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EVALUATION AND ESTIMATION OF SOIL ERODIBILITY BY USING DIFFERENT TECHNIQUES FOR SOIL EROSION CONTROL

(Research Report)

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ABSTRACT

Soil erodibility is regarded as a key parameter for evaluating the soil's susceptibility to erosion and is essential for predicting soil loss. To date, the available soil erodibility calculation techniques have been widely used around the world. However, it is not well known which of the erodibility calculation techniques is best for a given group of soil at specific geographical location. Likewise, very few investigations have been done so far for the specific situation of soils in Ethiopia. The limited availability of an appropriate method for the estimation of soil erodibility factor-K is the main bottleneck for prediction of a reliable sediment yield. Hence, this study was carried out to investigate the predictive capability of the K-values as estimated by different techniques; to study the interrelationship between different techniques of estimating soil erodibility, and to validate and suggest the best technique(s) for practical applications. Accordingly, different soil erodibility estimation techniques such as Wischmeier and Smith (178), Soil Erodibility Nomograph described by Wischmeier et al. (1971), Shirazi and Boersma (1984), Williams et al. (1984, and based on soil color and class were employed to estimate soil erodibility. The actual soil loss was collected from the runoff test plots and compared to the values of different techniques under investigation. The findings of the study show that the determined K value of soil of the study area, i.e., Cambisols found to be 0.11 t h (MJ mm)$^{-1}$$_{,}$whereas estimated K values using different soil erodibility estimation techniques range from 0.13 to 0.34 t h (MJ mm)$^{-1}$. The K value estimated using Shirazi & Boersma (1984) is relatively high, while those of estimated based on soil type and Wischmeier & Smith (1978) are relatively low. Compared to those K values estimated using different soil erodibility estimation techniques, the K value estimated by soil type was generally found to be closure to the measured K value under natural run off plots. Therefore, under unavailability of soil physicochemical properties of the soil that can be used in different soil erodibility estimators, K value estimated based on soil type is more reliable to be used in RUSLE.The study has shown that testing and validation of the estimated soil erodibility using measured soil loss from the standard RULSE runoff plots are critical for unbiased assessment of the magnitude and spatial distribution of soil erosion at the large-scale. However, as this experiment was conducted only for a single season, it is not likely to give definite recommendation; thus, similar experiment has to be repeated under the same condition. For all major soils in Ethiopia, different soil erodibility estimator techniques have to be validated for estimation of K values to be used in RUSLE model for soil erosion prediction.

Keywords: Soil erodibility, Soil erosion, Soil texture, Natural run off, Universal soil loss equation

1. INTRODUCTION

Soil erosion is a serious environmental, economic and social problem. In Ethiopia, as in many other developing countries, erosion is destroying the topsoil at an alarming rate that exceeds the tolerance rate of soil formation. With rising competition for the limited soil resources, the need for an effective soil erosion prediction model and conservation planning tool is self-evident and paramount. However, soil erosion prediction is a complex and multifaceted process that is affected by a host of factors.

Soil erodibility is regarded as a key parameter for evaluating the soil's susceptibility to erosion and is essential for predicting soil loss and evaluating its environmental effects. Soil erodibility is usually thought of as the amount of soil loss per unit of erosive force, whether it is rainfall, surface flow or seepage. The strength of the raindrop splashes and depth of the surface runoff occurring from precipitation determines the detachability of the individual soil aggregate and bulk transport of the detached soil particles. The detachability of the soil aggregate from the parent soil depends on the strength with which individual soil particles are bound together. The stronger the particles are bound together, the less they will be susceptible to erosion.

The soil susceptibility to erosion is expressed by a soil erodibility factor (K) of the Universal Soil Loss Equation (USLE) as described by Wischmeier & Smith, 1965. The K-factor is defined as the average annual rate of soil loss per unit erosivity index measured on a continuously clean-tilled fallow plot with a gradient of 9% and a slope length of 22.1m (Wischmeier *et al.,* 1971; Romkens *et al.,* 1997). However, different researchers had conducted experiments on plots having different lengths and slopes. Laflen and Moldenhauer (2003) carried out experiments at different locations in China under natural rainfall conditions on plots having a length less than or equal to 22.1m and a slope ranging from 3 to 18% for prediction of soil erosion. Similar experiment was also undertaken in Punjab, India under natural rainfall conditions on plots measuring 5 m x 1.5 m and the average slope of the plots at 4 percent to evaluate and estimate soil erodibility by different techniques and their relationships (Singh and Khera, 2010). Since the direct measurement of the K-value requires the establishment and maintenance of natural runoff plots for long observation periods at various locations, numerous attempts have been made to simplify the costly technique and to propose estimators for the soil erodibility calculation from readily available soil property data and standard profile description.

To date, the available soil erodibility calculation models, such as the USLE (Wischmeier & Smith, 1965), Revised Universal Soil Loss Equation (RUSLE) (Renard *et al.*, 1997), Erosion Productivity Impact Calculator (EPIC) (Sharply & Williams, 1990) and Dg models (Romkens *et al.*, 1988) have been widely used around the world. However, it is not well known which of the erodibility calculation models is best for a given group of soil at specific geographical location because these models were developed based on soil erosion databases from the USA, which are mostly of medium-textured soils. International comparisons have shown ambiguous results regarding which model is the best for soil erodibility estimation (Romkens *et al.*, 1988; Torri*et al.*, 1997). Some efforts have been made to compare models for specific regions or conditions (e.g., watershed/county-scale studies or rainfall simulation studies) (Zhang *et al.*, 2004; Hussein *et al.*, 2007; Zhang *et al.*, 2008; Wang *et al.*, 2012). Unfortunately, it is difficult to conclude which model presents the best calculation because researchers usually only state that one model overestimates or underestimates soil erodibility compared with the others, or even some comparisons are not based on observed data.

Soil erodibility can be assessed by any of three established methods, namely the direct measurement on a natural runoff plots, rainfall simulation studies and predictive relationships. The direct measurement on a natural plots method and rainfall simulation methods need standardized field experimental plots. The methods give a reliable erodibility factor, however, it is costly and time consuming. The predictive relationship approach is the relatively easier method, but the result is less accurate compared to the runoff plot and rainfall simulation methods (Romkens *et al.* 1977). The predictive approaches are based on the soil's physical, chemical and mineralogical properties. Wischmeier *et al.*, (1971) soil erodibility nomograph is the most commonly used predictive method.

Different attempts had been made to establish the erodibility factor relationships with different soil properties. Olson and Wischmeier (1963), El-Swaify and Dangler (1977), Young and Mutchler (1977), Williams *et al.*, (1984), Shirazi and Boersma (1984), Sharpley and Williams (1990) and Chen *et al.*, (1996) are among the common investigations conducted on soil erodibility estimation equations. These investigations suggest certain empirical relations giving soil erodibility values using certain data sets. However, adaptation of the research results of the investigations to other places still remains a big challenge due to the area specific nature of empirical models or the insufficiency of input data to make necessary adjustments for the specific situations of the area under consideration.

Likewise, very few investigations have been done so far for the specific situation of soils in Ethiopia (Habtamu, 2012). The limited availability of an appropriate method for the estimation of soil erodibility factor is the main bottleneck for prediction of a reliable sediment yield.

Therefore, there was a need to assess the existing soil erodibility estimation techniques with respect to data availability. Moreover, devising an alternative approach for the erodibility estimation with a more simplified input parameter makes calculations more effective.

