A Numerical Hydrologic Analysis to Predict the Cumulative Sediment at Shewasur Reservoir in Kurdistan Region-Iraq

By: Majeed Kakarash Omar

Date: 9th Sep 2014

School of Life and Medical Sciences
MSc, Postgraduate Diploma, Postgraduate Certificate
Water and Environmental Management

www.herts.ac.uk

Abstract

In Iraq, in particular, Shewasur Valley, the implications of high sediment concentrations in the watershed are becoming a major concern. Soil erosion and sediment-related problems threaten sustainable land management and water resources development. In response to such threats, there is an urgent need for improved catchment-based erosion control and sediment management strategies. One of the most important strategies related to erosion control measures and sediment yield is to estimate annual eroded soil and understanding of the factors that govern the delivery of sediment through the catchment area. In this study, the principal factors and processes controlling sediment yield from the watershed are critically discussed in the context of temporal and spatial scale. Three models were used to estimate sediment loads from soil loss due to rainfall in the 103 Km^2 Shewasur Catchment. The applied models were the Universal Soil Loss Equation (USLE), Universal Soil Loss Equation for discretised segments (DUSLE) and Modified Universal Soil Loss Equation (MUSLE) for annual and single event loading predictions. The gross soil erosion in each segment was accurately estimated using three different approaches. The parameters of the USLE were evaluated using digital elevation model (DEM), A watershed modelling system (WMS) was selected as a hydrological model to simulate Shewasur catchment for the feasibility study. For the purpose of deposition, the concept of sediment delivery was applied to the catchment using Vanoni's empirical equation. The results show that USLE overestimates the annual sediment yield as observed by the direct approach. However, both DUSLE and MUSLE provided different results for the total eroded soil, results obtained by MUSLE was closer than USLE and DUSLE from the actual amount of sediment yield. The average annual sediment yield has been considered to estimate the useful life and full life predictions of the reservoir and annual capacity loss. The useful life of the reservoir shows that over the next 38 years the reservoir can no longer serve it's primary objectives due to accumulation huge amount of deposited sediment in the base of the reservoir.

Acknowledgements

This research project would have been impossible to perform without a group of people who encouraged me, helped and advised me throughout its development.
I would like to express my deep gratitude to Dr. Tim Sands, my research supervisors, for his patient guidance, enthusiastic encouragement and useful critiques of this research work. I would also like to thank Dr. Avice Hall for her advice and assistance in keeping my progress on schedule. My grateful thanks are also extended to Mr. Abbas Jabbari for his help in collecting the surveying data analysis. I would also like to thank the staff of the following organizations for enabling me to visit their offices to observe their daily operations:

General Directorate of Water and Sewerage -Ministry of Tourism and Municipality-KRG

HCDP Team from the Ministry of Higher Education and Scientific Research- KRG

Ministry of Agriculture and Water Resources-KRG

Harman Company For General Contracting

HMR Company for Hydraulic and Civil Engineering Services

Koya Meteorological Stations.

I would also like to extend my thanks to the technicians of the laboratory of the College of Engineering Department-Salahaddin University for their assistance in offering me the resources in running the program. Finally, I wish to thank my parents for their support and encouragement throughout my study.

TABLE OF CONTENTS

List of Tables	Page No

List of Abbreviations and Acronyms

ASAE: American Society of Agricultural Engineers

ASCE: American Society of Civil Engineers

ASTM: American Society for Testing and Materials

BMP: Best management practices

CM: Cover Management Factor

CN: Curve Number

DEM: Digital Elevation Map

DUSLE: Discretised Universal Soil Loss Equation

EC: Erosion Classes

FAO: Food and Agricultural Organisation

ISI: International Sediment Initiative

KRG: Kurdistan Regional Government-Iraq

MAWR: Ministry of Agriculture and Water Resources -KRG-Iraq

NGL: Natural ground level

MUSLE: Modified Universal Soil Loss Equation

NCSL: Non-cumulative slope length

NRCS: Natural resources Conservation Service

OM: Organic Materials

OTTHYMO: hydrological and hydraulic computer model

PLU: Prior Land Use

R.M: Rational Method

SCS: Soil Conservation Service

SDR: Sediment Delivery Ratio

SM: Soil Moisture

SR: Surface Roughness

T.E: Trap Efficiency

USDA: United States Department of Agriculture

USGS: United States Geological Survey

USLE: Universal Soil Loss Equation

USSCS: United States Soil Conservation Service

WMS: Watershed Modelling System

1. Introduction

1.1. Background

The processes of erosion, sediment delivery and sediment transport are fundamental components and measures of the functioning of the Earth system (Walling D.E, 2007).The redistribution processes of erosion and sediment are the principal drivers of landscape development and play a significant role in soil development. Equally, the sediment load of a river basin supplies an important measure of its morphodynamics, the hydrology of its drainage basin, and the erosion and sediment delivery processes operating within that basin (Walling, D.E. and Fang, D, 2003). The construction of dam and reservoir projects plays important roles in the development of hydropower, management of water resources and flood control. However it makes a diverse impact on regional ecological environment. The environmental impact of hydrological system mainly concern with the numerical analysis of the measured runoff, inflow sediments and trap efficiency after the operation of the project. Before construction of hydraulic structures, dam projects are strategically and environmentally assessed according to the most updated advancements in engineering standards with respect to floods, seismic hazards and other causes of failure, such as overtopping of the dam, foundation defects, and slope instability (Wildi, 2010). After dam and reservoir projects are completed, the significant environmental threat to the sustainability of reservoirs is sedimentation (Figure 1).

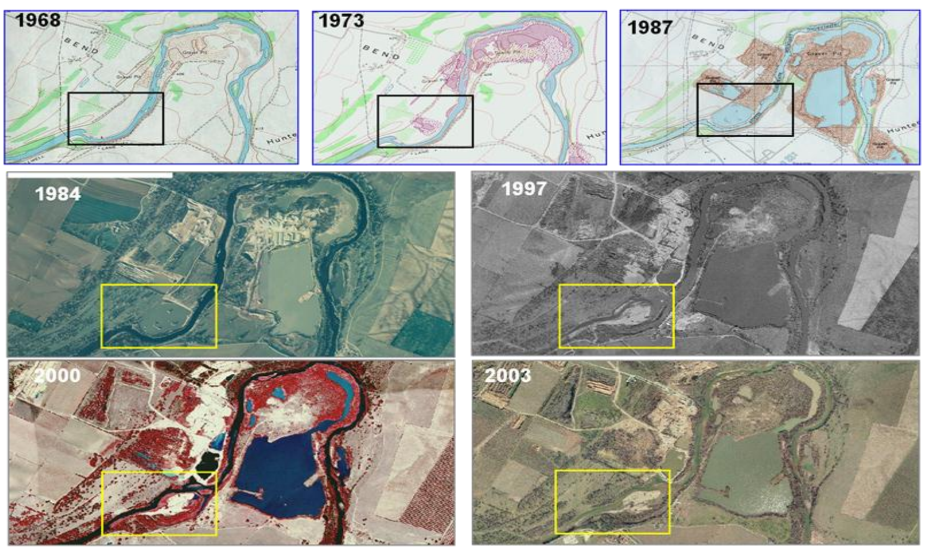


Figure 1. A series of adverse environmental impacts of Glen Canyon Dam on the Colorado River in northern Arizona in the United States. Source: https: // www. Google .co.uk/ search ? q = images+of+colorado+sedimentation

Notwithstanding, sediment deposition in reservoirs can cause detrimental effects for reservoir operation and downstream fluvial system such as channel incision, change in geochemical cycles by storage of contaminants, nutrients and major elements; for example nitrate and phosphorus cycles (Wang et al, 2012). In addition to their impact on the sustainable life of reservoir, the magnitudes of the sediment loads produced by a watershed have important implications for the functioning of the system.

For instance through their influence on material fluxes, geochemical cycling, water quality as shown in the (Figure 2), channel morphology, delta development, and the aquatic ecosystems and habitats supported by the river (Montgomery, 2007). As a result, necessary and accurate estimation of the soil erosion, Sediment Delivery Ratio (SDR), trap efficiency and annual lost capacity are therefore substantially important (Ran et al. 2013). In this study three different models of soil loss estimation are applied to the Shewasur Watershed with explaining and analysing the factors and parameters that are governing soil loss in the catchment. Secondly, a number of sediment management alternative techniques will be economically and hydrologically evaluated as a proper solution to reduce the amount of sediment deposition in areas with tolerable erosion. construction of checkdams and increased cultivation are among those mitigation processes that have a positive environmental impact on declining the annual eroded soil and sediment discharge rate in the proposed reservoir.

Figure 2. The Metolong Dam is overtopped due to high inflow sedimentation in March 2014. Lethoso- South Africa. (http://www.engineeringnews.co.za/article/lesothos-metolong-dam-close-to-completion-2014-05-05).

1.2. Sedimentation concerns from the global perspective

Currently, nearly 70% of the world's rivers are intercepted by large reservoirs. It is estimated, that 1% of the existing storage capacity in the world is lost each year by sediments, causing serious problems for water and electricity supply, flood control as well as for ecosystem development up and downstream dams (WCD, 2000).The theoretical sediment trapping efficiency in these reservoirs are high, half of the reservoirs showing a local sediment trapping efficiency of 80% or more (Vörösmarty et al., 2003). In some basins, such as the Colorado, and Nile as shown in the (figure 3), sediment is trapped completely due to large size of the reservoirs and flow diversion (Walling and Fang, 2003). Excessive sediment loads will also have important consequences for river management for navigation and flood control. Basson (2008) also emphasized that by the end of 2050, approximately 64% of the world’s current reservoir storage capacity will have been filled with sediment.

Figure 3. Kansas reservoir on the Colorado River filling up with sediment (USGS, 2007).

In the Middle East as highlighted in the Table1 & Chart 2, total volume of reservoirs lost by sediments is higher as compared to other parts of the world. More specifically, the present study area Shewasur Reservoir is losing more than 1 % of initial capacity annually according to the results obtained in this study. It is estimated that out of the total geographical area of 103.67 km^2 of Shewasur Watershed, approximately 32% of the entire catchment area which is designated as the bare lands, is affected by serious water erosion (figure 4).

