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Soil Erosion Measurement: Malaysia Perspectives

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Soil erosion is a serious environmental problem faced all over the world. Human activities such as agriculture, forestry, construction and urbanisation may cause the environmental impacts that leads to soil erosion. In addition, it leads to loss storage capacity of the reservoir and reduced food production. There are various approaches established to determine the potential soil loss, which can be categorised as traditional, modelling and tracing approach. The aim of this paper is to review the advantages, limitations, and applications of these approaches. This study will compile the soil erosion studies conducted in different parts of Malaysia to have an overview of the current state of erosion in the country. The overview will then lead to conclusion and recommendations to help improving the soil erosion study in Malaysia.

Keywords: erosion; soil loss; soil degradation; Malaysia

I. INTRODUCTION

Soil erosion can be defined as the removal of soil by erosion agents excessively that resulting in soil degradation processes. Soil degradation can be classified into seven main classes based on the cause of degradation, namely water erosion, wind erosion, mass movement, excess of salts, degradation due to physical, biological, and chemical. Soil erosion may cause multiple environmental problems on-site and off-site such as increasing in runoff and sediment load, riverbank damage, reducing water storage capacity, higher probability flooding due to the reduction of river channel capacity and losses of recreational and commercial value.

Naturally, uneroded soil is protected by natural land covers such as trees, leaves, lichens or mosses. Rapid changes in land uses and land covers may accelerate soil erosion problem. Human related land use activities such as agriculture, forestry, construction or urbanisation may cause various environmental impacts for example loss of important aquatic habitat, human health concern, loss of wetlands and increases in erosion. Researchers found that developing and undeveloped countries are facing great soil erosion risk due to population growth and continuous land clearing activity (Abdulkareem *et. al., 2017;* Borrelli *et. al., 2017;* Collins *et. al., 2001;* Zare *et al.*, 2017). Degraded soil resulting in disability of agriculture business where majority of the food supply is land produced (Pimentel, 2006).

Soil erosion caused by water consists of many forms namely sheet erosion, rill erosion and gully erosion. Sheet erosion is caused by the movement of soil from raindrop splash or runoff water. It can be seen in the changes of soil thickness and low crop production on the shoulder slopes. Arata *et al.* (2016) and Loughran *et al.* (1990) have discussed about the rate of sheet erosion in the catchment. Normally, this event occurs uniformly and unnoticed until productive topsoil has diminished. Rill erosion is happening when small channels were formed by the concentrated surface water runoff. This is happened on the tillage operation. Another form of water erosion is gully where it is an advanced version of rill erosion. Gully erosion can cause a massive topsoil lost where it is difficult to control if lack of soil management planning. A study in west China by Li *et al.*

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(2003) was investigated the total sediment production on various parts of slopes under different land use types.

Globally, the soil erosion by water is in the range of 20 – 30 gigatons per year considering effective measuring method adopted (FAO and ITPS, 2015). However, more precise investigation should be done to identify the accurate soil erosion rates according to local conditions. Similar authors have classified erosion rates ranges for different areas and climate condition. For example, hilly croplands with no soil cover in temperate climate has average erosion rates less than 10 tonnes per hectare per year as tabulated in Table 1. It is very important to accurately predicting the soil erosion rate according to the local condition to increase the crop productivity and towards better land management planning.

Table 1. The global average soil erosion rate in agriculture practice (FAO and ITPS, 2015)

Type of land	**Climate**	**Average soil erosion rate (t ha^{-1} $year^{-1}$)**
Hilly cropland	Temperate	Less than 10
	High intensity rainfall	100
	Tropical and subtropical	10 – 20
Rangeland and pastureland	Temperate	Less than 1

Extensive reviews of estimating soil erosion of varying approaches have been done before which focus on different aspects such as equation used to calculate erosion rate by water (Benavidez *et al.,* 2018). A review by Haddadchi *et al.* (2013) focussed more on the sediment fingerprinting method by using the tracing approach. Another review on tracing approach focused only on the individual radioisotopes namely caesium-137, excess lead-210 and beryllium-7 (Mabit *et. al.*, 2014; Mabit *et. al.*, 2008a; Taylor *et al.*, 2013). Other reviewers focused more on the soil erosion condition in particular places such as (Labrière *et al.,* 2015) which reviewed erosion in tropics, and erosion in Africa by *Maina et al.* (2018). On the other hand, reviews by Jahun *et al.* (2015) and Merritt *et al.* (2003) were mainly focused on the erosion models and the combination of the model with mapping tool.