In this study, the most commonly used soil erodibility techniques, explicitly Universal Soil Loss Equation (USLE), Soil Erodibility Nomograph, Shirazi and Boersma (1984) and Williams *et al.*, (1984) methods, and based on soil type and colour ‘’K’’ values were also evaluated as a reference for the derivation of the alternative formula for the estimation of the soil erodibility factor K. Hence, it was with this rationale that this study was initiated with the following objectives.

2. OBJECTIVES OF THE STUDY

2.1 General objective

The general objective of the study was to compare soil erodibility values as assessed by different techniques for the study area.

2.2 Specific objectives

The specific objectives of the study were:

- To investigate the predictive capability of different techniques in estimating the K-value, and
- To validate and suggest the best technique(s) for practical applications.

3. LITERATURE REVIEW

Soil erosion is an important problem in agricultural lands worldwide (Kirkby and Morgan, 1980; Jianping, 1999). In many cases, soil erosion causes an almost irreversible decline in soil productivity and other soil functions (Biot and Lu, 1995; Bruce *et al.,* 1995) and leads to environmental damage. Vegetation growth in semi-arid area is relatively slow, while rainfall events can be intense (Govers *et al.,* 2006). In such area a sudden rainfall event may have a particularly large effect on erosion rates and erosion patterns. Rainfall characteristics, management practices, and ground cover are the key factors contributing to soil erosion (Molnár and Julien, 1998; Arnaez*et al.,* 2007).

Soil erodibility (K), one of the key factors of soil erosion (Igwe, 2003; Fu *et al.,* 2005; Ferreira *et al.,* 2015), is defined as the susceptibility of soil to erosional processes (Bagarello*et al.,* 2012; Bryan *et al.,* 1989). It has been extensively used in both theoretical and practical approaches to measure soil erosion. However, it is a complex concept affected by many factors, including soil properties (Chen *et al.,* 2013; Wang *et al.,* 2015; Manmohan*et al.,* 2012), terrain (Wang *et al.,* 2012; Mwaniki*et al.,* 2015; Parajuli*et al.,* 2015), climate (Hussein *et al.,* 2013; Sanchis*et al.,* 2012), vegetation (Sepúlveda-Lozada*et al.,* 2009), and land use (Cerdà*et al.,* 1998; Tang *et al.,* 2016).

Many authors have used soil erodibility (K factor) in USLE as indicator of soil erosion (Barthès*et al.,* 1999; Parysow *et al.,* 2001) because soil erodibility is a measure of soil susceptibility to detachment and transport by the agents of erosion. The K factor is the integrated effect of rainfall and the resistance of the soil to particle detachment and subsequent transport. These processes are influenced by soil properties, such as particle size distribution, structural stability, organic matter content, soil chemistry and clay mineralogy and water transmission characteristics (Lal, 1994). It was originally derived from five variables, namely the silt plus the very fine sand content, the clay content, the organic matter content, an aggregation index, and a permeability index that have to be combined in a K factor nomograph (Wischmeier *et al.,* 1971). A nomograph to estimate the K factor was derived by Wischmeier *et al.,* (1971) from rainfall simulation experiments.

It was found that the K factor for a particular soil varies considerably on storm, season and year bases. The reason is mainly due to the variation in rainfall and antecedent soil conditions (Kirby and Mehuys, 1987; McConkey *et al.,* 1997). Long term measurements from natural runoff plots are necessary to obtain a representative value for the K factor.

To calculate soil erodibility, many strategies have been researched to understand soil erodibility, including measurements of physical and chemical soil properties, instrumental measurements, mathematical models, and graphical methods (Wei *et al.,* 2017a). Although the direct measurement of soil erosion in large plots under natural rainfall over long periods can provide accurate estimates of soil erodibility, this is a time-consuming and costly method (Bonilla *et al.,* 2012; Vaezi *et al.,* 2016a, b). Therefore, mathematical models are more commonly used to estimate soil erodibility.

Some of the most common estimation models are the universal soil loss equation (USLE), which is an empirical erosion model for predicting long-term average annual soil loss resulting from rainfall events from field slopes in specified cropping and management systems and rangelands (Renard *et al.,* 1997); the nomogram model (NOMO) and the modified nomogram model (M-NOMO), which were established by Wischmeier *et al.* (1971, 1978); the erosion-productivity impact model (EPIC), which was developed by Williams *et al.* (1990); the best nonlinear fitting formula using the physical and chemical properties of the soil, which was developed by Torri*et al.,* (1997); and the estimation model that uses the average size of the soil geometry developed by Shirazi *et al.* (1988).

Each estimation method differs in terms of applicability, even within the same area, because the different estimation methods include different physical and chemical soil properties (Lin *et al.,* 2017; Wang *et al.,* 2013b; Kiani*et al.,* 2016). Consequently, the estimated results can significantly differ among methods because soil conditions vary by region (Lin *et al.,* 2017; Wang *et al.,* 2013b). Selecting the optimal estimation method of soil erodibility is, therefore, critical to estimate the amount of soil erosion.

4. MATERIALS AND METHODS

4.1 Description of the Study Area

The study was carried out in Adama Science and Technology University (ASTU) campus, which is located 90 km Southeast of Addis Ababa with grid reference of 8º32’ longitude and 39º16’ latitude. The study site is characterized by a semi-arid climate having an altitude of 1580 m.a.s.l, an average annual rainfall of 838 mm, average temperature of 20ºC and mean relative humidity of 55.5%. The soil is generally light sandy soil (i.e. about 90% sandy, and 10% sandy-clay). Location map of study area is depicted in Figure 1 below.

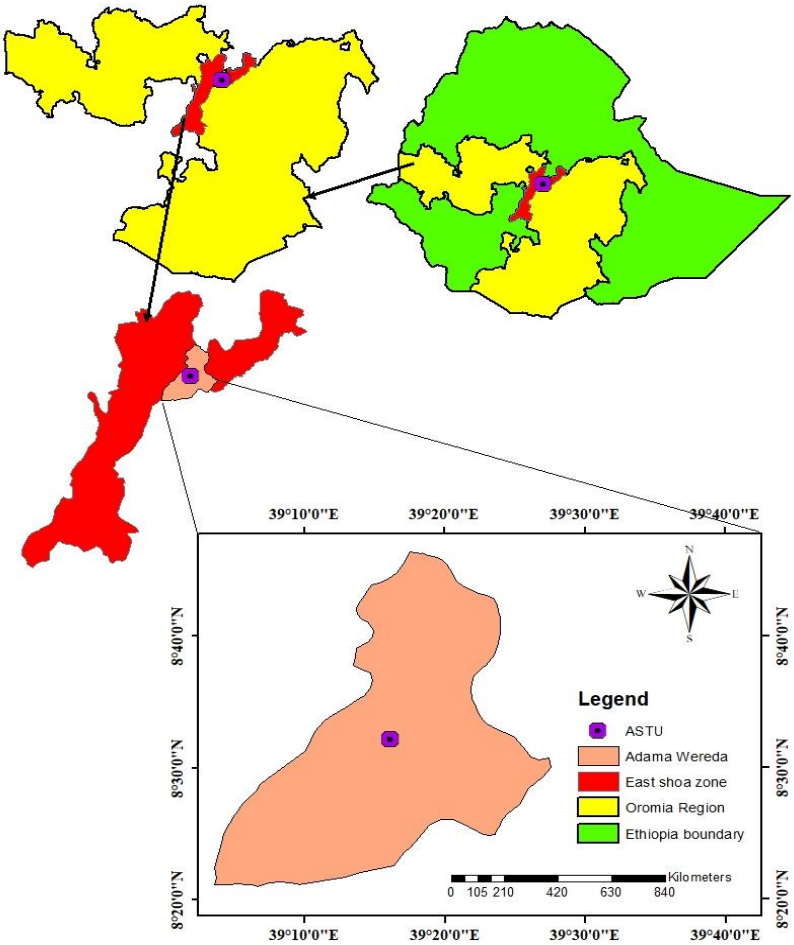


Figure 1:Location map of the study area

4. 2. Universal Soil Loss Equation (USLE)

