] Moehansyah, H., Maheshwar, B.L. and Armstrong, J. (2004). Field Evaluation of elected soil Erosion Models for Catchment Management in Indonesia. *Biosystems Engineering*, 88(4):491–506.

[18] Morelli, J. (2011). Environmental Sustainability: A Definition for Environmental Professionals. *Journal of Environmental Sustainability*, 1(2):1-11.

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

[20] Natural Science and Engineering Research Laboratory (NSERL) (1995). WEPP User Summary Version 95.7, National Soil Erosion Research Laboratory Report No. 11.

[21] Nugroho, S.P. (2003). Application of the Agricultural Non-Point Source Pollution (AGNPS) Model for Sediment Yield and Nutrient Loss Prediction in the Dumpul Sub-watershed, Central Java, Indonesia. Erosion Prediction in Ungauged Basins: integrating Methods and Techniques (Proceedings of symposium 1 OS I1S01 held during IUGG2003 at Sapporo, July 2003). IAHS Publ. No. 279, 2003.

[22] Penning de Vries, F.W.T., Agus, F. and Kerr, J. *Soil Erosion at multiple scales: Principles and methods for assessing causes and impacts.* CABI Publishing, United Kingdom, 1998.

[23] Phai, D.D., Orange, D., Migraine, J.B., Toan, T.D., and 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.

[24] Pieri, L., Bitelli, M., Wu, J.Q., Dun, S., Flanagan, D.C., Pisa, P.R., Ventura, F. and Salvatorelli, F. (2006). Using the Water Erosion Prediction Project (WEPP) Model to Simulate Field-observed Runoff and Erosion in the Appenines Mountain Range, Italy. *Journal of Hydrology*, 336:84-97.

[25] Renard, K.G., and Freimund, J.R. (1994). Using Monthly Precipitation to Estimate R-Factor in the Revised USLE. *Journal of Hydrology*, 127:287-306.

[26] Roose, E.J. (1977). *Use of the Universal Soil Loss Equation to Predict Erosion in West Africa. In Soil erosion: Prediction and control.* Soil Conservation Society of America, Special Publication no. 21. Ankeny, Iowa.

[27] Soil Conservation Society (SCS) (1972). Section 4, Hydrology, National Engineering Handbook. Soil Conservation Service, US 444 Department of Agriculture.

https://dx.doi.org/10.22161/ijaers.4.12.22 *ISSN: 2349-6495(P) | 2456-1908(O)*

[28] Shougang, Z., Na, L., and Ruishe, Q. (2014). The Application and Study of GIS in Soil Erosion Model. *Advances in Sciences and Engineering*, 6(2):31-34.

[29] Smith, H.J. (1999). Application of Empirical Soil Loss Models in Southern Africa: A Review. *South African Journal of Plant and Soil*, 16(3):158-163.

[30] Sutton, P. (2004). A Perspective on Environmental Sustainability. *A paper for the Victorian Commissioner for Environmental Sustainability*.

[31] Tesfahunegn, G.B. (2011). Soil Erosion Modelling and Soil Quality Evaluation for Catchment Management Strategies in Northern Ethiopia. Ph.D. Thesis, Rheinischen Friedrich-Wihelms University.

[32] United States Department of Agriculture (USDA) (1995). USDA—Watershed Erosion Prediction Project (WEPP). Technical Documentation. National Soil Erosion Research Laboratory, NSERL Report No. 10.

[33] Wischmeier, W.H. and Smith D.D. (1978). Predicting Rainfall Erosion Losses- A Guide to Conserving Planning, United States Department of Agriculture, Agriculture Handbook 537.

[34] World Commission for Environment and Development (WCED) (1987) *'Our Common Future'.* Oxford University Press.

[35] Young, R. A., Onstad, C. A., Bosch, D. D. and Anderson, W. P. (1989). AGNPS: A Nonpoint Source Pollution Model for Evaluating Agricultural Watersheds. *Journal of Soil and Water Conservation*, 44(2): 4522–4561.

[36] Young, R. A., Onstad, C. A., Bosch, D. D. and Anderson, W. P. (1995). AGNPS: A Nonpoint Source Pollution Model. In: *Computer Models of Watershed Hydrology*, Chapter 26:1011-1020. Water Resources Publications, Colorado, USA.