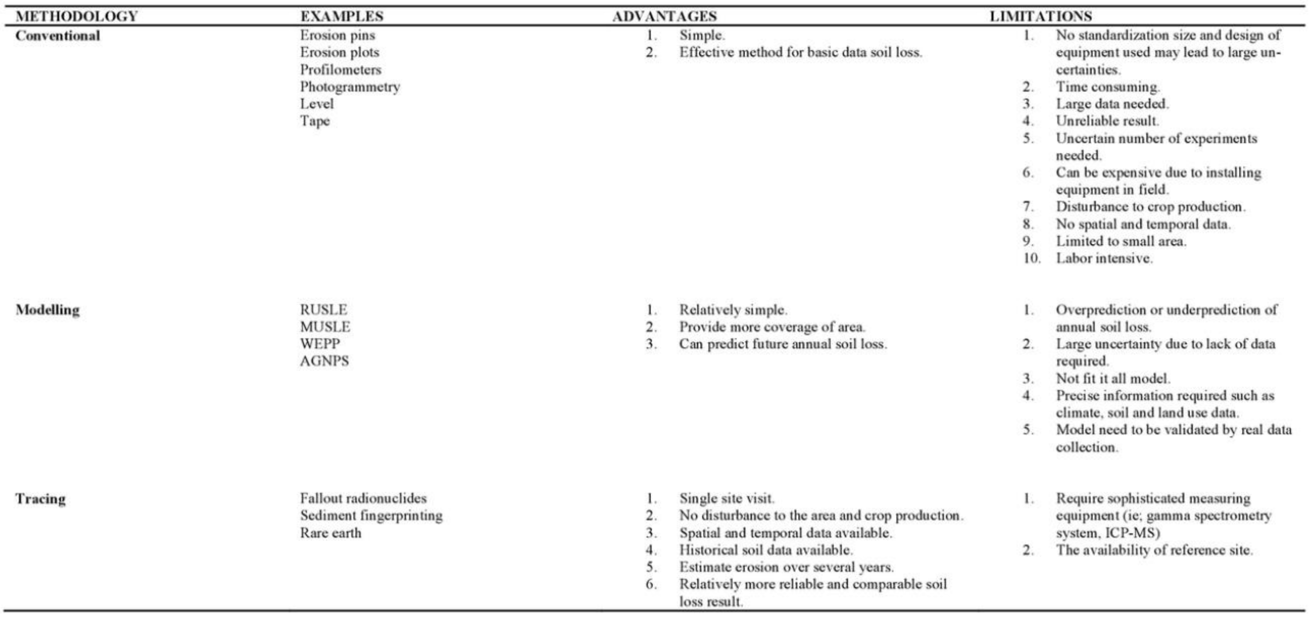
Soil erosion can be quantitatively measured by different approaches. Estimation of soil erosion has grown throughout the years from conventional to advance or any combination of both. The techniques for measuring water-caused soil erosion can be categorised into conventional, modelling software and tracing technique. These techniques are chosen mostly based on the availability of the data required and the accuracy of the results obtained. The purpose of this review is to provide an overview of the measuring techniques used to measure soil erosion caused by water. Most of the examples reviewed in this paper have been extensively discussed elsewhere.

The focus of this review is to investigate the measurement of soil erosion limited to Malaysia perspective. A brief description of the erosion and previous reviews are given in introduction. In section 2, the overview on the measuring techniques developed over the years including examples is discussed, while Section 3 will be discussing the role of geographic information system in soil erosion measurement. The approaches adopted in soil erosion measurement in Malaysia, and the results obtained are presented in Section 4. Finally, Section 5 is the challenges in estimating erosion and followed by the conclusion.

II. MEASURING TECHNIQUES

This section is discussing different approaches adopted to measure soil erosion rates. The methodologies can be categorised as conventional, modelling and tracing approaches. The advantages and limitation of each category has been discussed by including examples respectively and summarises in Table 2.

Table 2. The examples, advantages and limitations for categorised soil erosion movement techniques



METHODOLOGY	EXAMPLES	ADVANTAGES	LIMITATIONS
Conventional	Erosion pins Erosion plots Profilometers Photogrammetry Level Tape	1. Simple. 2. Effective method for basic data soil loss.	1. No standardization size and design of equipment used may lead to large uncertainties. 2. Time consuming. 3. Large data needed. 4. Unreliable result. 5. Uncertain number of experiments needed. 6. Can be expensive due to installing equipment in field. 7. Disturbance to crop production. 8. No spatial and temporal data. 9. Limited to small area. 10. Labor intensive.
Modelling	RUSLE MUSLE WEPP AGNPS	1. Relatively simple. 2. Provide more coverage of area. 3. Can predict future annual soil loss.	1. Overprediction or underprediction of annual soil loss. 2. Large uncertainty due to lack of data required. 3. Not fit it all model. 4. Precise information required such as climate, soil and land use data. 5. Model need to be validated by real data collection.
Tracing	Fallout radionuclides Sediment fingerprinting Rare earth	1. Single site visit. 2. No disturbance to the area and crop production. 3. Spatial and temporal data available. 4. Historical soil data available. 5. Estimate erosion over several years. 6. Relatively more reliable and comparable soil loss result.	1. Require sophisticated measuring equipment (ie; gamma spectrometry system, ICP-MS) 2. The availability of reference site.

There are several literatures discussing on soil erosion and its factors, namely rainfall, topography, the characteristic of the soil and land cover (Islam *et. al.*, 2018; Wang *et. al.*, 2018; Zare *et al.*, 2017). These factors were studied to gain understanding on how to measure soil erosion rate. Over the years, several techniques have been developed around the world to estimate rates of erosion under different land use systems (Mabit *et. al.*, 2008a; Merritt *et. al.*, 2003; Walling *et al.*, 2014).

A. Conventional Approach

Conventional or traditional method may consist of erosion plot, erosion pin, photogrammetry, level and tape (Loughran, 1989). Plots study has been established in the United States since 1915 by the Forest Service in Utah. According to Loughran (1989), erosion plot is in situ method where a tray or trough will be set up at the field, the sediment will be collected in the container and measured. Both water and sediment can be measured depending on the purpose of study such as on individual storm event or temporal based. Plots are limited to measure sheet and rill erosion. Erosion plot method has been used extensively by many researchers and still in use until now as complementary data. Several studies in particular places have reviewed on assessing soil erosion using plot such as Anache *et al.* (2017) in Brazil, Cerdan *et al.* (2010) and Guo *et al.* (2015) in Europe and China, respectively.