Wischmeier [1978] recommended USLE as the basis for soil loss estimation as shown in Equation (1). Its six main inputs for soil loss calculation reflect external and internal factors which specifically affect the rate of soil loss. Among them, external factors refer to rainfall erosivity (R), slope gradient (S), slope length (L), cover-management factor (C), and supporting practices factor (P). Internal factor refers to soil erodibility (K-factor). Soil erodibility mainly reflects the ability of soil to resist erosion, the impact of soil type on surface runoff quantity and its ability to resist surface runoff erosion. The six USLE factors often directly appear as individual, unique items to estimate the amount of soil erosion (Wischmeier, 1978) as expressed in the following equation.

$$A = R * K * L * S * C * P \tag{1}$$

Where, A is the annual average soil erosion per hectare (t ha^{-1} y^{-1}); R is the annual average rainfall erosivity factor (MJ mm ha^{-1} h^{-1} y^{-1}); K is the soil erodibility factor (t h MJ^{-1} mm^{-1}); L is the slope length factor (dimensionless); S is the slope steepness factor (dimensionless); C is the vegetation cover and management factor (dimensionless), and P is the erosion control practice factor (dimensionless).

4.3 Physico-chemical Properties of Soils

The soil Erodibility factor measures the susceptibility of soil particles or surface materials to transportation and detachment by the amount of rainfall and runoff input (Renard *et al.*, 1997). It is known that the most easily eroded soil particles are silt and very fine sand and the less erodible soil particles are aggregated soils because they are accrued together making it more resistible (Kim *et al.*, 2005).

The properties used to calculate the K-factor were the followings: the primary particle size fraction as percent clay, percent silt, percent very fine sand, percent organic matter, and the soil structure code and permeability classes. To determine physico-chemical properties of soils of the study site, a composite soil sample from 0-30cm depth of soil was collected from the runoff test plots at the beginning of the experiment. The sample was submitted to Debrezeit Agricultural Research Centre Soil Testing Laboratory for analysis of soil textural class, soil particle distribution and organic carbon (OC). Soil textural class (i.e., per cent sand, silt and clay) was determined by hydrometer method following (Bouyoucos, 1951), and soil particle size distribution was determined by mechanical analysis (sieving method). The mechanical analysis of sieve test was conducted with the available sieve. The procedure of determining the proportion of soil particles in each of sieves with apertures size: 2mm, 900µm, 400 µm), 250 µm), 200 µm) and 125 µm were used. Soil OC was determined following the wet digestion method as described by (Walkely and Black, 1934).

4.4 Soil Erodibility Estimation

Soil erodibility Factor (K) is defined as mean annual rainfall soil loss per unit of R for a standard condition of bare soil, recently tilled up-and-down with slope with no conservation practices and on a slope of 5° and 22 m length Morgan, (1994).Soil erodibility (K) is the intrinsic susceptibility of a soil to erosion by runoff and raindrop impact. The soil erodibility factor was devised by the Natural Resources Conservation Service for use in estimating soil losses with USLE.

Previous research has showed that, among the six USLE factors, there are great difficulties in the quantification of K-factor. This factor is a quantification index of in-situ soil resistance to the processes of separation and transportation. Therefore, it can be considered ‘soil erosion resistance’. Soil erosion resistance is affected by the weathering extent of the bedrock within soil as well as external terrain, topography, climate, vegetation coverage, development, soil and water conservation, erosion extents, etc. The soil erosion resistance decreases as the soil erodibility increases.

The values expressed for K-factor is regional, varies spatially, and is low precision for estimating the soil erosion of large-scale watersheds. Moreover, it cannot differentiate the erosion differences in small areas or plots. These issues create deviations in soil erosion estimates. Also, these values may only be applicable to limited areas downstream and is not representative of the amount of soil erosion for each sub-watershed. Therefore, the estimated results based on these values are greater than real data from field measurement (SWCB, 2011; Lin *et al*., 2016; Lin *et al.,* 2018). Many researchers have conducted in-depth studies to develop algebraic approximations or empirical equations for predicting the K-factor (Wischmeier, 1971; Kinnell, 2010; and Lin *et al*., 2018). The establishment of the parameters employed in these equations to calculate K-factor factor require performing field and laboratory tests on different soil samples. The most common methods used for estimation of soil erodibility are discussed below.

4.4.1 Using Runoff Plot Method

To measure soil erodibility directly, a runoff plots were established with three replications to conduct an experiment under natural rainfall condition. The experiment was conducted from June 2017 to September 2017. Each plot measuring 4 m x 4 m (16 m^2) was prepared on an average 6 per cent slope field to maintain the standard field slope used for soil loss estimation. The plots were protected by sheet metal, which extends 150 mm below and 200 mm above the soil surface. The runoff was collected in tanks. A sheet metal barrier was placed to ensure that only the soil loss and runoff from the plot was collected at the downstream end of each plot. The plots were treated in the same way as the field on which they were situated. The experimental plot layout is shown in Figure 2 below.

Figure 2: Experimental plot layout

Runoff data was collected during each rainfall event after 24 hours at 8:30am and runoff was calculated according to the depth of water collected in the tanks. Once the runoff water was collected in the tanks a sample of suspended water was taken after thoroughly mixing. Then, the tanks were drained and made ready for the next rainfall event. From the total collected runoff 500ml samples were submitted to Melkassa Agricultural Research Centre Water Testing Laboratory to determine soil loss per experimental plot. Accordingly, from the different samples taken for 21 rainy days, the total soil loss for each specific date was computed. Then, the K-values were calculated using Eq. (1), which is a modified USLE equation, where the description of each parameter is the same as the above Eq. (1).

$$K = \frac{A}{RLSCP} \tag{2}$$

For the determination of K value in this method empirically derived Universal Soil Loss Equation, USLE, by Wischmeier and Smith 1978, Eq. (2) was adapted to estimate annual soil lose. The most widely applied soil erosion model, USLE, represents the best compromise between applicability in terms of input data and reliability of soil loss estimate. Major erosion factors such as rainfall, soil erodibility, slope length, slope steepness, soil and crop management, and supporting conservation practices were assigned numerical values. Thus, values of each components of the USLE were determined using the following relations.