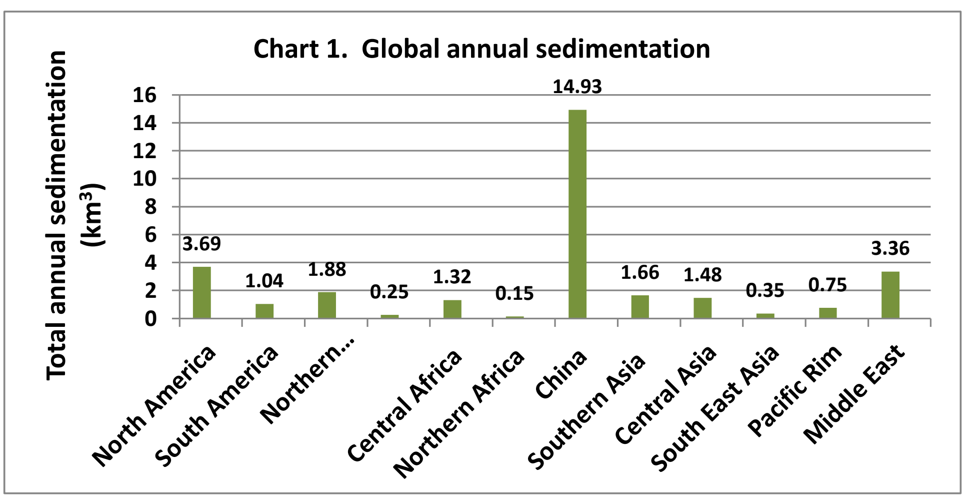
Figure 4. Current sediment discharge in the Shewasur Reservoir (Harman Company, 2011).

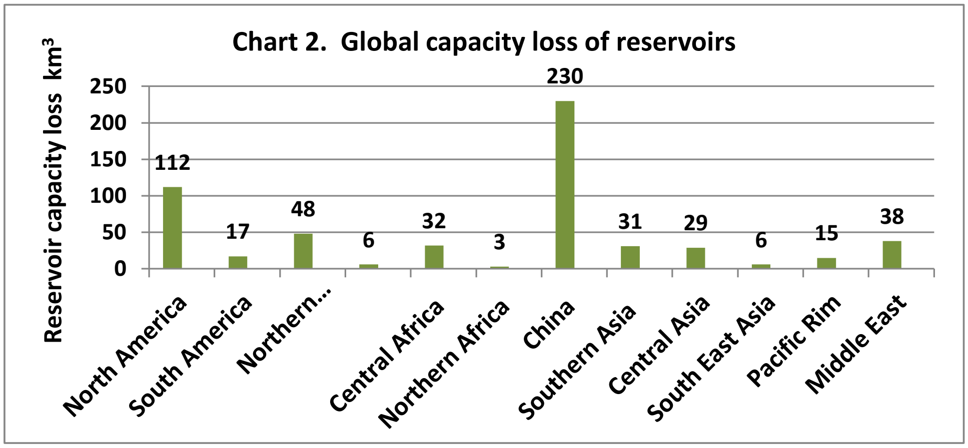
Table 1. Global distribution of storage volume and sedimentation loss

Region	Total capacity in (KM^3)	Annual sedimentation in (KM3)	Sedimentation loss (deposited) %	Total capacity loss in (KM3)
North America	1845	3.69	7.9	112
South America	973	1.04	2.5	17
Northern Europe	822	1.88	6.8	48
Southern Europe	135	0.25	5.6	6
Central Africa	574	1.32	7.8	32
Northern Africa	188	0.15	2.4	3
China	526	14.93	45.8	230
Southern Asia	233	1.66	13.1	31
Central Asia	132	1.48	26.9	29
South East Asia	117	0.35	8	6
Pacific Rim	232	0.75	7.6	15
Middle East	199	3.36	27.7	38
Global Total	5976	30.85	11.8	567

Source: Sumi, T. & Hirose, T. (2000). Water storage, transport and distribution: Accumulation of sediment in reservoirs. Department of Civil Engineering, Kyoto- Japan.

Sediment discharge from a watershed is the total quantity of sediment moving out of the watershed in a given time interval (mass/time), this sediment discharge is often defined as sediment yield (Lane et al.,1997). The major factor controlling sediment yield is soil erosion, which is a complex dynamic process by which productive surface soils are detached, transported and accumulated in a distant place resulting in exposure of subsurface soil and sedimentation in reservoirs (Jain et al 2001). The amount of rainfall and the rainfall intensity are primary determinants of water erosion under rain-fed conditions. Charts 1 & 2 presents both the global annual sedimentation and capacity loss of reservoirs, in which the Middle East's record indicates that sediment inputs into the reservoir were relatively high over the second half of the Twentieth Century.





1.3. Methods of soil loss estimation

1.3.1. Universal Soil Loss Equation -USLE

The Universal Soil Loss Equation (USLE) was originally deduced by a statistical analysis of a large data set of soil loss measurements (Ferro, 2010). The USLE was developed at the National Runoff and Soil Loss Data Center in cooperation between Agricultural Research Service and Purdue University (Wischmeier & Smith, 1978). Ahamed et al. (2000) suggested that this model has defined soil erosion as two-stage process consisting of the detachment of soil particles by the impact of raindrops falling on the soil surface and transport by erosive agents such as running water, which scours the soil surface. Watershed erosion is characterised by the detachment and entrainment of solid particles from the land surface. Soil erosion can be classified as sheet erosion and channel erosion. Sheet erosion is the detachment caused by raindrop intensity and the thawing of frozen grounds and subsequent removal by overland flow.

Simple methods such as Universal Soil Loss Equation (USLE), are frequently used for the estimation of surface erosion and sediment yield from catchment area (Ferro & Minacapilli 1995; Kothyari & Jain, 1997; Ferro et al., 1998). The equation has been applied to the proposed study area to determine the annual flow of sediments in to the reservoir.The amount of sediment depends on many parameters, each of them has a more complicated numerical analysis to determine its value so that the sediment yield will be estimated precisely. Generally, the amount of eroded soil is estimated by using the following equation (Eq.1).

E= R.K.LS.CM.P ……………………………………………………………….Eq.1

Where :

E : Is the gross amount of soil erosion in (mass/area/time) or (t $ha^{-1} y^{-1}$)

R : is the rainfall erosivity factor (MJ mm $ha^{-1} h^{-1}$)

K : is the soil erodibility factor (t ha h ha^{-1} MJ^{-1} mm^{-1})

LS : is the slope gradient and length factor (dimensionless)

CM : is the cover management factor (dimensionless)

P : is the supporting practice factor (dimensionless)

To calculate the amount of eroded soil in (m^3/year), the gross amount of soil erosion in Eq.1 is divided by the soil density which is (1.8 t/m^3) according to the soil investigation reports and instructions of American Society for Testing and Materials (ASTM). Each of the above parameters has been analysed by creating three models to calculate their values and entered to the USLE.

Rainfall Erosivity Factor (R)

The rainfall erosivity factor (R-factor) is based on kinetic energy considerations of falling rain (Whelan, 1980) and represents a measure of the erosive force and intensity of rain in a normal year (Goldman et al. 1986). Two components of the factor are the total energy and the maximum 30-min intensity of storms (i.e., the EI factor as defined by Wischmeier and Smith (1978). The R-factor is the sum of the product of these two components for all major storms in the area during an average year. Mathematically the amount of R is calculated by the following equation.

R=0.01 ∑(E.I) …………………………………………………………………Eq.2

Where the summation is for the time increments of the storm

E= Kinetics energy per foot-tones per acre-inch, is given by :

E= (916+331 log(I)) …………………………………………………………………Eq.3

Where I= Rainfall intensity (inch/hr)

However, the amount of R can be directly calculated , there are inadequate measurements of rainfall intensity in one hour and the kinetics energy was not calculated precisely by the nearest meteorological stations. For that reason, and for obtaining high precision a variety of alternative models have been taken in to account to calculate the amount of R. In this case study, six indexes by different authors have been applied to find out the precise value of R (Table 2). The reason of using multiple indexes was in spite of providing high accuracy in the measurements , there was also related to the existence a great discrepancy in the climatic conditions, divergent topography of the catchment and different hydrogeological characteristics of the watershed area for example, groundwater table, hydraulic conductivity, tributaries and surface soil conditions. Specifically, the occurrence of rainfall events with high intensity and duration is a natural phenomenon at the study area (Table 10). For this purpose the modified Fournier formula has been adopted in the USLE modelling, in which the climatic aggressiveness has been principally taken in to account (Gregori et al. 2006). The results of the R-value are calculated on the basis of the following models which have been presented in the Table 2.

Table 2. Rainfall erosivity by six different models

Index No	Authors	Models
1	Arnoldus (1980)- Linear	R=(4.17 * F - 152)* 17.02
2	Arnoldus (1977)- Exponential	$R= 0.302 * F^{1.93}$
3	Renard and Freimund (1994)- F	$R= 0.739 * F^{1.847}$
4	Renard and Freimund (1994)- P	$R = 0.0483 * P^{1.61}$
5	Lo et al (1985)- Linear P	R = 38.46 + 3.48 * P
6	Yu & Rosewelt (1996)- Exponential-F	$R = 3.82 * F^{1.41}$

Where: R is the rainfall erosivity factor (MJ mm ha^{-1} h^{-1}), P and F are called climatic aggressiveness is given by the following equations:

$$P = \sum_{i=1}^{12} pi \qquad \text{…………………………………………………….Eq.4}$$

$$F = \sum_{i=1}^{12} \frac{pi^2}{P} \qquad \text{…………………………………………………….Eq.5}$$

Where: P(mm) is the annual precipitation and the pi (mm) is the monthly precipitation.

Goldman et al. (1986) stated that there are variety of models and equations which have been developed for estimating R-factor. For instance, R=0.2232 * (16.55* $P^{2.2}$), which is mainly dependent on storm type and rainfall-frequency distribution. However, the model addressed precipitation, the erosive forces from regions of thaw or snowmelt have not been taken in to account. Furthermore, McCool et al. (1976) show that a major erosion potential occurs in the form of low-intensity rainfall or snow during winter months. As a result, Wischmeier and Smith (1978) suggested that modifying the R-factor at those sites where snowmelt is arising may be important. From their perspective, to provide more discrimination between those sites that traditionally have snowmelt runoff from those where it occurs occasionally, the average-annual R-factors, as defined by the Equation, are increased by an amount equaling 0.591 times the total precipitation (in cm) associated with those months having an average monthly temperature below freezing, including the first month following the last freezing month.