Several studies claimed that this method provides simple and effective measurement to obtain basic data on soil erosion for numerous purposes. Erosion plot is useful if there are permanent automated instruments installed in the area of interest. However, it is appeared that runoff plot method may consume relatively longer time. Mabit *et al.* (2009) used 13 years of sampling data to assess deposition and erosion rates in an agricultural field in Austria. This method takes longer time because the needs to integrate the erosion data with the climate variance. Erosion plot can be very expensive to be implemented as it needs continuous sampling and data collection. This is supported by Higgitt and Lu (2000), an uncertain number of experiments needed may contribute to over budgeting on sampling process. In addition to that, the results obtained may not be representative of the sampling areas as it is only applicable to small, enclosed area (Higgitt and Lu, 2000, Porto and Walling, 2012). Furthermore, there are no fixed guidelines for the plot design which may introduce a large number of uncertainties.

Erosion pins are considered a survey technique or reconnaissance method where the first impression on erosion can be made. Basically, the mechanism of erosion pins is very simple where nails or steel rods were inserted into the ground as a 'datum'. The erosion loss is determined by the height of the nails or rods. The uncertainties of this method extensively reviewed by Haigh (1977). Present study by Kearney *et al.* (2018) has improved on the relationship of pins height and the erosion data measured. This is because there are arguments on how accurate the height is can be assessed from the ground surface and how accurate is this method to compare with other measurement techniques. A very limited study can be found using this measurement technique. Most researchers have combined this method and other measurement techniques to get a perspective value. Research by Jugie *et al.* (2018) coupled the erosion pins and photogrammetry survey technique to understand the riverbank erosion, whereas Shi e*t al.* (2011) has compared the soil redistribution value using radioisotope technique, erosion pins and runoff plots. In another case, erosion rates recorded by profilometers were higher compared to results obtained from erosion pins which means that the result from erosion pins might be underestimated the erosion rates (Sirvent *et al.,* 1997).

The main advantages of traditional method are that they are economical, cheaper, and simpler. The erosion rate result obtained is suitable for screening purposes and more precise and accurate studies must be followed. This approach also requires very less maintenance and flexible. The drawback of this technique is that it requires fieldwork to install the equipment. The pins are visible and exposed to other disturbances such as theft risk and vandalism. Furthermore, there are various arguments due to the validity and reliability of the data. This method also cannot provide the spatial distribution of erosion or else it might not be economical. Moreover, the equipment installation may interfere with the crop's productivity and tillage operation.

B. Modelling Approach

Limitation in traditional method has encourage the development of soil erosion measurement. Soil erosion by water has been mathematically predicted in the effort to integrate the factors that influence the occurrence of soil erosion. Numerous studies have been conducted to develop modelling approaches to suit the local condition in soil erosion measurement. One may refer to Merritt *et al.*(2003) for the model existed where the complexity, requirements, processes and conditions are discussed but limited to sediment generation and transport process.

Universal Soil Loss Equation (USLE) is a widely used mathematical model to predict the average rate of soil erosion considering the crop system, management practice, soil type, rainfall pattern and topography. It is designed to calculate long term average soil losses from sheet and rill erosion under specific conditions (Wischmeier and Smith, 1958). As reported by Renard *et al.* (1997), the erosion model prediction has begun in 1936 when one researcher came up with three major factors affecting soil erosion by water namely; rainfall and runoff erosivity, susceptibility of soil to erosion and soil protection by plant cover. Then, four years later, another researcher has published the first soil loss equation where it described the relationship between slope steepness and slope length. Later, the equation was modified by adding up the cropping system and support practices to the equation. The author improvised the model by adding up the specific annual loss limit and used the equation to build a simpler way to choose conservation practices for different soil conditions in the midwestern United States. The works continued with several modifications and it lasted when a joint conference was held at Purdue University in February and July of 1956 (Renard *et al.,* 1997). In 1956, USLE was developed by Science and Education Administration (National Runoff and Soil Loss Data Centre), United States of America (USA) in cooperation with Purdue University, USA aiming to keep erosion within acceptable limits with consideration of climate, slope and production factors. Since it is accepted globally, USLE has had tremendous impact and has become a major tool in soil conservation planning worldwide.

USLE has been used extensively in many continents for example Asian, South American, and African countries (Abdulkareem *et. al.*, 2017; Correa *et. al.*, 2016; Tadesse *et. al.*, 2017; Zare *et al.*, 2017). This model is relatively simple and easy to use compared to other models that is extensively reviewed in Merritt *et al.* (2003). Abdulkareem *et al.* (2017) agreed with this statement because all parameters required are straightforward and available to access. Due to this factor, it is easier for decision-makers to make prediction on soil management and town planning activities.

Revised Universal Soil Loss Equation or RUSLE is the revised version of USLE. Numerous alterations and modifications on the data has been done such as correction on the rainfall data for some locations, adding up more features on soil erodibility factor, revision on the slope length and steepness and some modification on the cover management factor (Renard *et al.,* 1997).