Rainfall Erosivity Factor (R). The rainfall and run-off factor (R) represents the energy available to erode in units of MJ-mm/ha/hr/year. Computing R-factor require a continuous record of rainfall intensity. In countries with well-organized meteorological stations, this information is available from weather stations. But, in our case such records are not common in many parts of the Region. At these point the best temporal resolution to provide an input for USLE is a predictive model relating erosivity indices to rainfall amount. Thus, for the determination of this rainfall factor values annual predictive model developed by Zelalem (2008) for central Oromia Regional State was used.

$$R = 0.59 * P^{1.22} \tag{3}$$

Where, P is annual rainfall in mm

Topographic Factor (LS). Topographic factor was determined using an equation developed by Wischmeier and Smith (1978) based on the observations from crop land on slopes ranging from 3 to 18 % and 10 to 100 m long.

$$LS = \frac{n^m}{22.13}\left(65.41\sin^2\theta + 4.58\sin\theta + 0.065\right) \tag{4}$$

Where, n is slope length (m); θ is the angle of slope; m is an exponent depending on the slope. m = 0.2 for gradients < 1 percent, 0.3 for 1 to 3 percent slopes, 0.4 for 3.5 to 4.5 percent slopes, 0.5 for 5 percent slopes and steeper.

Land Cover Factor (C). Crops and cropping practices affect soil erosion in many ways such as the kind of crop, quality of cover, root growth, water use, etc. Its significance is also manifested in the variations of these features within the periods from planting to harvesting, and accordingly affects the soil loss too. Thus, the value of C developed for Ethiopian condition by Hurni (1985) was adopted.

Support Practice Factor (P). Although different erosion control practices exist within the study area, it was not be possible to incorporate them into the model. So, contour ploughing was assumed as a common soil conservation practice. Accordingly, P-factor for the USLE (Morgan, 1995) as shown in Table 1 is considered.

Table 1: Slope gradient and P-factor values for different management practices

Management Practice	Slope Gradient (%)	P-factor
Contouring	<1	0.60
Contouring	2 to 5	0.50
Contouring	6 to 7	0.60
Contouring	8 to 9	0.70
Contouring	10 to 11	0.80
Contouring	12 to 14	0.90
Contouring	>14	1.00

Finally, by combining all the parameters, an estimation of soil erodibility K-factor was determined.

4.4.2 Indirect Methods of K Value Estimation

Direct measurement of the erodibility factor is both costly and time consuming and has been feasible only for a few major soil types. To achieve a better understanding of how and to what extent each of various properties of a soil affects its erodibility, an interregional study was initiated in 1961 (USDA, 1978). In this study different Methods for indirectly estimating soil erodibility were applied by equations based on soil physical properties (texture and organic matter content) as input data: Wischmeier & Smith (1978), Eq. (4); Wischmeier *et al.*, (1971) Soil Erodibility Nomograph, Shirazi Boersma (1984) Eq. (5), Williams *et al.*, (1984) Eq. (6). For the estimation of K value soil types and color were also employed.

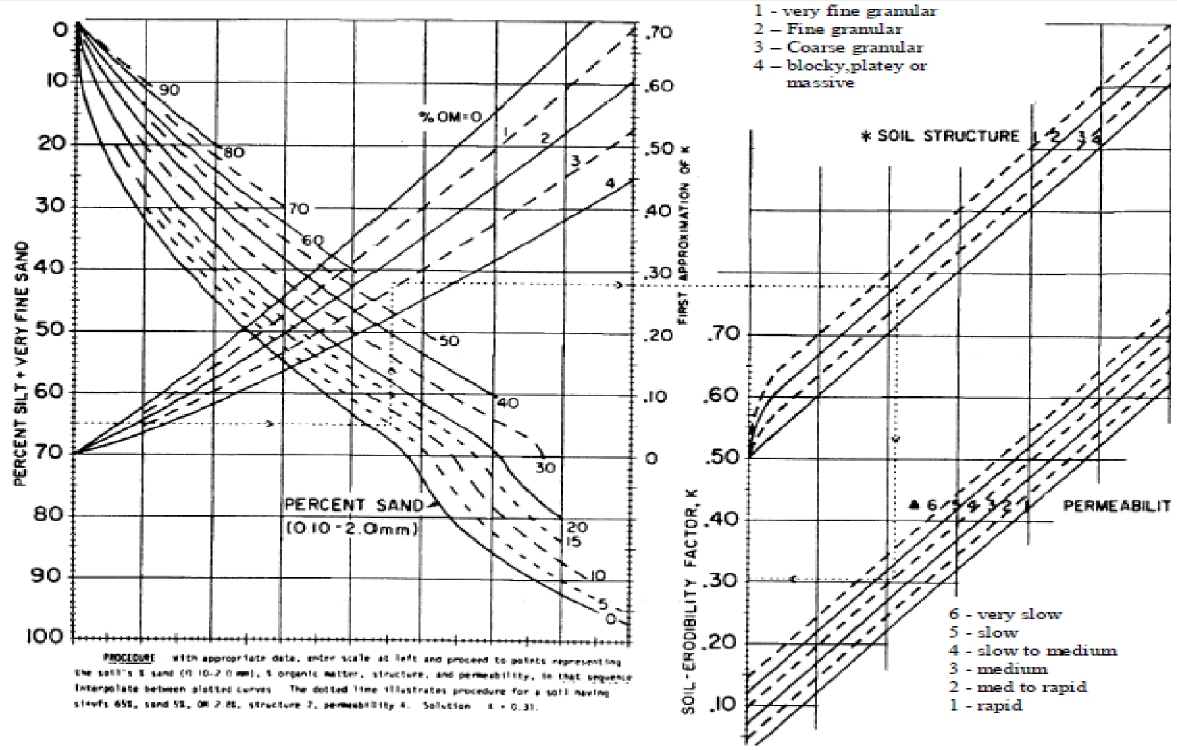
4.4.2.1 Soil erodibility estimation using Wischmeier & Smith (1978] equation

$$K_{USLE} = \frac{0.0002M^{1.14}(12 - OM) + 3.25(C_{soilstr} - 2) + 2.5\,(C_{per} - 3)}{100} \qquad (5)$$

Where, $M = (m_{silt} + m_{vfs}) \times (100 - m_c)$; $OM = 1.7orgC$, m_{silt} = Percent silt (0.002 mm - 0.05 mm); m_{vfs} = Percent of fine sand (0.05 mm - 0.10 mm); m_c = Percent of clay (less than 0.002 mm); orgC = Percent organic carbon; $C_{soilstr}$ = Soil structure code used in soil classification, and C_{perm} = Soil permeability class.

4.4.2.2 Soil erodibility estimation using Nomograph

The most widely used and frequently cited relationship to estimate the K factor using measurable soil properties is the soil-erodibility Nomograph. The soil erodibility Nomograph comprises five soil profile parameters: percent of modified silt (0.002-0.1mm), percent of modified sand (0.1-2mm), percent of organic matter (a), class for soil structure (b) and permeability (c). Per cent organic matter, per cent sand, soil structure and permeability of the soil determined at field condition was transferred to the modified version of Nomographic expression given by Wischmeier *et al.,* (1971) for estimating K in SI units (t/hr/ha/yr-MJ mm) as described in Figure 3 below.



PROCEDURE: With appropriate data, enter scale at left and proceed to points representing the soil's % sand (0.10-2.0 mm), % organic matter, structure, and permeability, in that sequence. Interpolate between plotted curves. The dotted line illustrates procedure for a soil having si+vfs 65%, sand 5%, OM 2.8%, structure 2, permeability 4. Solution: K = 0.31.