Soil erodibility factor (K)

One of the key parameters that contribute to the modelling of soil erosion is the soil erodibility, expressed as the K-factor in the most predominant soil erosion models such as, the Universal Soil Loss Equation (USLE). According to Panagos et al. (2014) the K-factor, which expresses the vulnerability of a soil to erode, is related to soil properties such as organic matter content, soil texture, soil structure, particle size distribution and permeability. Insufficient data on soil characteristics or imprecise information on the particle size distribution are considered as one of the greatest impediments to soil erosion modelling at larger spatial scales. The soil erodibility factor (K-factor) is a quantitative description of the inherent erodibility of a particular soil; it is a measure of the susceptibility of soil particles to detachment and transport by rainfall and runoff. For a particular soil, the soil erodibility factor is the rate of erosion per unit erosion index from a standard plot.

According to Mitchell and Bubenzer (1980) the soil erodibility factor reflects the fact that different soils erode at different rates when the other factors that affect erosion are the same. For instance, infiltration rate, permeability, total water capacity, dispersion, rain splash, and abrasion affect soil erosion at similar rates. However, soil texture is the principal factor affecting soil erodibility, but structure, organic matter, and permeability also play important roles to alter the amount of erodible soil. According to the majority of existing data and studies the amount of soil erodibility factor ranges from 0.02 to 0.69. There are several methods and hydrological models to determine the precise value of soil erodibility factors including Soil Conservation Service (SCS) and nomograph method.

Firstly, The SCS contains soil maps superimposed on aerial photographs. The maps permit easy location of sites and tentative determination of soil series. Recent surveys list K-factors for the soil series in the table outlining the soil's physical and chemical properties. Goldman et al. (1986) note that this method of determining K-factors should only be used if minimal soil disturbance at the site is anticipated and a site analysis is unavailable. From his view, the preferred method, for determining K-factors is the nomograph method and modified method based on the work by Wischmeier et al. (1971) and is mathematically represented as follows:

$K = 2.1 * 10^{-6} F_p^{1.14} (12-P_{om}) + 0.0325 (S_{stru}-2) + 0.025 (F_{perm} - 3)$ ……………………..Eq.6

In which $F_p = P_{silt} (100-P_{clay})$

$K = 2.77 * 10^{-7} M^{1.14} (12-P_{om}) + 4.28*10^{-3} (S_{stru}-2) + 3.29*10^{-3} (F_{perm} - 3)$ ………..Eq.7

In which $M = (P_{silt} + P_{fine\ sand})(100-P_{clay})$

Where :

K = Soil erodibility factor in SI units (t ha hr / ha MJ mm)

F_p is the particle size parameter (dimensionless)

P_{clay} is the percent clay (dimensionless)

P_{om} is the percentage of organic matter (dimensionless)

S_{struc} is the soil structure index(dimensionless), is defined by the type and class of soil structure existing in the horizon. The soil structure has been classified in to four primary classes and ranges from (1 to 4), as shown in the table below.

F_{perm} is the profile-permeability class factor (dimensionless), which is the capacity of soil to transmit water through the most confined layers. The permeability classes are based on the lowest saturated hydraulic conductivity ranges from (1 to 6) as highlighted in Table 3.

Table 3. Soil structure codes and profile permeability classes for different types of soil

Permeability	Permeability Class	Description
Rapid	1	(> 150 mm/hr)
Moderate to rapid	2	(50-150 mm/hr)
Moderate	3	(15-50 mm/hr)
Slow to moderate	4	(5-15 mm/hr)
Slow	5	(1-5 mm/hr)
Very slow	6	(< 1 mm/hr)
Soil Structure	Structure Code	Description of grain size
Very fine granular	1	< 1 mm
Fine granular	2	1-2 mm
Medium & coarse	3	2-10mm
Very coarse	4	> 10 mm

In spite of this, the nomograph method can be applied for the prediction of eroded soil in a wide range of agricultural lands, the modified version of nomographic estimation of soil erodibility (Eq.7) as given by Rosewell (1993), was used as the maximum design criteria for providing more safety to the reservoir capacity and other structures in the downstream part of the dam. This was because the amount of (K) was greater when the modified version was considered for the whole catchment area. However, for the purpose of annual estimation the average value is sufficient as the soil is moderately susceptible to erode according to the geotechnical data obtained from the laboratory tests to the soil sample (Appendix A).

Moreover, according to Singh and Khera (2009), the nomograph method of estimation soil erodibility are not applicable under different studied conditions, in other words, it cannot be extrapolated to non-homogenous locations. The reason may be that the first methods are based on the data sets or experiments which were not conducted under specific conditions and being empirical in nature. However, the studied area contained 2% of organic materials, but if the suggested catchment had a percentage of more than 4% of organic materials, the method would not have been applicable under these circumstances in particular (USLE) . Thus, the modified method was taken in to decision to calculate the K factor under the specific conditions of Northern Iraq.

Slope Length factor (LS)

The L and S factors are commonly combined as LS and referred to as the Slope factor (Wilson, J.P. 1986). Slope length is defined as the horizontal distance from the origin of overland flow to the point where either (1) the slope gradient decreases enough that deposition begins or (2) runoff becomes concentrated in a defined channel (Wischmeier and Smith 1978). Research has shown that increased slope length and steepness produces higher overland flow velocities and correspondingly higher erosion (Haan et al., 1994). In order to derive LS-factor values, a series of digital elevation model (DEM)-derived grids are produced by running the LS-factor program and are subsequently used in the final calculations. A grid containing the cell slope length, or non-cumulative slope length (NCSL) of each grid cell, is calculated from the slope angle and flow direction grids as either the cardinal or half-cardinal length of that cell according to its outflow direction. The basic input for generating an LS factor grid in GIS is a DEM dataset of suitable scale that has been clipped to encompass the zone of interest, usually a topographically defined catchment or watershed. Although, the LS factor can be separately calculated by using equations (10, 11, 12, 13 &14), Wischmeier and Smith (1978) derived a combined model to predict soil loss as given by Eq.15.

$$\mathbf{L} = \left(\frac{\lambda}{22.13}\right)^{m} \qquad \text{..............................Eq.10}$$

λ = Actual slope length

m= The slope length exponent

The slope length exponent m is related to the ratio β of rill erosion caused by flow to inter-rill erosion caused by raindrop impact is given as follows:

$$\mathbf{m = \beta\ (1+\beta)} \qquad \text{..............................Eq.11}$$

$$\beta = \frac{11.1607\ Sin\phi}{3.0\ (Sin\ \phi)^{0.8} + 0.56} \qquad \text{……………………………Eq.12}$$

Where θ= slope angle in (degrees)

The slope steepness factor (S) is evaluated from (McCool etal., 1987)

S=10.8 Sinθ + 0.03 for s<9% ……………………………**Eq.13**

S=16.8 Sinθ + 0.05 for s>9% ……………………………**Eq.14**

Wischmeier and Smith (1978) stated that LS is the expected ratio of soil loss per unit area from a field slope to that from a 72.6-ft length of uniform 9 percent slope under otherwise identical conditions. They derived a model to predict soil loss as given below:

$$L\,S = \left(\frac{\lambda}{22.13}\right)^{m} \cdot (65.4\ Sin^2\phi + 4.56\ Sin\ \phi + 0.0654) \qquad \text{……………… Eq.15}$$

m = 0.5 if the percent slope is ≥ 5 , 0.4 on slopes of 3.5 to 4.5 percent, 0.3 on slopes of 1 to 3 percent, and 0.2 on uniform gradients of less than 1 percent.

Cover management factor (CM)

The CM factor represents the impacts of surface cover and roughness on soil erosion. The cover factor is the most common factor used to assess the impact of best management practices (BMP) on reducing erosion because the CM factor represents the effect of land use on soil erosion (Renard et al., 1997). CM factors vary from region to region because they are strongly influenced by different R factors (Wischmeier and Smith, 1978). By definition, CM = 1 under standard fallow conditions (Figure 4 & Table 4). But, as surface cover is added to the soil, the CM factor value approaches from zero. For example, a CM factor of 0.20 indicates that 20% of the amount of erosion will occur compared to continuous fallow conditions. The cover management factor can be explored in two ways. The first method, which can be derived from the linear regression of soil loss data.

Figure 5. Current situation of reservoir outskirts

Table 4. CM-values for various land uses and crops calculated by the USLE. **Source**: Leihner et al., (1996), for Cauca, Colombia.; Roose, E.J. 1977. & David, W.P. 1987).

Vegetation cover		CM-Value			
		1	2	3	4
Forest	Primary forest (with dense undergrowth)	0.001			
	Second-growth forest with good undergrowth and high mulch cover	0.003			
	Second-growth forest with patches of shrubs and plantation crops of five years or more	0.006			
Industrial Plantation	Benguet pine with high mulch cover	0.007			
	Mahogany, Narra, eight years or more with good undergrowth	0.01-0.05			
	Mixed stand of industrial tree plantation species, eight years or more	0.07			
Agroforesty Tree Species	Mixed stand of agroforestry species, five years or more with good cover	0.15			
	Coconuts, with annual crops as intercrop	0.1-0.3			
	Leucaena leucocephala, newly cut for leaf meal or charcoal	0.3			
	Cashew, mango and jackfruit, less than three years, without intercrop and with ring weeding	0.25			
Grasslands	Oil palm, coffee, cacao with cover crops		0.1-0.3		
	Imperata or thermeda grassland, well established and undisturbed, with shrub	0.007			
	Shrubs with patches or open, disturbed grasslands	0.15			
	Well-managed rangeland, cover of fast development, ungrazed two years or more	0.01-0.05			
	Savanah or pasture without grazing	0.1	0.01		
	Grassland, moderately grazed, burned occasionally	0.2-0.4	0.1		
	Overgrazed grasslands, burned regularly	0.4-0.9			
	Guinea grass (Panicum maximum)				
Cover crops/green manures	Rapidly growing cover crop		0.1		
	Velvet bean (Mucuna sp)			0.05	
Annual Cash Crops	Diversified Crops	0.2-0.4			
Other	Bare soil and fallow condition	1	1.0	1.0	1

The second method involves estimating a CM value from five subfactors (Renard et al., 1997). The subfactors are frequently classified in to five groups including:

1- Prior Land Use (PLU)

2- Canopy Cover (CC)

3- Surface Cover (SC)

4- Surface Roughness (SR)

5- Soil Moisture (SM)

In this study, specifically in USLE, a subfactor method was used to compute soil loss ratios as a function of five subfactors (Laflen et al., 1985) given as:

CM = PLU *CC*SC*SR*SM Eq.16

The prior land use subfactor (PLU) expresses the influence on soil erosion of prior cropping, dominant tillage practice, soil consolidation, time, and biological activity. The canopy cover subfactor (CC) expresses the effect of vegetative canopy on reducing rainfall energy impacting the soil surface. While most rainfall intercepted by crop canopy eventually reaches the soil surface, it usually does so with much less energy than non-intercepted rainfall. These intercepted raindrops either fracture into smaller drops with less energy, drip from leaf edges or travel down crop stems to the ground. Cogo et al.,(1984) stated that rough surfaces trap water and sediment, and erode at lower rates as compared to smooth surfaces under similar conditions. Surface cover and soil moisture, on the other hand, affects erosion by reducing transport capacity of runoff water (Foster, 1982), by causing deposition in ponded areas (Laflen, 1983), and by decreasing the surface area susceptible to raindrop impact. In other words, a soil surface with high moisture content is more vulnerable to erosion than unsaturated soil under the same circumstances.