RUSLE is not limited to agricultural used only but widely useful for other conditions as well such as construction site. The application of RUSLE is not only producing spatial and temporal data, it is also helping in making decision to reduce non-point source pollution (Pradhan *et al.,* 2012). Though RUSLE was developed in the United States, the equation can still be used globally where the rainfall characteristics, soil types, topographic features or management practices of the local produce may be used. Several guidelines and features were already simplified for local research to be applied on the conditions of interest. Compilations of RUSLE studies around the world were compiled by Benavidez *et al.* (2018).

The principal equation for the RUSLE can be presented as below:

$$A = \mathrm{R \times K \times LS \times C \times P} \tag{1}$$

Where:

A: Mean annual soil loss (metric tons hectare^{-1} year^{-1})

R: Rainfall and runoff factor or rainfall erosivity factor (megajoules millimetre hectare^{-1} hour^{-1} year^{-1})

K: Soil erodibility factor (metric tons hectare hour megajoules^{-1} hectare^{-1} millimetre^{-1})

L: Slope length factor (unitless)

S: Slope steepness factor (unitless)

C: Cover and management factor (unitless)

P: Support practice factor (unitless)

Without one of these data, it is impossible to calculate soil erosion rate (Pillay & Zullyadini, 2014). Rainfall erosivity factor, R is depending on its intensity and volume of rainfall. The relationship of rainfall energy to soil loss is extensively studied by Wischmeier and Smith (1958). Their study has published a rainfall energy table to estimate rainfall erosion accurately. According to the study, it is necessary to investigate the characteristics of the rainfall and how it is affecting the soil erosion problem. Over the years, several researchers study solely on the rainfall effect to the soil erosion and how it changed the streamflow behaviour (Jha *et. al.*, 2015; Mohmadisa *et. al.*, 2016; Noorazuan *et. al.*, 2003; Walling *et. al.*, 2014; Sepulveda *et al.*, 2008). Different equations have been developed to suit into the climate and suitability of the study (Arnoldus, 1980, Brown & Foster, 1987). Studies proved that rainfall intensity is directly proportional to soil loss.

Soil erodibility factor, K is the rate of soil loss per rainfall erosion index. The process involved the transportation and removal of soil by raindrop impact and surface flow that is depending on the topography, tillage condition and rainwater infiltration into soil profile. Soil erodibility is depending on the type of soil, its characteristics, texture, permeability, soil contents as well as its structure (Abdulkareem *et al.*, 2017).

Slope length, L and slope steepness, S are used as single entity to represent the topographic factors. The slope length is the distance from the source of runoff to the point where deposition starts (Zare *et al.,* 2017). As the slope length increases, the erosion risk is increased. It is best to measure slope length at the field. However, for a steep slope, the length should be converted to the horizontal distance to be used in RUSLE. Upon the increasing use of technology, researchers adopted the digital elevated model (DEM) to estimate the slope characteristics in the area of interest (Islam *et. al.*, 2018; Rendana *et al.*, 2017).

Cover and management factor, C is used to show how conservation plan give impact to soil loss potential. It is very difficult to quantify this factor especially on the large region of interest. This factor is calculated in terms of soil loss ratio (SLR) because it is constantly changing over time. Therefore, care should be taken to determine C factor to reduce very high uncertainty.

Another RUSLE factor is management practice factor, P where it is the ratio of soil loss with a specific support practice to the corresponding loss with upslope and downslope tillage. There are different types of management practice namely contouring, strip-cropping, terracing and subsurface drainage (Renard *et al.,* 1997). Input data used to calculate P factor is normally from the experimental observation. At 0% slope, the contouring subfactor used is 1.0 because there is no flow direction is defined. For 2% and 7%, the values of 0.6 and 0.5 are used, respectively. In the meantime, for very steep slopes assuming it is steeper than

25%, the subfactor used is 1.0.

Although RUSLE is considering all factors that are contributing to soil erosion, there are several limitations to the model. This model is not considering deposition and sediment yield, also it is not suitable for gully erosion and mass movement. RUSLE can be used in other parts of the world by modifying some of the equations and parameters to suit the climate, soil types, or management practice of the local area. For example, Khalit *et al.* (2011) has used the modified soil loss equation (MSLE) to estimate soil erosion, sedimentation, climate variation and different vegetation on the forest environmental conditions. In addition, the modified universal soil loss equation (MUSLE) can be used to predict both soil erosion and sediment yield.

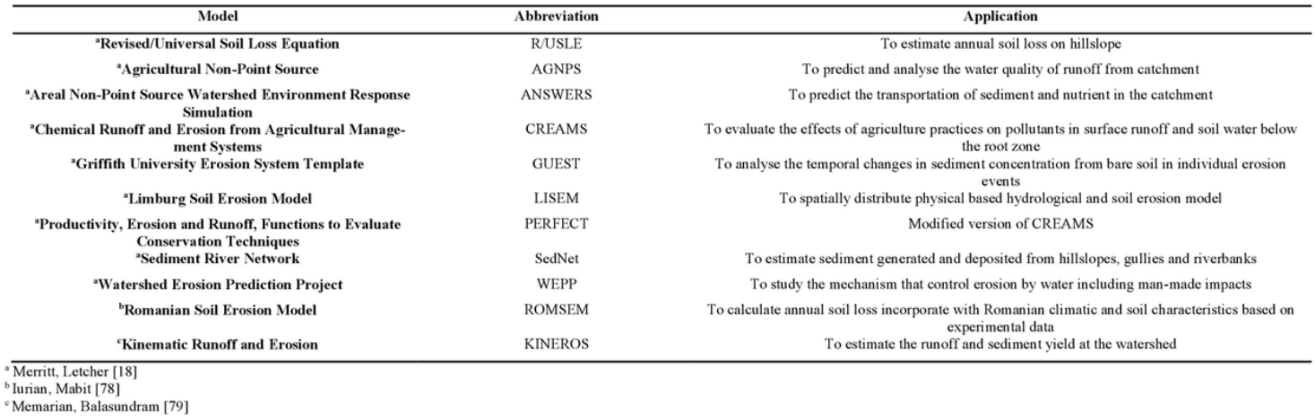
Another model called the Agricultural Non-Point Source Model (AGNPS) is developed in the United States to predict the water quality of runoff from various sizes of catchment. Basically, there are three stages to use AGNPS. Firstly, several parameters include the runoff volume, erosion, pollutants point source inputs and level of soluble pollutants are calculated. Then, the runoff volume and sediment yield leaving the catchment is estimated. Finally, the amount of sediment and nutrient in the catchment can be predicted.