Figure 3: Soil erodibility estimation Nomograph (Wischmeier et al, 1971)

4.4.2.3 Soil erodibility estimation using Shirazi and Boersma (1984) - based on physical properties of soil

The soil erodibility Nomograph (Wischmeier *et al.,* 1971) is a popular tool for estimating K values, but it does not apply to some soils. Updating the K-factor for RUSLE involved developing guides so the user could identify soils where the Nomograph does not apply and estimate K using alternative methods. Erodibility data from around the world have been reviewed, and an equation has been developed that gives a useful estimate of K as a function of an "average" diameter of the soil particles. Only soils with less than 10% of rock fragments were considered. The equation in SI units (Foster *et al.*, 1981) can be expressed as:

$$K = 7.594\left\{0.0017 + 0.0494\exp\left[-\frac{1}{2}\left(\frac{\log(D_g + 1.675)}{0.6986}\right)^2\right]\right\} \tag{6}$$

$$D_g(mm) = \exp\left(0.01\sum f_i \times Inm_i\right)$$

Where, fi is the primary particle size fraction in percent, and m_i is the arithmetic mean of the particle size.

4.4.2.4 Soil erodibility estimating using Williams *et al.*, (1984) – soil texture and organic carbon content as an input variable

$$K = f_{csand} \times f_{cl-si} \times f_{org} \times f_{hisand} \tag{7}$$

$$f_{csand} = \left(0.2 + 0.3\exp^{(-0.0256ms)\left(1-\frac{m_{silt}}{100}\right)}\right)$$

$$f_{cl-si} = \left(\frac{m_{silt}}{m_c + m_{silt}}\right)^{0.3}$$

$$f_{org} = \left(1 - \frac{0.25orgC}{orgC + \exp^{(3.72-2.95orgC)}}\right)$$

$$f_{hisand} = \left(1 - \frac{0.7\left(1-\frac{m_s}{100}\right)}{\left(1-\frac{m_s}{100}\right) + \exp^{\left(-5.51+22.9\left(1-\frac{m_s}{100}\right)\right)}}\right)$$

Where, **m_s**= percentage of fine sand (0.05 mm - 0.10 mm); m_{silt}= percentage of silt (0.002 mm-0.05 mm); **m_c** = percentage of clay (less than 0.002 mm), and OrgC = percentage of organic carbon.

4.4.2.5 Based on soil color and soil class ‘K’ values

Main determinants of soil erodibility are soil structural stability and the soils ability to absorb rainfall. These properties in turn depends on a number of characteristics of the soil, such as texture, structure, organic matter content, soil depth and other physical and chemical properties of the topsoil. Though in reality, especially at reconnaissance level, these data are often difficult to find and may not be suitable for extrapolation from one area to another. For these reasons Hurni (1985) derived K values based on easily observable soil colour as shown in Table 2 given for Ethiopian condition is considered.

Table 2: K-values for different soil colors

Soil colour	**Black**	**Brown**	**Red**	**Yellow**
Factor K	0.15	0.2	0.25	0.3

K values for some soils types were experimentally derived using a standard evaluation procedure. These results are then extrapolated to other soil types based on their physical and chemical characteristics as shown in Table 3.

Table 3: K-values for different soil class Rift Valley Lower Basin-RVLB (MoA, 2008)

SI	**RVLB-Soils**	**K-Factor**
1	Andosols	0.2
2	Arenosols	0.19
3	Cambisols	0.13
4	Fluvisols	0.18
5	Luvisols	0.11
6	Luvisols (haplic)	0.09
7	Fluvisols	0.18
8	Leptosols	0.22
9	Nitosols	0.25
10	Solonchaks	0.15
11	Vertisols	0.15
12	Wetland	0

5. RESULTS AND DISCUSSIONS

The results of this study were presented based on the available data despite the whole damage of experimental plots of two treatments (i.e., covered-teff planted and mulching) by wild game during the night time. Since cost was incurred and time was spent, it was commanding to consider the available data of experimental plots of bare soil.

Accordingly, results of estimated soil erodibility index, K value for bare soil in the study area was compared with that of soil erodibility index values determined by different techniques. Then, assessed the accuracy of the widely used erodibility estimators when applied to the study site, and recommended a set of empirical relationships to improve their accuracy for general use in using the RUSLE framework. Finally, implications of this study were discussed for broader application of the RUSLE for soil erosion prediction in the study area.

5.1 Soil Properties of Study Area

The measured soil properties, which were used to estimate soil erodibility for the selected soil attributes were soil textural class (per cent sand, silt and clay particles), per cent organic matter (OM) and soil primary particle sizes as depicted in Tables 4 and 5 below. Soil texture of the experimental field comprised of sand (54.8%), silt (23.4%) and clay (21.8%) as determined by Walkely and Black (1934), which was grouped as sandy clay loam based on the soil textural classification of USDA (1987). The organic matter (OM) content of soil was 0.51%, which was at low level (Murphy, 1968 and Tekalign, 1991), who rated soils having OM value in the range between 0.50 to 1.50% as low. The low soil OM content of the experimental site indicated that very low rate of nutrient mineralization in the soil. The observed soil primary particles, i.e., very course sand, course sand, medium sand, and silt+clay as determined by Sieve Method were in the range of USDA (1987) reference standard except for fine sand of 7.5% in weight. The analysis showed that composite soil sample contained 12%, 21.2%, 16.1%, 8.7%, 7.5% and 34.5% very course sand, course sand, medium sand, fine sand and silt+clay, respectively, which are the most common soil texture classes.

Table 4: Soil texture and organic matter content of the experimental field

Soil properties				
OM (%)	Sand (%)	Silt (%)	Cay (%)	Class
0.51	54.8	23.4	21.8	Sandy clay loam

Table 5: Soil primary particles as determined by mechanical analysis (sieving method)

Particle Size (mm)	Weight (%)	Textural Class	USDA (1987) Reference Standard (mm)
2-0.9mm	12.0	Very course sand	2 - 1
0.9-0.4mm	21.2	Course sand	1 – 0.5
0.4-0.25mm	16.1	Medium sand	0.5 – 0.25
0.25-0.2mm	8.7	Fine sand	0.25 - 1
0.2- 0.14mm	7.5		
< 0.14mm	34.5	Silt +clay	< 0.1

5.2 Estimated Soil Erodibility under Natural Rainfall Condition

Under natural rainfall condition the measured annual soil loss from an experimental field was found to be 58.67 kg/year, on converting this soil loss to hectare base, the total soil loss from the study area was found to be 36.7 ton/ha/year. From this estimated annual soil loss the computed mean soil erodibility index for the study area, clay loam soils, was found to be 0.11.Results indicate that sandy clay loam soil has the least mean erodibility index (0.11). This indicates that the soils falls within a low-moderate erodibility range. The results also fall within the range reported by USDA, (1978) for the sandy clay loam.

5.3 Computed ''K'' Values as Estimated by Different Techniques

Based on the determined soil parameters, K-values of the study area were estimated using different soil erodibility techniques. The estimated K values as determined by different techniques ranged between 0.13 and 0.34, and all values were higher than the estimated K value (0.11) under natural rainfall condition (Table 6).

Table 6: Computed K values as determined by different techniques

Estimation technique	**Computed K value**	**Measured K value**
Using Wischmeier & Smith (1978] equation	0.181	
Using Nomograph (Wischmeier et al., 1971)	0.25	
Using Shirazi & Boersma, [1984] equation	0.34	0.11
Using Williams *et al.*, 1984 equation	0.184	
Based on soil type	0.13	
Based on soil colour	0.3	

The K values for the study area were calculated using different techniques showed that the K values varied from 0.13 to 0.34 (Table 6). The K value (0.34) estimated using Shirazi & Boersma, [1984] equation was found relatively higher than the k values estimated using the other equations, whereas the K value (0.13) estimated using soil type was generally lower than the K values estimated using the other equations. In addition, the difference between the K values estimated using Wischmeier & Smith (1978) equation, Wischmeier *et al.*, 1971 equation, soil colour and soil type, were found negligible. On the other hand, the estimated K value (0.11) under natural rainfall condition is nearly closure to the K value (0.13) estimated based on soil type, and followed by Wischmeier & Smith (1978) equation (0.181) and Williams *et al.,* 1984 equation (0.184) as shown in Table 6 above.