Figure 6. Different surface covers of the Catchment

Support practice factor (P)

The support practices are often used on cultivated land comprise strip cropping and buffer strips, terracing, subsurface drainage and contouring (Renard, 1997). In other words, it is a ratio between soil loss generated by a specific support practice and the corresponding erosion with straight-row upslope and down slope tillage. These practices principally affect erosion by modifying the flow pattern, grade, or direction of surface runoff and by reducing the amount and rate of runoff (Renard and Foster 1983). Thematic maps on land use and slope, and the field information on the conservation practices were used to adopt the values of P (Table 5) for the study area and to derive a P-factor map (Wishmeier and Smith, 1978).

Table 5. Conservation practice factor (P) on different slope gradients and land uses (USDA-NRCS, 1983).

Slope %	P-factor
1.0-2.5	0.6
3.0-5.5	0.5
6.0-8.5	0.5
8.0-12.5	0.6
13.0-16.5	0.7
17.0-20.5	0.8
21.0-25.5	0.9
Up and down the slope	1
Cross Slope	0.75
Contour farming	0.5
Strip cropping, cross slope	0.37
Strip cropping, contour	0.25

Advantages and limitations of USLE

The multiplicative structure of the model has been criticised due to the considerable interdependence between the variables (Ferro, 2010). However, the parameters are straightforward to understand and input values such as rainfall information are frequently available, the USLE model considers only sheet and rill erosion with exceptional of gully erosion. In addition to that, USLE does not estimate sediment deposition, it also predicts long term erosion and average soil loss. In contrast, USLE has a vast experience which will be approximately 60 years and it is not accounted for land use conditions in agricultural and urban areas. A major theoretical problem with the USLE model is that soil erosion cannot be adequately described merely by multiplying together factor values (Stocking, 1980). For instance, Morgan (1995) stated that rainfall influences the R and C factors and terracing affects on the L and P factors. Despite the fact that USLE was developed as conservation planning tools for farmers, Bonda et al., (1999) argued that Problems of scale can complicate the magnitude of soil loss critical in understanding erosion and sedimentation.

For example, only 10 percent or less of the calculated soil lost from a hillslope may actually be transported out of a drainage basin. The remainder is simply moved and deposited somewhere between the hillslope and the large drainage basin (Figure 7). Therefore, most soil loss estimation techniques, including the USLE fall short in their ability to capture scale issues associated with erosion hazard assessment.

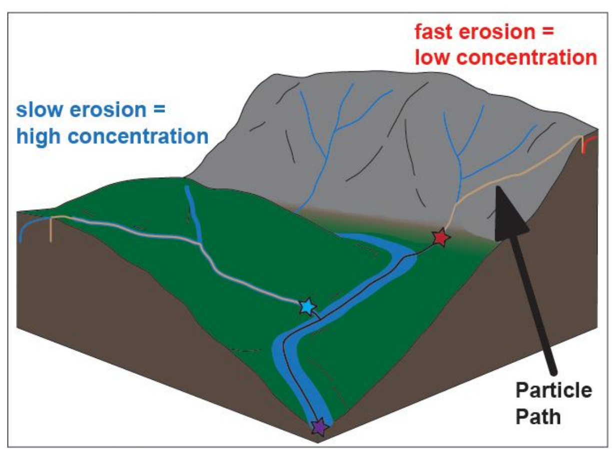


Figure 7. Hillslope Morphology (www.geomaps. Wr.usgs.gov)

1.3.2. Discretized Universal Soil loss Equation- DUSLE

The DUSLE method is exactly the same as USLE, but different values of cover management and support practice factors are applied to each agro-climatic zone as shown in Table 6. The DUSLE is based on the catchment discretization, as the parameters of USLE are applied individually to the areas that have been discretized. Similarly, the parameters in the DUSLE are not generalised equally on the whole catchment area. According to the results obtained by this study, the amount of eroded soil estimated by USLE is classified under EC2 in which the soil is slightly eroded. But, some segments may face tolerable erosion with respect to the nature of the topography, soil characteristics and land use type (Wischmier and Smith, 1978).

Table 6. Area percentage of four agro-climatic zones in Shewasur Watershed. **Source:** (MAWR, 2010) taken from Digital Elevation Map (DEM).

Type of landuse	Area Km^2	Area Percentage
Grasslands	33.18	32.01%
bare soil	33.31	32.13%
Annual crop	26.00	25.08%
Forest	11.18	10.78%
Total	103.67	100.00%

Accordingly, estimation of erosion on the basis of discretized portions of the area may be more reasonable to predict the implications and make recommendations on the results obtained. For instance, a segment with cross slope and completely fallow condition produce high amount of eroded soil as compared to the segment with grass land and annual crop under similar hydrological conditions. For this purpose a digital land cover data was established for the area , in which the land cover was further classified in to four sub-catchments including grasslands, bare soils, croplands and forests as shown in (Table 6). Using the land use and land cover in conjunction with soil information, rainfall incident on a sub-catchment was proposed to predict annual soil loss in the discretized portion, as this method appears to have more precision than the USLE.

1.3.3. Modified Universal Soil Loss Equation (MUSLE) - The Sidement Runoff Model

The MUSLE method was developed to take advantage of the tools and developments made on both USLE and DUSLE, but applied to single storm events. MUSLE is similar to USLE except for the energy component. USLE depends mainly upon rainfall as the source of erosive energy. Contrarily, MUSLE uses storm-based runoff volumes and runoff peak discharges to simulate erosion and sediment yield (Williams 1995). The use of runoff variables rather than rainfall erosivity as the driving force enables MUSLE to estimate sediment yields for individual storm events. The model was combined with runoff and peak discharge models and tested in 26 watersheds in Texas (Johnson, C. W., Gordon, N. D. & Hanson. C. L. 1985). Particularly, the MUSLE is precisely the same as USLE, except the R factor used in the USLE equation is replaced by a new factor R_W calculated with the equation below (Eq.17 & 18).

The MUSLE method has many positive aspects. Firstly, it is more accurate when predicting sediment yield and also eliminates the need for delivery ratio (Williams and Berndt, 1977). Next, regarding prediction accuracy, Johnson et al (1985) discovered that for 1,200 rain events in a watershed in the United States MUSLE overpredicted smaller events and underpredicted large events. Some studies for small watersheds, however, have given accurate estimates (Tripathi et al, 2001). Finally, another advantage of MUSLE are its simplicity, the direct conceptual and physical relevance of its factors, the large database upon which the empirical relationship was developed, and the capability to insert management considerations into factor selection (Williams, J. 1975). The amount of sediment detached is computed by the following equations:

E= Rw * K.LS.CM.P ……………………………………………………………………….….Eq.17

Where E is the amount of eroded soil in an individual storm event. (KLSCMP) is the same parameters in USLE, except R is different and is given by the following formula which is a combination of runoff and peak discharge.

$R_w = 11.8 * (V * q_p)^{0.56}$ …………………………………………………………………..…..Eq.18

where :

V is the volume of runoff in m^3 , for an individual storm event

q_P is the peak discharge rate in m^3/s

The value of V in equation (18) is predicted with a daily runoff model (Williams and Laseur, 1976), based on the Soil Conservation Service (SCS), curve number technique and a soil moisture index accounting procedure (USSCS, 1972). The volume of runoff can be calculated by using the following equation (Eq.20). Hence, assume there are 365 individual storm events, based on the average annual precipitation which is illustrated in Table 3. The amount of total annual yield is the sum of all storm events in the year.

Volume of runoff (V)= Depth of runoff (Q) x Watershed area (A) …………….……..Eq.19

$$Q = \frac{(P-0.2S)^2}{(P+0.8S)}$$ **……………………………………………………………..…..Eq.20**

Where: Q= Depth of runoff over the entire watershed in (mm)

P= Average daily rainfall in (mm)

S= Potential maximum retention in (in) after runoff begins is computed as follows:

$$S = \frac{1000}{CN} - 10$$ **……………………………………………..……………………..…..Eq.21**

Where CN is the curve number, varies dependent on soil group and moisture condition as illustrated in Table 7. Hydrologic soil group is an index of the runoff potential
of the soil under unit plot conditions. These designations are A (lowest potential), B, C and D (highest potential) (NRCS, 2003).

Table 7. Curve Numbers for Antecedent Soil Moisture Condition II. Source: From USDA-NRCS, 1984.