Similar to RUSLE, AGNPS is being modified and improved to suit the current situation and condition. An annualised pollutant loading model called AnnAGNPS is developed as the complimentary model. Shamshad *et al.* (2008) has applied this model to understand sedimentation and hydrology mechanism in Malaysia. It was found that the erosion map generated using this model agrees with the erosion map produced locally in Malaysia by the Department of Agriculture, Malaysia. AnnAGNPS can be used besides RUSLE to simulate the pollutant loading surface runoff in the catchment.

The input data for AnnAGNPS can be quite extensive compared to RUSLE as explained in Shamshad *et al.* (2008). The authors used watershed physical characteristics such as soil and slope properties and climate data. The simulated result for Malaysia concluded that rubber estates, urban lands, mines and bare land are the major land uses in contributing to soil erosion. Although this model is suitable to be applied in Malaysia, there is still limited application and study on this model as well as lack of information on crop and field management practice. In addition, this model is requiring a huge data and it is more complex to analyse compared to RUSLE.

Watershed Erosion Prediction Project (WEPP) is another physical-based model developed in the United States. This model is used to determine water-caused erosion including the man-made impacts; however, it does not include erosion, transport, and deposition processes in permanent channel. WEPP can be used to estimate spatial and temporal distribution of soil loss, sediment yield, volume of runoff and soil water balance. Haque *et al.* (2016) has developed the GeoWEPP which is the integration of WEPP and geographical information system (GIS) to estimate the sediment load and runoff at the Langat sub-basin, Peninsular Malaysia. The findings were that the model overestimates the sediment load and under estimates runoff at the area of interest. Merritt *et al.* (2003) and Fernández and Vega (2018) agrees that WEPP required a huge data to be computed besides the calibration needed for the parameters. As extensively mentioned in Merritt *et al.* (2003), the models are differently varied in their complexity, parameters required, process representative and the scale for intended used. The summary of the model and its application is presented in Table 3.

Table 3. Erosion and hydrological transportation model



Model	Abbreviation	Application
[a]Revised/Universal Soil Loss Equation	R/USLE	To estimate annual soil loss on hillslope
[a]Agricultural Non-Point Source	AGNPS	To predict and analyse the water quality of runoff from catchment
[a]Areal Non-Point Source Watershed Environment Response Simulation	ANSWERS	To predict the transportation of sediment and nutrient in the catchment
[a]Chemical Runoff and Erosion from Agricultural Management Systems	CREAMS	To evaluate the effects of agriculture practices on pollutants in surface runoff and soil water below the root zone
[a]Griffith University Erosion System Template	GUEST	To analyse the temporal changes in sediment concentration from bare soil in individual erosion events
[a]Limburg Soil Erosion Model	LISEM	To spatially distribute physical based hydrological and soil erosion model
[a]Productivity, Erosion and Runoff, Functions to Evaluate Conservation Techniques	PERFECT	Modified version of CREAMS
[a]Sediment River Network	SedNet	To estimate sediment generated and deposited from hillslopes, gullies and riverbanks
[a]Watershed Erosion Prediction Project	WEPP	To study the mechanism that control erosion by water including man-made impacts
[b]Romanian Soil Erosion Model	ROMSEM	To calculate annual soil loss incorporate with Romanian climatic and soil characteristics based on experimental data
[c]Kinematic Runoff and Erosion	KINEROS	To estimate the runoff and sediment yield at the watershed

[a] Merritt, Letcher [18]
[b] Iurian, Mabit [78]
[c] Memarian, Balasundram [79]

C. Tracing Approach

Despite the continuous improvement in modelling approach, there is a limitation in validating the parameters used to calculate erosion rate. Similar to traditional method, which is requiring field work, the tracing approach is offering something more valuable. A review by Guzmán *et al.* (2013) is discussing the example of tracing approaches in water erosion study, the application and limitation of the tracers. The example of tracers reviewed in the paper consist of fallout radionuclides, rare earth elements, magnetism, and sediment fingerprinting.

Recently, fallout radionuclides (FRN) has been introduced globally in Morocco, China, Nigeria, United Kingdom, Zambia and Serbia (Benmansour *et. al.*, 2013; Collins *et. al.*, 2001; Junge *et. al.*, 2010; Higgitt & Lu, 2000; Owens & Walling, 1998; Petrović *et al.*, 2016) to determine the soil erosion rates. A very thorough review on the application of FRN, comparative of advantages, limitations and the application of FRN in several places in the world have been compiled in several papers (Mabit & Bernard, 2007; Mabit *et. al.*, 2007; Mabit *et. al.*, 2008a; Mabit *et. al.*, 2008b; Mabit *et. al.*, 2009; Mabit *et al.*, 2014).