In the contrary, the estimated K values using Nomograph expression, Shiraz and Boersma (1984), and based on soil colour were higher than the actual K value by 227%, 272%, 309%, respectively. This broad comparison of the magnitude of the K values between different soil erodibility estimation techniques suggests that Shirazi & Boersma, (1984) equation and soil colour based estimators may over-predict soil erodibility when applied to sandy loam soil of the study area. Of the eight major soils in Awash Basin, soil property data of Cambisols were used to test and validate of Eqs. (5) to (7), Wischmeier & Smith (1978), Shiraz and Boersma (1984) and Williams *et al.,* 1984, respectively, soil erodibility Nomograph, soil type and colour based to assess the accuracy of these erodibility estimators. The estimated K values using Eqs. (5) to (7), soil erodibility Nomograph and based on soil colour all considerably higher than the measured K value for Cambisols in the study area. Direct application of the erodibility estimator without adjustment would lead to over prediction of soil erosion rates in the study area. The estimated K values using Eqs. (5) to (7) were 1.65 – 3.1 times greater than the measured value, and the estimated K value was on average higher than the measured value by 0.23 using Eq. (6), 0.19 for K value estimated using soil colour and 0.14 using soil erodibility Nomograph as shown in Table 6 above.

In terms of this set of empirical relationships for erodibility estimation, soil type based K value estimation, when compared with Eq. (6), was by far the best of the five estimators followed by the Eq. (5) & (7).

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The K factor is one of the key parameters required for soil erosion prediction using RUSLE in Ethiopia and elsewhere in the world. At present, long-term monitoring of soil loss from natural runoff plots is the only way to obtain the K value for the soil. However, Ethiopia has a vast territory with a wide range of soils. It is difficult and impractical to set up runoff plots for each and every soil type. Therefore, there is a genuine need for estimators of soil erodibility from soil data that are more readily available. Testing and validating these estimators of soil erodibility has been one of the primary objectives of the research.

Using the measured soil loss from natural runoff plots from single site and single season, this study revealed a set of measured K value and a set of estimated K values, and the following conclusions are forwarded:

- The measured K value of for the study area, i.e., Cambisols found to be 0.11 t ha (MJ mm)$^{-1}$$_{,}$ whereas estimated K values using different techniques range from 0.13 to 0.34 t h (MJ mm)$^{-1}$. The K value estimated using Shirazi & Boersma (1984) is relatively high, while those of estimated based on soil type and Wischmeier & Smith (1978) were relatively low.

- Compared to those K values estimated using different techniques, the K value estimated at soil type was generally found to be closure to the measured K value using the natural run off plots.

- There was a close relationship between the measured value (0.11 t h (MJ mm)$^{-1}$) and those calculated from the existing soil erodibility estimators, based on soil type [0.13 t h (MJ mm)$^{-1}$], although the calculated values are higher than the measured K value in the case of Shirazi & Boersma (1984) equation.

- The Shirazi & Boersma (1984) equation and Nomograph method estimation of soil erodibility estimators are not applicable under studied conditions for the estimation of K value to be used in RUSLE. The reason may be that these methods are based on the data sets or experiments which were not conducted under Ethiopian conditions and being empirical in nature these cannot be extrapolated to other locations. Shirazi & Boersma (1984) and Nomographic method have to be modified to be used under Ethiopian conditions.

- The soil erodibility values calculated indirectly by the different techniques tested are distinct for the considered soil type, except for the soil type based estimator, which produced K-factor similar to measured K value using natural run off plots. Soil erodibility can be estimated indirectly by models fed with data on soil texture and organic matter. However, the models proposed by Wischmeier et al., (1971), Shirazi & Boersma (1984), Williams et al., (1984) and soil colour based estimation are not suitable for the study area because they overestimate K- factor values for Cambisols, which are highly vulnerable to soil erosion.

6.2 Recommendations

- Under unavailability of soil physicochemical properties of the soil that can be used in different soil erodibility estimator, K-factor value estimated based on soil type is more reliable to be used in RUSLE.
- The study has shown that testing and validation of the estimated soil erodibility using measured soil loss from the standard RULSE runoff plots are critical for unbiased assessment of the magnitude and spatial distribution of soil erosion at the large-scale. However, as this experiment was conducted on small scale only for a single season, it is not likely to give definite recommendation. Hence, similar experiment has to be repeated under the same condition.
- For all major soils in Ethiopia, different soil erodibility estimator methods have to be validated for estimation of K values to be used in RUSLE model for soil erosion prediction.

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ANNEXES

Annex 1: **Soil physicochemical properties**

	Name of institute ETHIOPIAN INSTITUTE OF AGRICULTURAL RESEARCH	Doc. number: EIAR/RL/F5.10-2	Version No: 2 Page 1 of 3
Document Title:	TEST REPORT	Effective date:	July 2016

Issue Date: - 18/12/2017

Report No:

Service RequestNo.D/097/17

1. Name of Laboratory: Debrezeit Agricultural Research laboratory

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3. Date and Place of Sampling: 4. Sampled and Submitted by: Dr. Mengistu Sime

5. Date Sample Received: 12/10/2017 6. Type of Sample: soil

7. Sample condition: Dry 8. Date of test performed: November, 2017

Lab.ID.	RESULTS/PARAMETERS TESTED				
	OC (%)	TEXTURE			
		Clay (%)	Silt (%)	Sand (%)	Class
3215	0.51	21.8	23.4	54.8	Sandy Clay Loam
Method	Walkley &Black (1934)	Hydrometer			

Mechanical analysis (sieving method)

Lab.ID.	RESULT/PARAMETER TESTED					USDA Reference standards (mm)
	TEXTURE					
	Sieve No	Sieve size	Aperture(mm)	Weight (%)	Textural class	
3215	10-20	0.9mm	2-0.9mm	12.0	Very course sand	2-1
	20-40	0.4mm	0.9-0.4mm	21.2	Course sand	1-0.5
	40-60	0.25mm	0.4-0.25mm	16.1	Medium sand	0.5-0.25
	60-80	0.2mm	0.25-0.2mm	8.7	Fine sand	0.25-0.1
	80-100	0.14mm	0.2- 0.14mm	7.5		
	>100		< 0.14mm	34.5	Silt +clay	<0.1

Remark:

- The mechanical analysis of sieve test was conducted with the available sieve
- The procedure of determining the proportion of soil particles in in each of sieves with apertures size : 2mm , 900µm , 400 µm) , 250 µm), 200 µm) and 125 µm

Sieve no	Apertures (mm)
10	2mm
20	900 microns
40	400 microns
60	250 microns
80	200 microns
100	140 microns