Landuse Description	Hydrologic Soil Group			
	A	B	C	D
Commercial, row houses and townhouse	80	85	90	95
Fallow, poor condition	77	86	91	94
Cultivated with conventional tillage	72	81	88	91
Cultivated with conservation tillage	62	71	78	81
Lawns, poor condition	58	74	82	86
Lawns, good condition	39	61	74	80
Pasture or range, poor condition	68	79	86	89
Pasture or range, good condition	39	61	74	80
Meadow	30	58	71	78
Pavement and roofs	100	100	100	100
Woods or forest thin stand, poor cover	45	66	77	83
Woods or forest, good cover	25	55	70	77
Farmsteads	59	74	82	86
Roads	74	84	90	92

Peak discharge

The peak discharge of a catchment is the maximum volume flow rate passing a particular location during a storm event. In other words it is the design flood that will occur for a specific return period, e.g. 20, 25, 50 and 100 years. Although, there are many different approaches for determining the peak discharge (e.g. storm water management models), the most widely used un-calibrated equation is known as the Rational Method was which was applied to determine the maximum rate of flow in the watershed. Applying Rational Method to determine peak discharge is associated with many advantages including: Firstly, runoff coefficients have been predicted to be appropriate to use in the rational method as they are a simplified representation of reality, representing a ratio of volume of runoff generated to actual volume of rainfall. For example, a runoff coefficient of 0.25 means 25% of rainfall contributing to runoff while a runoff coefficient of 0.90 means 90% of rainfall contributes to runoff. Secondly, there are only a few variables that must be known about a study area in order to use the rational method to calculate the peak discharge rate generated during a storm event. As a result the rational method's main advantage is its simplicity.

Oppositely, stormwater management models, such as OTTHYMO, doesn't have the same inherent uncomplicatedness in reckoning of peak flow in the watershed. While this model is also a simplified method of reality, it can consider a wide range of surface parameters to more approximately representation of the actual hydrogeological characteristics of a study area (Wisner and Lam, 1983). Additionally, the main negative point of using OTTHYMO is that a significant amount of hydrogeological information should be prepared before peak discharge rates are computed. In such cases there are a number of parameters that must be derived from geotechnical investigations and sets of calculations based on the characteristics of the study area. When all of these parameters are correctly used smaller rainfall events mostly produce less runoff than that delivered by the rational method and larger events can generate discharges closer to or higher than calculated using the rational method (Anderson, 2002). The rational method takes three hydrologic parameters in to account for determining the peak discharge. The parameters are including drainage area, the rainfall intensity and the runoff coefficient (C). It can be mathematically expressed as follows:

q= CIA ………………………………………………………………………………Eq.22

where :

q = design peak runoff rate in (m^3/s)

C = the runoff coefficient representing ratio of runoff to rainfall

i = rainfall intensity in (mm/hour) for the design return period and for a duration equal to the "time of concentration" of the watershed.

A = watershed area in (hectares)

<u>Limitation of the MUSLE</u>

Although the MUSLE can estimate soil loss from a single event, it cannot estimate detachment, entrainment, transport and redistribution of sediment within the watershed. Secondly, many parameters of the runoff and peak discharge model are not frequently existent such as maximum daily precipitation and coefficient of surface runoff. Despite these problems, the MUSLE's benefits are more than drawbacks and should be applied at all watershed development sites, even in drylands and semiarid regions with low precipitations.

1.3.4. Sediment Delivery Ratio (SDR)

It is a measure of sediment transport efficiency, which accounts for the amount of sediment that is actually transported from the eroding sources to a measurement point or catchment outlet compared to the total amount of soil that is detached over the same area above that point (Mutua & Klik, 2006) . Specifically, In the proposed catchment, a substantial part of the soil eroded in an overland region deposited within the catchment before reaching the inlet of reservoir (Figure 6). SDR can be defined by many studies as a ratio of sediment yield to total surface erosion, it is hydrologically termed as delivery ratio (D_R)(Bhattarai, R. & Dutta, D. 2007). Values of D_R for a catchment area are found to be affected by catchment physiography, sediment sources, transport system, texture of eroded material and land cover (Walling, 1988). However, variables such as catchment area, land slope and land cover have been mainly used as parameters in empirical equations for D_R (Kothyari and Jain, 1997; Williams and Berndt, 1972; Hadley et al., 1985). Ferro (1997) and Ferro and Minacapilli (1995) hypothesized that D_R in sub-catchments is a strong function of the travel time of overland flow within the cell. For the purpose of considering deposition Vanoni (1975) used the data from 300 watersheds throughout the world to develop a model by the power function. This model is considered a more generalized one to estimate SDR, and is given as follows.

SDR = 0.42 $Ar^{-0.125}$ ……………………………………………… **Eq.23**

SY = SDR * E ………………………………………………**Eq.24**

Where:

SDR = the sediment delivery ratio

SY = the final delivery sediment yield in m^3/year

E = the gross erosion per unit area above a measuring point in t/year

Ar = drainage area in square miles (1 mi^2=2.59km^2)

Figure 8. Deposited sediment at the Elwha river mouth before reaching the reservoir (www.washington.edu)

It is known that there are some limitations of using the general SDR methods. One is these SDR methods can not explicitly predict the locations and rates of sediment deposition in the lowland phases, and another is the problem of temporal and spatial lumping and lack of physical basis (Vente et al., 2007). Moreover, the SDR-area relationship does not take into account local descriptors, such as rainfall, topography, vegetation, land use and soil characteristics. There are other empirical relationships which show that SDR varies with various physiographic attributes but the data required in these relationships are few and only of local extent (Khanbilvardi and Rogwski 1984).

1.3.5. Annual capacity loss of the reservoir

Trap efficiency (TE)

Trap efficiency (TE) is one of the important parameters in quantifying reservoir sedimentation which is defined as the ratio of deposited sediments to the amount of inflow sediment (Toniolo H. and Schultz J. 2005). Accurate quantification of sediment trapping in reservoirs improves the estimates of river sediment export, allows the useful life of reservoirs to be determined, and provides insights into sediment transport and dynamics of watersheds (Lewis et al., 2013). Trap efficiency (TE) is the proportion of the incoming sediment that is deposited, or trapped, in a reservoir. TE is given as follows:

$$\textbf{Trap Efficiency} = \frac{\textbf{Sediment Inflow} - \textbf{Sediment Outflow}}{\textbf{Sediment Inflow}} \textbf{ x 100\%}$$

Where:

S_{inflow} is the sediment mass entering a reservoir (i.e. the sediment yield or delivery).

$S_{outflow}$ is the sediment mass leaving the reservoir with the outflowing water.

The difference between inflow sediment and outflow is known as sediment settled which is the sediment mass deposited within the reservoir. Trap efficiency is dependent on several parameters, including sediment size, distribution; the time and rate of water inflow to the reservoir; the reservoir size and shape; the location of the outlet structure and water discharge schedules (Morris and Fan, 1998; Verstraeten and Poesen, 2000; Campos, 2001; Yang, 2003). From the general remarks of TE which was highlighted, the amount of out flow sediment is unclear, since it requires a precise measurements and daily monitoring in the downstream parts of the dam. Hence, three models have been used to estimate the TE of the reservoir. The first method is derived by Brune (1953) which is widely used in estimating the sedimentation of reservoirs and is given as follows.

$$TE = 100 * (0.97)^{0.19^{\log\left(\frac{V}{I}\right)}}$$ **…………………………Eq.25 Brune's Formula**

Where:

TE = trap efficiency

V = reservoir capacity in m^3 = Reservoir Volume at Spillway Sill level (m^3)=6,689,955 computed as a design capacity of the reservoir (HMR Company, 2010).

I = annual average inflow (m^3/year)

The second method of estimating TE is dependent on detention time and mean velocity which was derived empirically by churchil, M.A. (1948). The formula is given as follows:

$$TE = 100 * \left[1 - \frac{1}{0.0021 * \frac{D * V}{W}}\right]$$ **…………………………Eq.26 Churchil's method**

Where, V = reservoir storage capacity expressed in m^3

W = catchment area expressed in km^2=103.67 Km^2

D ranges from 0.046 to 1, with a mean value of 0.1

The overestimation of Brune's method was observed by Bashar et al (2010) and Lewis et al (2013) in their studies on different reservoirs in different continents. Consequently, Harbor et al (1997) revised the Brune's formula in to a new version which has been empirically derived over a large number of reservoirs in different parts of the world. Hence, the average of three methods may have more precision as more parameters have been considered or using the third method which is a median of them to determine the useful life of reservoirs.

$$TE = -22 + \left[\frac{119.6 * \frac{V}{I}}{0.012 + (1.02 * \frac{V}{I})}\right]$$ **…………………..Eq.27 Revised Brune's Formula**

Where:

TE = trap efficiency

V = reservoir capacity in m^3

I = annual average inflow (m^3/year)

Useful Life Estimation of the Reservoir

The period up to which the reservoir can serve the defined purpose is called usable life, the period after which the cost of operating the reservoir exceeds the additional benefits expected from its continuation is called economic life, design life is generally the useful life, full life period is that when no capacity is available in the reservoir for useful purpose (Murthy, 1980; Kulkarni et al. 1994). Useful life is the period during which the sediment collected does not affect the intended primary use of the reservoir (Arora and Goel, 1994; Kulkarni et al. 1994, Agrawal and Singh, 1994). In most of the developed countries full life said to be arrived, when half of the total capacity of reservoir is depleted. While, in case of Trinity River basin reservoirs (Texas), it was considered as the period when the useful storage would be completely destroyed (Arora and Goel, 1994).

Useful life is an important design parameter of a reservoir which may affect the economic feasibility and sustainability of a water resources project (Gill, 1979). He also derived a direct method for useful life estimation of a reservoir which correlates the reservoir capacity with age in years algebraically. This method has been used to estimate the useful life of the proposed reservoir on the basis of data obtained by sedimentation calculation and trap efficiency which was calculated in the previous sections. The following equations can be used to determine useful life after the relationship between sedimentation rates, TE, specific weight of sediment deposited, the storage available after sedimentation for a given period useful life in years was estimated.

$$T_L = \left(\frac{\lambda I}{G}\right) * (0.4935\frac{C_0}{I} + 0.3 * 10^{-5}\frac{I}{C_0} + 0.00436)$$ **Eq.28 Coarse grained sediments**

$$T_L = \left(\frac{\lambda I}{G}\right) * (0.008 + 0.51\frac{C_0}{I})$$ **……………………….Eq.29 Medium sediment**

$$T_L = \left(\frac{\lambda I}{G}\right) * [0.51328\frac{C_0}{I} - 0.133 * 10^{-3}\frac{I}{C_0} + 0.153 * 10^{-5}(\frac{I}{C_0})^2 + 0.018167]$$ **…..Eq.30**

Where:

C_o is the initial capacity of reservoir in m^3

G, is characteristic weight of annual sediment inflow Kg/year

λ is specific weight of sediment deposited Kg/m^3

I: is the average inflow in m^3/year

The above approach has the following drawbacks: Firstly, it assumed a constant specific weight of sediment deposit, however the specific weight may increase with time due to consolidation which occurs when fresh sediment gets deposited over the old deposited sediment (Garg & Jothiprakash, 2008). Secondly, the TE approach does not take into consideration the location of sedimentation, but only gives the quantity of sediment deposited anywhere inside the reservoir. To account for the increase in specific weight of sediments Lane and Koelzer (1953) suggested a following formula:

λ = λ1+B x ln(t) **…………………………………………………..…….Eq.31**

Where λ is specific weight of sediments at an age of t years; λ1 is specific weight at the end of 1 year; and B is a constant with dimensions of specific weight.