The FRN consists of caesium-137 (^{137}Cs), unsupported or excess lead-210 ($^{210}Pb_{ex}$) and beryllium-7 (^{7}Be) are used as tracers and markers to soil redistribution as they are strongly fixed to the surface soil or sediment particles in most environments and subsequently if redistribution occurs it will reflect on erosion and sedimentation (Junge *et al.,* 2010). Soil erosion assessment and deposition rates can be determined by comparing the FRN activity density or inventory in the area of interest against the same property of a reference site known as representative stable landscape. With this, the erosion and sedimentation rates can be further estimated using conversion model that defines the relationship between FRN inventories compared to the reference inventory site. Generally, FRN requires field sampling of both bulk and sectioned core samples including gathering the site characteristics such as topography, climate and soil properties. The field sampling provides the areal activity density, inventory at the individual site and the depth distribution information. This information may be cross-referenced with the site characteristics. Further in-laboratory process consist of drying, grinding and sieving for soil samples are required before measuring soil samples by using the gamma spectrometry system because all three isotopes are gamma emitters (Mabit *et al.,* 2008a).

Soil erosion rates are important to give an overview or ideas in structuring more efficient land planning. FRN has the benefit to provide a wide timeframe from weeks to years of soil activity depending on their half-lives. ^{7}Be with short half-life of 53.3 days can offers a potential soil erosion process that occurred over shorter period particularly during storm event or monsoon. Meanwhile, ^{210}Pb is a naturally occurring isotope that provides soil redistribution information for longer term timescale for about 100 years or more. This isotope can be used to study the historical changes on the land uses over the years on the application of sediment dating. For example, Gharibreza *et al.* (2013) has successfully investigating the changes in land use in Bera Lake catchment, Pahang, Malaysia since 1971. It was found that the sediment distribution in Bera Lake was controlled by the morphological shape and stream pattern. Another approach is the man-made isotope with 30.2 years of half-life, ^{137}Cs can provide information on medium term average rates of soil erosion (Fang *et. al.*, 2012; Mabit *et al.*, 2009).

Another important part is that the use of conversion model to estimate the soil erosion rates. There are numerous models were developed to convert the radioisotopes activity to the erosion rates to make the measurement comparable to the non-isotopic models like RUSLE or WEPP. The conversion models used namely mass balance, vertical distribution, profile distribution, constant rate supply, proportional model, diffusion and migration and diffusion-sorption model (Maina *et al.,* 2018).

Sampling is a crucial methodology in assessing soil erosion and sedimentation rates. Field sampling for FRN consist of soil, sediment and freshwater samples are relatively simple and cost-effective as it requires only one-time site visit depending on the size of the area investigated. There will be no equipment installed in the sampling area permanently, thus minimal disturbance to the site. The experiment method will have no interference with seeding or cultivation operations allowing natural runoff and erosion processes (Mabit *et al.,* 2008a).

Another advantage of FRN is that it provides spatial pattern and estimation of soil erosion for entire field or landscape unit. This is important to have an overall overview regarding the soil loss and deposition on the catchment or watershed. Even though FRN sounds promising with less hard work and provide more realistic data, the critical part is to provide a local reference site to estimate erosion and sedimentation. Reference site must be comparable to the study area with less or zero erosion (Owens & Walling, 1998). Mabit *et al.* (2008a) has extensively stressed out that the reference site must not be from mountainous, stony soils and overgrazing area because it may not be representative of the local reference inventory.

Sediment fingerprinting is more focused on identifying the source of sediments rather than the erosion studies. Basically, this approach is comparing the composition of soil properties collected at the catchment with the soil properties from different areas surrounding the catchment. Sediment fingerprinting is acting as soil forensic to detect which land use responsible in loading up the catchment.

Great work by Reiffarth *et al.* (2016) focused on the development of fingerprinting method, discussing the past work, current and future work. Study in Spain has successfully identified the main sediment source in the Spanish catchment (Palazón *et al.,* 2016). This is important so that the decision-makers may tackle the specific problem in the catchment management planning. However, the study by Manjoro *et al.* (2016) has found the limitation in this approach. The estimated sediment source in Eastern Cape catchment, South Africa was in good agreement with the available published data on erosion processes. The uncertainties produced is very huge therefore more detailed study on the model development and understanding on the approach should be conducted.

The compound specific stable isotope (CSSI) is a biomarker type of sediment fingerprinting. The work of CSSI is based on the differential plants producing CSSI signature such as δ13C or δ15N. By using the biomarker, the sedimentation zone source can be easily identified using proportional contribution model.

D. Geographic Information System (GIS)

Geographical Information System (GIS) has become a great help in many areas namely education, health, manufacturing, environmental, water and transportation. It is more than an attractive tool used to gather, manage and analysing data. GIS is a great way to make maps communicate, perform analysis by sharing the information and solving many problems around the world. The collection of geographic and spatial data especially in soil erosion study may become easier in the application of GIS. The data integration and exploration may be feasible and simpler in the science point of view (Noorazuan *et al.,* 2003).

Historically, GIS started in the 60s as the geography study is blooming. The system has been developed and modified to facilitate the natural resources data available and eventually can be used in many fields. As computer technology become more powerful, the application of GIS become wider in various applications. Nowadays, there are numerous commercially available GIS products that allow the user to create their own digital map layers in many fields.