Prepared by (name & sign.):____________

Approved by (name & sign.):________________

Annex 2: **Measured soil loss from runoff plots Data**

Lab no.	Rep.	Trt.	Run-off	Date	Beaker and dry soil weight in gm dried at 105 C^0	Beaker weight in gm	soil loss weight in gm
1	1	3	13	7/11/2009	406.8	405.4	1.4
2	1	3	16	9/11/2009	410.1	407.9	2.2
3	1	3	36	15/11/09	424.8	408	16.8
4	2	3	5	9/11/2009	403.3	402.1	1.2
5	2	3	5	15/11/09	407.9	406.5	1.4
6	2	3	2	23/11/09	407.3	405.9	1.4
7	3	2	9	9/11/2009	632.5	631.1	1.5
8	1	2	4	26/11/09	255.6	244.9	4.1
9	1	1	11	15/11/09	238.7	234.1	4.6
10	1	2	1	23/11/09	257.7	249.1	8.6
11	1	3	3	23/11/09	227.9	225.9	2
12	1	2	65	24/11/09	242.6	236.5	6.1
13	2	3	5	26/11/09	242.9	240.7	2.2
14	2	3	1	26/11/09	245.7	235	10.7
15	2	3	2	1/12/2009	247.2	243.6	3.6
16	3	2	84	26/11/09	244.7	237.8	6.9
17	3	3	16	26/11/09	411.4	409	2.4
18	3	3	1	26/11/09	253.2	242.3	10.9
19	3	2	1	23/11/09	248.4	245.3	3.1
20	1	3	34	30/12/09	412	410.2	1.8
21	1	3	9	1/12/2009	411	405.9	5.1
22	1	3	12	2/12/2009	409	407.3	1.7
23	1	3	75	6/12/2009	633	630.8	2.2
24	1	3	54	12/12/2009	412	409.1	2.9
25	1	3	8	18/12/09	408.6	406.1	2.5
26	2	3	4	18/12/09	408.1	407.1	1
27	1	3	42	21/12/09	415.1	412.1	3
28	1	3	9	26/12/09	409	408.1	0.9
29	2	3	24	30/12/09	237.5	213.4	6.1
30	2	3	4	2/12/2009	234.5	232.3	1.9
31	2	3	4	6/12/2009	254.5	245	9.5
32	2	3	47	12/12/2009	257.4	242.2	15.2
33	2	3	35	21/12/09	223.6	220.9	2.7
34	2	3	27	20/12/09	237.6	235.9	1.7
35	2	3	22	26/12/09	242.2	239.4	2.8
36	3	3	19	30/12/09	233.2	236.3	1.9

Annex 2: Cont'd …

Lab no	**Rep.**	**Trt.**	**Run-off**	**Date**	**Beaker and dry soil weight in gm dried at 105 C^0**	**Beaker weight in gm**	**soil loss weight in gm**
37	3	3	19	1/12/2009	234.5	233.5	1
38	3	3	4	2/12/2009	249.7	239.4	10.3
39	3	3	4	6/12/2009	221.7	217.3	4.4
40	3	3	6	12/12/2009	237.7	227.2	10.4
41	3	3	13	18/12/09	237.9	219.9	20
42	3	3	25	21/12/09	232	230	2
43	3	3	15	24/12/09	244.9	240.9	4
44	3	3	10	26/12/09	235.7	234.8	0.9
45	3	3	61	1/13/2009	236.4	239.2	2.2
46	1	1	10	2/13/2009	245.9	240.3	5.6
47	1	2	21	1/13/2009	246	242.4	3.6
48	1	2	16	1/13/2009	239.7	230.7	6
49	1	3	27	2.13/09	245.7	243.7	2
50	1	3	17	2/13/2009	243	242	1
51	2	3	15	1/13/2009	247	239.7	7.1
52	2	3	12	2/13/2009	252.5	248.2	4.9
53	2	1	18	1/13/2009	239	235.1	3.9
54	2	2	38	1/13/2009	235.6	233.2	2.4
55	2	1	9	2/13/2009	242.6	237.9	4.7
56	2	1	51	1/13/2009	241	240.9	0.1
57	3	1	15	2/13/2009	406.3	401.3	5
58	3	2	11	1/13/2009	408.2	407.2	1
59	3	2	31	2/13/2009	407.9	405.3	2.6
60	3	3	12	1/13/2009	411.9	409.9	2
61	3	3	12	2/13/2009	410.9	408.3	2.6
62	3	1	10	2/13/2010	407.3	406.9	0.4
63	3	1	37	6/1/2010	408.9	407.3	1.6
64	3	1	57	1/1/2010	408.9	406.9	2
65	3	1	10	13/1/10	408.8	407.8	1
66	3	1	120	21/1/10	407.9	407	0.9
67	3	2	24	2/1/2010	237.2	234.3	4.9
68	3	2	20	6/1/2010	410.9	409.9	1
69	3	2	23	1/1/2010	412.9	410.2	1.99
70	3	2	7	13/1/10	409.7	408.7	1
71	3	2	65	21/1/10	249.2	239.9	10.3

Annex 2: Cont'd…

Lab no	Rep.	Trt.	Run-off	Date	Beaker and dry soil weight in gm dried at 105 C^0	Beaker weight in gm	soil loss weight in gm
72	3	3	8	2/1/2010	248.9	238.9	2
73	3	3	10	6/1/2010	260	257.3	2
74	3	3	17	1/1/2010	416.7	414.9	1.8
75	3	3	2	13/1/10	411.7	409.3	2.4
76	1	3	9	2/1/2010	409	403.4	5.6
77	1	3	21	6/1/2010	407.3	407	2.3
78	1	3	26	11/1/2010	415.3	410.5	1.9
79	1	3	5	13/1/10	416.7	411.3	5.1
80	1	3	47	21/1/10	410.3	406.5	3.8
81	3	3	8	2/1/2010	408.1	404.2	3.9
82	3	3	10	6/1/2010	414.6	405.3	9.3
83	3	3	17	11/1/2010	407.5	402.1	5.4
84	3	3	2	13/1/10	413.2	411.3	1.9
85	3	3	31	21/1/10	405.4	401	3.5
86	2	3	1	2/1/2010	407.3	404.3	3
87	2	3	7	6/1/2010	409.9	406.2	3.1
88	2	3	14	11/1/2010	412.2	409.3	2.9
89	2	3	3	13/1/10	417.2	416	1.2
90	2	3	42	21/1/10	405.3	403	2.3

Annex 3.**Soil erodibility estimation as computed by different techniques**

A/ Soil erodibility estimation using universal soil loss equation (USLE)

A= R*K*L*S*C*P

A= total soil loss (ton/ha/yr.) = 36.7 ton /ha/yr.

R= Rainfall erosivity factor= 2398.36 (calculated)

K= soil Erodibility factor =?

L= Slope length factor

S= slope gradient factor $\}$ 0.243 (calculated)

C= Land cover factor = from table = 0.60

P= Management factor = from table = 1.0

LS =$(\frac{L}{22})^{0.5}$ (0.065 + 0.045*S+ 0.0065*S^2)

L= Slop length (m) = 4m

S= Slop deepness (%) = 6%

Point "A"- upper altitude = 1695.gm

Point "B" Lower Altitude = 1683.gm

Height = 12.0m sin∅ = 12/20 = 6%

LS= $(\frac{4}{22})^{0.5}$(0.065 + (0.045x6) + (0.0065 x6^2)

= $(\frac{4}{22})^{0.5}$ x 0.569 = 0.24262242 = $\underline{\underline{0.243}}$

Annual soil loss from (4x4) m = 5867.46gm

= $\underline{\underline{58.67\text{kg}}}$

Annual soil losses from one hectare

16m2 = 58.67 kg

10,000m2 =?