Lane and Koelzer (1953) have also given the values of λ1 and B for different degree of submergence of sediments of different sizes as shown in Table 8.

Table 8. Values of λ1 (specific weight of sediment deposited) in kg/m^3 and B for estimating specific weight of reservoir. **Source:** (Morris and Fan, 1998; Annandale, 1987).

Reservoir Operation	Sand		Silt		Clay	
	λ1	B	λ1	B	λ1	B
Sediment submerged or nearly submerged	1550	0	1120	91	416	256
Normally a moderate reservoir drawdown	1550	0	1140	29	561	135
Normally considerable reservoir drawdown	1550	0	1150	0	641	0
Reservoir normally empty	1550	0	1170	0	961	0

1.4. Erosion Control Measures (ECM) and Sediment Management Strategies

Concern for the impact of accelerated rates of soil erosion on agricultural land, resulting from land clearance and poor land management, has traditionally focussed on their effects in terms of soil degradation, reduced crop productivity, problems of food security, and destruction of an essentially non-renewable resource (e.g. Wischmeier and Smith, 1978; Evans and Boardman, 1994; Lal, 1998). In many areas of the world, control of soil erosion and sediment delivery to watercourses is seen as being of great importance in reducing nutrient inputs to fluvial and lacustrine systems, as well as in reducing diffuse source pollution more generally. In the UK, for example, reduction of soil loss and associated sediment mobilisation and transfer to watercourses is seen as an important component of the recent development of Catchment Sensitive Farming (DEFRA, 2004).

Against this background, there is a growing need to design and implement improved land management strategies, aimed at reducing sediment mobilisation and transfer to watercourses. Erosion control measures are proposed to prevent and reduce movement of eroded soil sediments in the catchment area. Selection of the proper erosion control measure take the magnitude and type of erosion into consideration, as well as the resources available for implementation is critically evaluated. Three land use management techniques are suggested and financially discussed based on the assumptions that will be made for reducing the annual sediment inflow in to the reservoir.

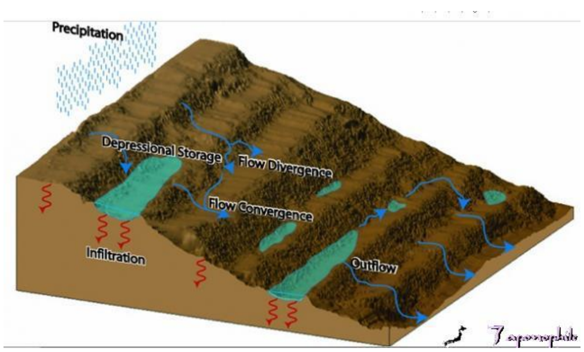


Figure 9. Examples of erosion control measures **Source:** (Extracted from Environmental Habitat Management Restoration).

1.4.1. Constructing of check dam as a drainge control technique

A check dam is a small transverse structure designed mainly for three purposes: control water flow, conserve soil and improve land (Castillo et al, 2014). One of the most common purposes of check dams is to enhance sediment deposition before getting the reservoir, reducing the hill side slope and retarding flow velocity in order to check soil erosion within the catchment. Check dams can be constructed easily with local materials. This image shows roughly built check dams, which require little labour and maintenance.

Advantages of check dams

The purpose of constructing check dams is to prevent soil erosion, reduce the flow of water downstream and help re-establish vegetation for grazing. Moreover, as can be seen from Table 27 and 29, check dams are one of the most effective and cheapest way to improve watershed conditions. Due to availability of local materials on site such as, stones and gravel, this technique is strongly recommended as a mitigation process to retard the flow of water and reduce excessive sediment load. Consequently, the constructed check dams will encourage water to percolate through the soil, recharging groundwater resources and helps re-establish vegetation (Walling, D.E., 1983).

Disadvantages of check dams

Constructing check dam requires periodic sediment removal, in particular to those areas produce severe sediment yield for example bare lands. In spite of having annual maintenance, it is ineffective of impeding sediment during intensive rainfall period such as, in December and January, there are large storm events, therefore the proposed check dams may not be efficient to obstruct large quantity of inflow sediment. Finally, check dams are not practical for steep areas with slope greater than 10%. However, it will be practical if the construction materials are restrained by grouting or lean concrete which is cheaper than construction of reinforced concrete retaining wall to obstruct the sediment flux in the down slope of the region (Armanini and Larcher, 2011).

1.4.2. Construction of Terraces as sediment control technique

Terracing is a combination of contouring and land shaping in which the slope length is reduced by the construction of ridges or channels across the slope. Terracing reduces slope steepness and divides the slope into short gently sloping sections (Morgan, 1986). The principal function of creating terraces is to intercept surface runoff, encourage it to infiltrate, evaporate or be diverted towards a predetermined and protected safe outlet at a controlled velocity to avoid soil erosion (USDA Soil Conservation Service, 1992; FAO, 2000). Terraces are suitable on slopes similar to contouring but preferably with long slope lengths. Long terrace lengths are also desirable because of the high initial costs associated with land forming. Values of P-factor are reduced on the order of one-half that of strip cropping. However, annual loss is further reduced because the L-factor is the terrace spacing interval rather than the entire slope length.

Benefits and drawbacks of terracing

Landscape is altered by terracing. As a result, terracing directly affect local hydrology and consequently runoff characteristics (SCAPE, 2000). In addition, Terraces indirectly affect soil moisture and soil characteristics (Chow et al. 1999). However, terracing has only an effect on water erosion, it cannot prevent or minimise the wind erosion impacts. Many scientists, soil conservation services and related institutions for example (USDA, 1980; AAFC, 1999; FAO, 2000; FFTC, 2004. GPA, 2004) agree that terracing reduces runoff and soil loss due to water erosion. Results obtained in (Chow et al. 1999) observed dramatic decrease in soil loss, from an average of 20 tonnes per hectare, to less than one tonne per hectare by terracing sloping fields in combination with construction grassed waterways and contour planting practices. Runoff was reduced by approximately 25% of the total growing season rainfall, making it more available to the crop.

In spite of a wide range of positive aspects, construction of terraces is extremely expensive as analysed from the calculations below. There are also many researchers that explained disadvantages of terracing. Some authors explain that terraces retain excessive water leading to saturation and consequently storm runoff (Gallart et al., 1994). Nevertheless, Lasanta et al. (2001) describe that the foot of a terrace wall is often affected by erosion, because of the steepness and the sparse vegetation cover. The research carried out by Van Dijk and Bruijnzeel (2003) supports this finding. In addition, they state that the poor management of the terrace toe drain in combination with the steep slope gradient of terraced slopes and the high amount of generated runoff are important causes for the lack of efficacy of terracing in combating erosion. Lasanta et al. (2001) also observed that erosion on the foot of the terrace slope could lead to deterioration of the terrace as a whole as well as gully formation, which eventually leads to increased erosion.

1.4.3. Erosion control through agroforestry in practice

Agroforestry practices encompass an entire spectrum of land use systems in which woody perennials are deliberately combined with agricultural crops and/or animals in some spatial or temporal arrangement (Lundgren and Raintree, 1982). Advocates have contended that soil conservation is one of its primary benefits (Young, 1989). The presence of woody perennials in agroforestry systems may effect several bio-physical and biochemical processes that determine the health of the soil substrate (Nair, 1993). The less disputed of the effects of trees on soil include: amelioration of erosion, primarily through surface litter cover and under story vegetation; maintenance or increase of organic matter and diversity, through continuous degeneration of roots and decomposition of litter; nitrogen fixation; enhancement of physical properties such as soil structure, porosity, and moisture retention due to the extensive root system and the canopy cover; and enhanced efficiency of nutrient use because the-tree-root system can intercept, absorb and recycle nutrients in the soil that would otherwise be lost through leaching (Sanchez, 1995).

2. Study Area

2.1. Study area and catchment characteristics

The proposed dam is located on the Shewasur Valley-Kirkuk Governorate-Northern Iraq. The geographical coordinates of the predestined dam are X=460362.5, Y=3960369 and Z=451.04m above sea level (Figure 1). The reservoir capacity is 6,689,955 m^3, designed to irrigate 9,375,000 m^2 of agricultural lands with a population number of 4250. The total catchment area of the dam as shown in the figure below is 103.67 km^2. The dam reservoir area till the elevation of 479 m is equal to 0.542 Km^2. The height of the dam is 35 m above natural ground level, and classified as small earth dam. The area has an average annual rainfall equal to 664 mm as shown in the Table 10. The annual rainfall is bimodal with short rains occurring from September to November and the long rains from December to April. Generally, the highest intensity of precipitation is in January (Table 10). The constructional work of the project was finished in 2012 and currently serves the primary purposes.