GIS has facilitated soil erosion study by integrating its widely used erosion models based on empirical, conceptual and physical types in estimating spatial distribution and calculate the magnitude of the erosion risk (Jahun *et al.,* 2015). Researchers worldwide agreed that this system has proved economical approach with highly accurate results (Abdulkareem *et. al.*, 2017; Anees *et. al.*, 2018; Ghani *et. al.*, 2013; Mabit *et al.*, 2007).

Prediction of soil loss measurement may be improved using the combination method of two or more approaches with the geographic information system (GIS). The measurement is clearer and presentable with the map distribution. Sujaul *et al.* (2010) investigated different types of erosion in agricultural area in Chini Lake catchment, Malaysia using the integration of GIS and RUSLE model. Using the approaches, the author predicted that sedimentation rate is increasing with increasing erosion rate. It is important to study these phenomena because when sediment rate is increasing, the sediment will sink faster at the bottom of the river which eventually, will reduce the water level.

On another point, Pradhan *et al.* (2012) has helped in locating the landslide zone based on the soil erosion map that has been analysed using RUSLE and spatially distributed in GIS application. This is very important to the decision-makers to design mitigation program in reducing soil erosion. Similar study conducted by Ghani *et al.* (2013) and Pillay and Zullyadini (2014) showed the spatial distribution of soil erosion in the Cameron Highland and Timah Tasoh, Malaysia, respectively for the purpose of proper catchment management.

Apart from a simple tool, numerous researchers agreed that using RUSLE model implemented in GIS requires minimal data and very easy to use with satellite images that is widely available (Pillay & Zullyadini, 2014; Pradhan *et. al.*, 2012; Rendana *et al.*, 2017). Moreover, this application is more economical and may produce highly accurate results. The combination of RUSLE-GIS provides more added values and measurable data to prevent on-site and off-site erosion problems besides the changes in any of the factors contributing.

Furthermore, the historical land use changes also can be studied using the RUSLE-GIS based programme. Abdulkareem *et al.* (2017) in their study the effect of long-term land use/land cover (LULC) to Kelantan River basin, Malaysia. The LULC changes in Kelantan basin for almost three decades showed that 67.54% of the soil loss is under low erosion potential. However, even though a great finding were discovered from the study, the author pointed out the limitation with the model such as no validation of the model due to unforeseen factors namely economical problem, difficulty, and time constraint.

Another successful integration was conducted by Navas *et al.* (2005) combining the GIS and ^{137}Cs technique in assessing soil erosion for soil conservation purposes in Mediterranean condition. Similar approach applied by Mabit *et al.* (2007) in Canada where the watershed was subdivided to identify the erosion prone zone.

III. MEASUREMENT OF SOIL EROSION IN MALAYSIA

Variation of soil erosion measurement techniques have been conducted in Malaysia covering a wide range of spatial and temporal scales. Techniques used to monitor soil erosion consists of prediction and sampling approaches.

This section reviews the amount of soil loss in various part of Malaysia. Malaysia is in the Asian continent is referred to as Southeast Asia. Malaysia consists of two parts which are Peninsular Malaysia located between Thailand in the north and Singapore in the south whereas Sabah and Sarawak are located on Borneo. Table summarise soil erosion studies conducted in Malaysia by previous research. The data compiles are focused on the annual soil loss, or the soil erosion class proposed by the Department of Drainage and Irrigation, Malaysia. The annual soil loss distribution summarised according to the region in Malaysia.

Table 4. The study area for soil erosion in Malaysia region

Malaysia region	Study area
Peninsular	
- North	Timah Tasoh catchment
	Penang Island
	River Kuala Tasik
- South	Johor river basin
	Seremban
- West coast	Semenyih watershed
	Langat basin
	Kalumpang agriculture station

- East coast	Kelantan watershed
	Chini lake
	Cameron Highland
	Pahang river
	Bera lake
East Malaysia	Tikolod
	Danum Valley

A. North

The north part of Malaysia consists of Perak, Penang, Kedah, and Perlis. A lot of work has been done in Timah Tasoh catchment, Penang Island and Kuala Tasik River. The methodology used to assess soil erosion rate is modelling namely RUSLE and AGNPS. Shamshad *et al.* (2008) has tested the annual AGNPS using the Malaysian conditions and climate data to predict the runoff effect on sediment and nutrient at the Kuala Tasik River. The study was successfully adopted where it is estimated that the average annual erosion rate for 2004 and 2005 were 62 t ha^{-1} year^{-1} and 123 t ha^{-1} year^{-1} respectively.

Further, another researcher adopted RUSLE in Timah Tasoh catchment estimated that 0.52 – 1.98 t ha^{-1} year^{-1} sediment losses at the catchment (Pillay & Zullyadini, 2014). The author has suggested that the model needs to be validated prior to using it for more effective catchment planning. The same attempt by Pradhan *et al.* (2012) has found the increment of approximately more than 20% in erosion rate from 2005 to 2010. This is suggested that all the models can be used to predict soil erosion in different parts of Malaysia. The results obtained are relatively different due to distinguished geography, topography, rainfall distribution and land use covers.

The preferences of choosing the models are based on the availability of the data and the corresponding results acquired. The limitation in using the model has proved that the need of validation such as analysing the physical soil from the area of interest other than relying on the interpolation method.