From one ha = $\frac{10{,}000m2\ x\ 55.67kg}{16m2}$ = 36,668.87kg

= 36,669kg

Annual soil loss= $\underline{\underline{36.7}}$ ton/ha/yr. = $\underline{\underline{36.7}}$ ton

R = 0.5g x p $^{1.22}$

P value for Adama = 908.35 (Average)

R= 0.59 x (908.35) 1.22

R= $\underline{\underline{2398.40}}$

K = $\frac{A}{R\ x\ LS\ xC\ xP}$ = $\frac{36.7\ ton/ha/yr}{(2398.36\ x\ 0.243\ x\ 0.6x1)}$ =$\frac{36.7}{349.65}$ = 0.10495 = $\underline{\underline{0.11}}$………Measured "K" value for Adama area

B/ Determination of “K” value using different techniques

i) Soil erodibility estimation using USLE

$$\text{KUSLE} = \frac{0.0002\ M^{1.14}\ (12\text{-OM}) + 3.25\ (\text{Csoilstr} -2) + 2.5\ (\text{Cperm}-3)}{100}$$

Where: M= (Msilt + M_{vfs}) * (100-Mc)
OM= 1.7 OrgC
M_{silt}= percent of silt
M_{vfs} = percent of fine sand
Mc= percent of clay
OrgC = percent Organic carbon
$C_{soilstr}$= soil structure code used in soil classification
C_{perm} = soil permeability class.
OM= 1.7 * OrgC

Given Required:

Msilt= 23.4 % = 1.7 * 0.51 K =?
M_{clay} = 21.8% = 1.7 * 0.51
$M_{vfs} =$ 7.5% = 0.867%
C_{perm} = 2.5
$C_{soilstr}$ = 3

Solution:

OM= 1.7 * OrgC = 1.7*0.51
= **0.867%**
M = (23.4 + 7.5) * (100 - 21.8)
= 30.9 * 78.2 = 2,416.4

$$K_{USLE} = \frac{0.0002 * (2{,}416.4)^{1.14}\ (12 - 0.867) + 3.25\ (3 - 2) + 2.5\ (2.5 - 3)}{100}$$

$$= \frac{1.438\ (11.133) + 3.25 - 1.25)}{100} = 0.1801$$

ii). Soil erodibility estimation using Nomograph

Given: Required:

Percent of Silt = 23.4 K=?
Percentage very fine sand = 7.5 } 30.9%
Percent of sand = 54.8%
OM= 0.867%
Soil structure =moderate to coarse granular
Permeability = Moderate

Solution:

By having this data, we can determine “K” = 0.25 t/hr /ha/yr.-MJmm

iii) Soil erodibility estimation using shirts & Boersma (1984) based on physical properties of soil

$$K = 7.594\left\{0.0017 + 0.0494\exp\left[-\frac{1}{2}\left(\frac{\log\left(D_g + 1.675\right)}{0.6986}\right)^2\right]\right\}$$

$$D_g\left(mm\right) = \exp\left(0.01\sum f_i \times Inm_i\right)$$

Where fi= is the primary particle site fraction in percent
Ni = is the arithmetic mean of the particle size.

For very coarse sand = 2 to 0.9 $=\frac{0.9+2}{2}= 1.45$

Course sand = 0.9 to 0.4 = $\frac{0.9+0.4}{2}= 0.65$

Medium sand = 0.4 to 0.25 = $\frac{0.4+0.25}{2} = 0.325$

Fine sand = 0.25 to 0.2 = $\frac{0.25+0.2}{2} = 0.225$

vfs and = 0.2 to 0.14 $=\frac{0.2+0.14}{2} = 0.17$

S.H + clay = 0.14 = 0.14

∑fi*lnmi

= 12*in 1.45 = 4.45876

= 21.2 * in 0.65 =-9.1329

= 16.1 * in 0.325 = -18.1

= 8.7 * in 0.225 = -12.977

= 7.5 * in 0.17 = -13.3

= 34.5 * in 0.14 = - 67.83

= -116.881

Dg ($_{\text{mm}}$) = exp (0.01* - 116.887 =exp (-1.16887) = <u>0.06778</u>

K= 7.594 (0.0017 + 0.494 exp [$-\frac{1}{2}\left(\frac{\log(0.06778+1.675}{0.6986}\right)^2$]}

= 7.594 {0.0017 + 0.0494 exp(-0.059624)}

= 7.594 (0.4323286) = 0.339= **<u>0.34</u>**

iv) Soil erodibility estimation using Williams (1984)

Soil texture & Organic carbon content us an input variable.

$$K = f_{csand} \times f_{cl-si} \times f_{org} \times f_{hisand}$$

$$f_{csand} = \left(0.2 + 0.3 \exp^{(-0.0256 ms)\left(1-\frac{m_{silt}}{100}\right)} \right)$$

$$f_{cl-si} = \left(\frac{m_{silt}}{m_c + m_{silt}} \right)^{0.3}$$

$$f_{org} = \left(1 - \frac{0.25 orgC}{orgC + \exp^{(3.72 - 2.95 orgC)}} \right)$$

$$f_{hisand} = \left(1 - \frac{0.7\left(1-\frac{m_s}{100}\right)}{\left(1-\frac{m_s}{100}\right) + \exp^{\left(-5.51+22.9\left(1-\frac{m_s}{100}\right)\right)}} \right)$$

<u>Given</u>:<u>Required:</u>

Ms = 54.8% K=?

Mc = 21.8

Msilt = 23.4

OrgC = 0.51

<u>Solution:</u>

F$_{\text{csand}}$ $= 0.2 + 0.3\ (-0.0256 * 54.8)\ (1 - \frac{23.4}{100})$

= 0.2 +0.3 exp (-1.0746) = <u>0.2253</u>

Fc1 –s1 = $\left(\frac{23.4}{21.8+23.4}\right)^{0.3}$ = 0.821

F$_{\text{org}}$ = 1- $\frac{0.25*0.51}{0.51+1\exp 2.2155}$ = 0.<u>1275</u> =<u>0.999</u>

$$F_{csand}= \frac{0.7\ (1-\frac{54.8}{100})}{(1-\frac{54.8}{100})+\exp\ (\ -5.51+22.9\ (1-\frac{54.8}{100})}$$

$$\text{Fcsand}\ = 1-\frac{0.7*0.452}{0.452+\exp 4.8408}$$

$$= 1\text{-}\ \frac{0.3164}{0.452+\exp 4.8408} = \underline{\underline{0.999}}$$

K= 0.2253 * 0.821 * 0.999 *0.999

= $\underline{\underline{\mathbf{0.184}}}$

Annex 4. **Fund utilized**

The amount of fund allocated for the research project was Birr194, 550 (One Hundred Ninety Four Thousand Five Hundred Fifty Birr), of which Birr164, 303.08 was utilized for the purpose. Detail cost items are described in the table below.

S/N	Cost Items/Descriptions	Allocated (Birr)	Utilized (Birr)	Difference (Birr)
1.	Local travel (car rent)	48,000.00	17.000.00	+31,000.00
2.	Field subsistence	46,560.00	46,560.00	-
3.	Laboratory service	30,000.00	30,000.00	-
4.	Purchase of equipment & materials	69,490.00	70,350.60	-860.60
5.	Consumables	500.00	392.48	+107.52
	Total	**194,550.00**	**164,303.08**	**30,246.92**
Fund utilized in per cent (%)		**84.02**		

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