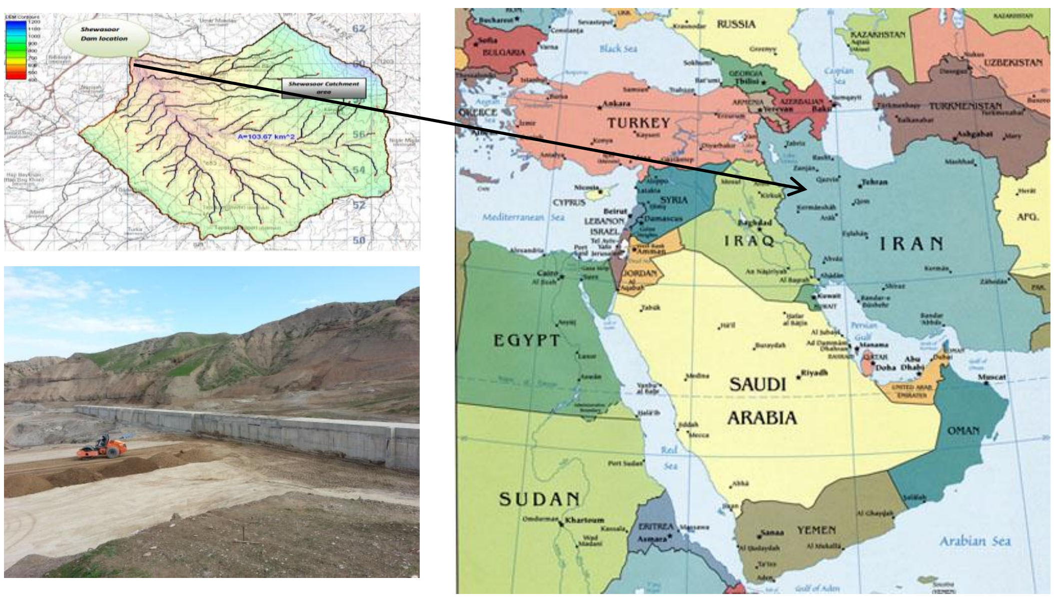


Figure 10. Location of the study area on the Iraqi map and Middle east. Source: http://www.worldatlas.com/webimage/countrys/me.htm

The catchment falls within four agro-climatic zones, ranging from semi-arid in the west to humid near the eastern side. The maximum temperatures vary from 25.0° C to 45.0° C generally being experienced in June, July, August and September, prior to the onset of the main rain season which starts in early December. Minimum mean temperatures of 0.0° C to 20.0° C occur in the months of December, January and February. The main purpose of constructing the dam was to controlling flood, hydropower and irrigational uses. The monthly and annual amount of precipitation have been illustrated in the Table 1.The topography of the area is very rugged and non-homogenous in characteristics, the catchment is consisted of a wide range of different sub-areas contains grass, pastures and trees. The watershed also contained many fallow areas as shown in the figure 11.

Figure 11. Different types of segments in the watershed. **Source:** Harman Company for General Contracting, 2010.

2.2. Geology of the study area

The studied area is located at the core of an anticline called "Chamchmal North Anticline" which extends for about (70 Km) from the east of Chamchmal Town to the Lesser Zab river, a situation which to leads to almost horizontal layers. This anticline trends in NW-SE direction (MAWR, 2010). Stratigraphically, the exposed rocks in the studied area are represented by three different formations including: Upper Fars Formation, Lower Bakhtiari and Upper Bakhtiari Formations. Figure 12 and Table 9 contain more detail on geological information on the formation classes.

Surface Area = **545,000 m^2**

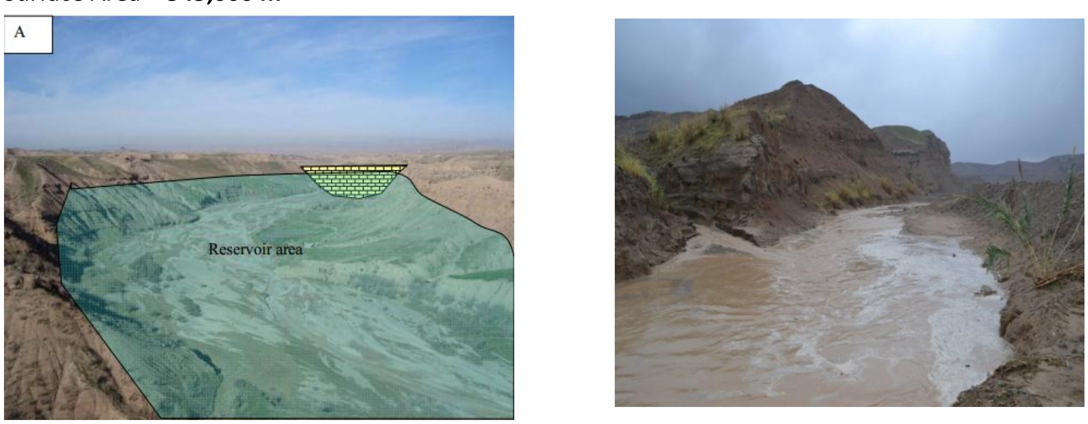


Figure 11. Photograph showing dam reservoir area and sediment discharge

The common drainage pattern is dendritic (Fig. 3). A dendritic drainage pattern tends to develop where a whole drainage basin is made up of the same type of rocks. Dendritic drainage resembles the shape of a tree, with the smallest tributaries being the outermost twigs and the main river channel forming the trunk. In a dendritic drainage pattern, tributary streams generally join at an acute, or less than 90 degree, angle, forming Y-shaped junctions. There is only seasonal water flow; at winter and spring while the rest time of year generally the stream is dry except few weak in springs in or near villages which consumes by daily activity.

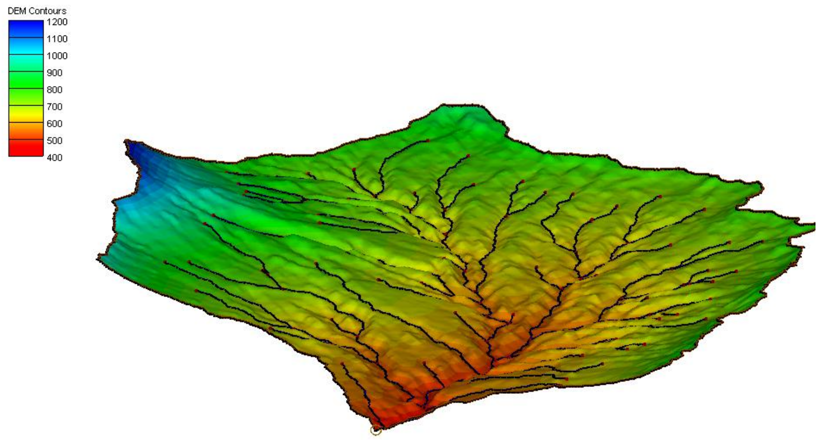


Figure 12. Dendritic view for Shewasoor Dam Site and Watershed area. **Source:** Harman Company for General Contracting, 2010.

Table 9. Geological description of study area (MAWR, 2010)

Formation name	Age	Descriptions
Alluvial deposits	Quaternary	mixing of sandstone, claystone and, gravels
Upper Bakhtiari Formation	Pliocene	thick to medium bedded, conglomerate, and claystone
Lower Bakhtiari Formation	Early Pliocene	thick to medium bedded,conglomerate sandstone,
Upper Fars Formation	Late Miocene	medium bedded, alternation between sandstone and claystone
Lower Fars Formation	Middle Miocene	medium bedded, alternation between limestone and

3. Rationale

From a regional level, sheet and rill erosion is the most predominant types of water erosion in the non-agricultural districts of Kurdistan Region of Iraq. Moreover, from a watershed level, measure of soil erosion, transport and deposition sediment yield enables design procedures of dams and reservoirs before the constructional processes because deposition at the head of the reservoir, leading to an increase in flood levels in the contributing river upstream (Meadow croft et al, 1992). Erosion Severity Rating is high in Shewasur drainage basin, the need of this study is also related to assess the erosion risk and provide mitigation approaches such as land use management alternative and sediment control process to reduce the negative environmental and socio-economic impacts of annual inflow sediments.

4. Aims and objectives

The overall goal of this research is to use the experimental data and applying them in three different models of Universal Soil Loss Equation (USLE) to enable design procedures and provide mitigation processes to control the annual inflow sediment in the reservoir. These aims can be achieved by the following objectives:

1) Applying the measurement approaches to identify the quantity and quality of eroded soil and deposited sediments in the reservoir.

2) Identifying the factors that governing the sediment yield in the reservoir such as, soil erodibility factor, slope steepness factor, crop management factor and supporting practice factor.

3) Applying Vanoni's equation and Brune's formula to calculate the sediment delivery ratio (SDR), Trap Efficiency for the purpose of deposition and estimation of useful life and full life of the proposed reservoir (Shewasur Dam).

4) Using the literature and selected case study to identify procedural and substantive factors and institutional drivers associated with the sediment management techniques that lead to mitigate the amount of eroded soil and reduce sediment in the reservoir.

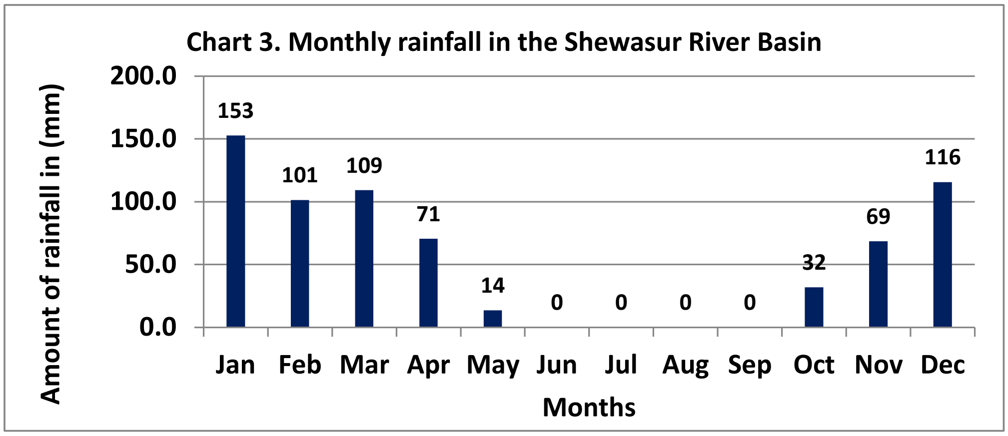
5. Methodologies

5.1. Methods of data collection

Primary and secondary data have been used in this study. The data collection and analysis is based on numerous approaches of soil loss estimation. Three methods have been used to estimate soil erosion including Universal soil loss equation, USLE for discretized sub-catchments and Modified Soil Loss Equation (MUSLE). For this purpose Firstly, a Digital Elevation Model (DEM) has been applied to discretize the catchment in to 34 sub-catchments according to the soil characteristics, landuse and topography information. Then, the second model, was created which is completely associated with the general hydrological data, based on the reports, which have been provided by the nearest meteorological station. Applying USLE needed a hydrologic model that considered many catchment characteristics such as, types of land use, soil information, climatic data and rainfall data for a long period of time. Thus, the watershed modelling system was selected to simulate the Shewasur River basin for the feasibility study. The rate of soil erosion from the area was strongly dependent upon its soil, vegetation and topographic characteristics. In actual situations, these characteristics are expected to change considerably within the various segments of the catchment.