B. South

Southern Malaysia includes Melaka, Negeri Sembilan and Johor. Study on soil erosion can be found in Seremban and Johor River basin. Obaid and Shahid (2017) have adopted USLE and MUSLE to classify the soil erosion prone zone in Johor River basin. The USLE has estimated the soil loss in the range of 0.22 – 248.2 t ha^{-1} year^{-1} whereby MUSLE estimated erosion per individual event in the range of 19.2 – 2179.9 tonnes per peak discharge of 283.56 m^3/s.

The annual soil loss for Seremban which is approximately 271 km away from Johor River basin estimated at 883 t ha^{-1} year^{-1}. This is about 70% higher than Johor River basin may be contributed from the open space in Seremban. Land cover is one of the factors contributing to the soil erosion problem. Uncovered space or open space is more susceptible to soil erosion compared to higher covered area. This is supported by (Abdulkareem *et. al.*, 2017; Nampak *et. al.*, 2018; Tadesse *et. al.*, 2017; Vijith *et al.*, 2018).

C. West Coast

The west coast or the central region is where the centre of administration and urbanisation taking place. The area consist of Putrajaya, Selangor and Kuala Lumpur ideally exposed to very high erosion risk. Rizeei *et al.* (2016) used the Land Transformation Model (LTM) to spatially predict the future land cover and correlate it to soil erosion rate by using the USLE. The soil erosion rate at the Semenyih basin has increased about 10% for the last 8 years. The most eroded area could be observed in agriculture, oil palm and open areas.

Roslan *et al.* (2017) has established a risk assessment index for riverbank erosion. According to the author, Langat River is seriously exposed to erosion risk due to minimal percentage of clay. This is proven by the visual observation near the site study. Moreover, it is supported by Mohd Fozi *et al.* (2014) where the slope at the Hulu Langat area is under critical condition. A thorough study must be conducted to identify the effect of soil erosion from the factors contributing and to help in mitigation aspects.

D. East Coast

There are numerous studies conducted in the east coast especially in the freshwater sources namely Chini lake and Bera lake. The east coast consists of Kelantan, Pahang, and Terengganu. There are various methods applied in different areas for example (Rendana *et. al.*, 2017; Sujaul *et al.*, 2015) were adopted RUSLE in Chini Lake. In addition, in Bera Lake has adopted the FRN method to calculate soil erosion rate (Gharibreza *et al.,* 2013). Pahang River and Kelantan watershed also are being investigated and both adopting the RUSLE method (Ageel *et. al.*, 2013; Anees *et al.*, 2018).

Study by using RUSLE integrated in GIS was able to categorise soil erosion by classes. It was found that erosion class in Chini lake and Kelantan watershed exhibit a very low soil loss. Gharibreza *et al.* (2013) mentioned that Bera lake soil redistribution map is the first attempt made using ^{137}Cs technique in Malaysia and it provides a good guideline in future use.

E. East Malaysia

Sabah, Sarawak, and Labuan are known as east Malaysia that are separated by the South China Sea from the Peninsular. There is limited study on soil erosion can be found in east Malaysia. A study to compare the annual soil loss for different types of agriculture has been conducted in Sabah. There is quite significant soil loss between hill rice and ginger at a hillslope (Gregersen *et al.*, 2003). Such study is important to investigate the conservation practices incorporated in future land management to prevent the soil degradation and poor water quality.

A preliminary study in Danum Valley Sabah has indicated the different erosion rates for different types of soil. It is a great move to have an understanding on the soil erosion factors to help in forest preservation plan (Cleophas *et al.*, 2017).

IV. CHALLENGES IN SOIL EROSION MEASUREMENT

A comprehensive literature review on soil erosion measurement used in water erosion studies was carried out, describing the example of the approach, application, limitations, and advantages. The approaches reviewed represent the ability of the method to describe sediment generation and soil lost through landscapes. Different methods may represent different values depending on the accuracy and validity of the data processes. One should carefully plan on the objective of the study as to prepare the required input data to estimate soil erosion rate accurately. The availability of the data is important as the input parameters are significantly different according to geographical location.

The accuracy of the existing model is always questionable where frequent validation is needed. Even though with all the required input available, accurate soil erosion estimation is still challenging. Each of the input parameter used must be carefully defined and justifiable. Failure in doing so will lead to underestimating or overestimating the erosion rate.

In addition, the whole process of collecting field data can be time-consuming as well as costly. Proper planning and selection of sampling location need to be made carefully to avoid complications such as financial issue. Research methodology should be clearly planned as to avoid constant monitoring which will incur more cost and time taken.

As for future direction, estimation of soil erosion can be made more accurate nowadays with the availability of software and mathematical model that have been developed specifically to predict soil erosion.

V. CONCLUSION

A challenge still exists in selecting a suitable measurement method of soil erosion. More study required using different methods to improve on the quality of the results. Furthermore, a continuous study should be conducted in identifying the advantages and limitations of the associated soil assessment method. Although studies using the approaches are well documented, there remains a need for further work aimed at exploring the potential use of combination method particularly focusing on the accuracy and validity of the data.

The information on soil erosion rates is still lacking in some parts of Malaysia. Due to rapid development with tropical climate, Malaysia is very much exposed to soil erosion risk. Therefore, it is very important to have a clear overview on the factors contributing to the soil erosion, the validity of the approaches used and the presentation of the data to help in decision making. It is recommended to study the effect of factors that contributes to soil erosion by establishing an accuracy assessment on the chosen methodologies.

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