5.2. The rainfall information data

The rainfall information data was provided by the Koya Meteorological Station, because it was the nearest meteorological station from Shewasur catchment. The eighteen annual and monthly precipitation readings for the case study is presented in the table 10, and illustrated in charts 3.



The rainfall information data was simulated to calculate the rainfall erosivity factor, volume of runoff and peak discharge calculation. Two sets of rainfall information was collected including: the average monthly data and maximum daily intensity (Table 10 & 20).

Table 10. Monthly and average annual rainfall data in (mm) (Koya Meteorological Station, 2010).

Years	Months											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1987-1988	192.5	113.5	228.1	77.2	12.6	0.0	0.0	0.0	0.0	128.8	39.5	388.1
1988-1989	25.3	41.1	102.7	0.0	0.0	0.0	0.0	0.0	0.0	3.1	19.6	221.9
1989-1990	117.9	129.1	26.9	125.0	0.0	0.0	0.0	0.0	0.0	11.6	274.7	110.1
1992-1993	82.0	90.0	101.0	316.5	69.0	0.0	0.0	0.0	0.0	0.0	0.0	90.5
1993-1994	181.1	101.0	122.0	78.0	8.0	0.0	0.0	0.0	0.0	185.2	182.0	78.5
1995-1996	225.3	50.8	272.9	77.2	12.3	0.0	0.0	0.0	0.0	0.0	15.0	37.8
1996-1997	110.0	205.5	155.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8	17.2	112.3
1997-1998	221.3	102.7	214.6	56.2	16.8	0.0	0.0	0.0	0.0	16.5	95.2	131.2
1998-1999	127.6	113.4	5.9	26.0	0.0	0.0	0.0	0.0	0.0	5.5	23.8	5.3
1999-2000	174.3	41.1	36.0	15.4	2.5	0.0	0.0	0.0	0.0	14.0	17.0	91.0
2000-2001	60.2	85.4	131.5	26.2	15.0	0.0	0.0	0.0	0.0	12.5	15.0	132.5
2001-2002	230.5	38.5	139.5	52.5	6.0	0.0	0.0	0.0	0.0	9.3	36.3	161.7
2002-2003	172.5	103.0	184.3	40.5	12.5	0.0	0.0	0.0	0.0	2.1	86.6	256.8
2003-2004	335.5	123.0	25.5	129.3	12.0	0.0	0.0	0.0	0.0	11.8	142.7	168.0
2004-2005	167.0	169.0	74.0	47.0	1.0	0.0	0.0	0.0	0.0	0.0	206.5	17.0
2005-2006	169.8	103.1	7.0	103.5	36.5	0.0	0.0	0.0	0.0	0.0	17.0	39.5
2006-2007	81.0	159.1	75.8	100.4	41.8	0.0	0.0	0.0	0.0	171.5	41.0	28.0
2007-2008	76.5	57.6	63.5	1.5	0.0	0.0	0.0	0.0	0.0	0.0	5.5	13.0
AMR	152.8	101.5	109.2	70.7	13.7	0.0	0.0	0.0	0.0	31.9	68.6	115.7
Total annual rainfall=∑Average monthly rainfall = 664 mm, Average daily rainfall =1.81mm/day												

5.3. Digital Elevation Modelling

From hydrological perspective, the entire catchment area has been divided in to a numerous of smaller size sub-areas according to their catchment characteristics. The sub areas has numbered and separated by different colours as shown in the (Fig. 3). Then the homogenous sub-catchments further categorized in to four groups according to their hydrological conditions and landuse circumstances. The model spatial framework, catchment boundaries and stream networks, were determined using the digital elevation model data (DEM) (MAWR, 2010). A DEM of 90 x 90 m for this study was acquired from the USGS. The DEM was corrected for the “sinks” and then data set which consisted of sub-catchments delineations and stream networks bearing topological identification numbers, as well as grids of flow direction, flow accumulation, slope, and other variables were determined. The delineated catchment was discretised into four sub-catchments (Fig. 13) based on the discharge points of the delineated stream network. The main hydrological and physical properties for the discretised sub-catchments are summarised in Table 7.

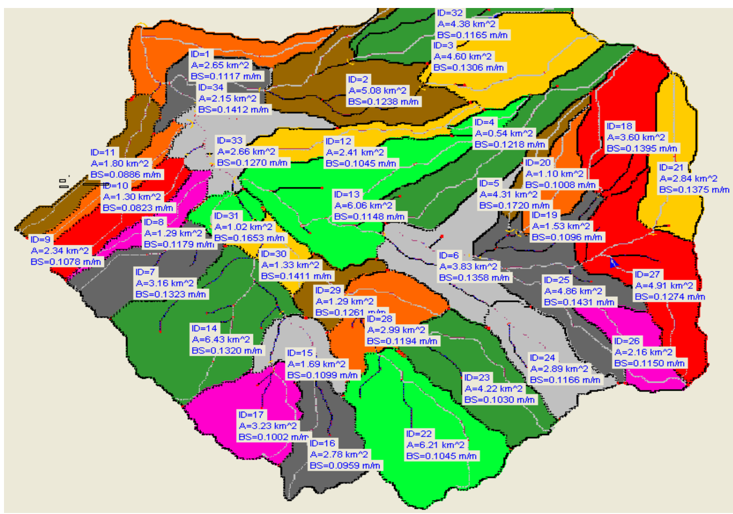


Figure 13. Digital Elevation Map for the whole Segments of Shewasur Catchment**. Source:** Ministry of Agriculture and Water Reseources- Kurdistan Regional Government. 2010.

5.4. Field investigations and soil sampling

It involved of drilling eighteen boreholes for the whole catchment area at different locations to collect samples and geological information (MAWR, 2010). The auger and core drilling method was used in advancing the boreholes. The location, depth and number of boreholes are shown in the tables (Appendix A). Then, Soil samples were taken at different depth interval from each borehole to determine the general soil characteristics such as, soil classification, hydrologic condition, groundwater observations and geological inspection. The details of the most relevant geotechnical investigation are tabulated for using the data in the USLE analysis. Standard methods such as standard penetration test, disturbed sample and rock core were employed to analyse the collected soil samples in both static and dynamic states of water table for exploring the mean weight diameter, particle size analysis, steady state infiltration rate, saturated hydraulic conductivity and soil organic carbon. The summary of the geotechnical investigation results for all the boreholes are presented in Appendix A.

5.5. Hydrological Model

A study of this nature required a model that reflected as many catchments characteristics as possible (land use, soils information, temperature data, and rainfall data). Some of these characteristics needed to be in the smallest temporal scale possible; in this case daily values were needed. The WMS 7.1 (Watershed Modelling System version 7.1) was selected as hydrological Model to simulate Shewasur River catchment for the feasibility study.

The input data

1) Digital Elevations Map for Study area was chosen. The accuracy of this map is about 10m. The map is conducted using Global Mapper Software, and then utilized by WMS program.

2) The dimensions of the dam location given by GPS instrument, which is (X=460362.5, Y=3960369, Z=451.04 m.a.s.l) using Universal Transverse Mercator (UTM).

3) Field information about the type of soil and land use Appendix A.

4) Rainfall information (depth and durations) as shown in table 10.

The output data and information

1) The delineation of Shewasur dam catchment area as shown in figure 13.

2) Storage capacity curve of Shewasur dam reservoir as it can be seen in Appendix B.

3) All geometrical information about the catchment area such as its area, slope, streams lengths and contour lines as presented in Appendix B.

6. Model analysis and calculations

6.1. Estimating soil loss using USLE

6.1.1. Calculation of the rainfall erosivity factor

Table 11. A model created to calculate the average R value from different indexes

RU.S	R S. I	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
176.8	3009	152.8	101.5	109.2	70.7	13.7	0.0	0.0	0.0	0.0	31.9	68.6	115.7
Applying Equations 4 and 5 above to find P and F					P=	664.1		F=	105.21				
No	Authors					Models				R in (MJ. mm . ha^{-1} h^{-1})			
1	Arnoldus (1980)- Linear					R=(4.17 * F - 152) * 17.02				4880.179			
2	Arnoldus (1977)- Exponential					$R= 0.302 * F^{1.93}$				2413.177			
3	Renard and Freimund (1994)- F					$R= 0.739 * F^{1.847}$				4012.318			
4	Renard and Freimund (1994)- P					$R = 0.0483 * P^{1.61}$				1689.441			
5	Lo et al (1985)- Linear P					R = 38.46 + 3.48 * P				2349.528			
6	Yu & Rosewelt (1996)- Expon-F					$R = 3.82 * F^{1.41}$				2711.269			
	Average result of six models = (1+2+3+4+5+6)/6									3009.3			

6.1.2. Calculation of the soil erodibility factor

Table 12. A model created to calculate the average K value from different indexes

Input data	Percentages of soil texture
Percentage of clay	2
Percentage of silt	21
Fine sand	61
Coarse sand	16
Organic materials (OM)	2
Soil structure code	1
Permeability class	1
Fp = Psilt (100-Pclay)	2058
M = (Psilt + Pfine sand)(100-Pclay)	8036
K= 2.1 * 10^{-6} $Fp^{1.14}$ (12-Pom) + 0.0325 (Sstru-2) + 0.025 (Fperm - 3)	
K= 2.77 *10^{-7} $M^{1.14}$ (12-Pom) + 4.28*10^{-3} (Sstru-2) + 3.29*10^{-3} (Fperm - 3)	
Output data	S.I Units
Value of K from Eq.6	0.043
Value of K from Eq.7	0.068
Average value of K	0.055

Limitations of the soil erodibility factor by nomograph method

1) Standard procedures used to identify sand, silt and clay content do not always work perfectly for tropic soils of volcanic origin. The soil erodibility nomograph does not apply to soils of volcanic origin, organic soils such as peat, Oxisols, low activity clay soils, calcareous soils, or soils high in mica. Also, the nomograph is less accurate for sub-soils than for topsoils (NRCS, 2003).

2) The soil erodibility nomograph was derived from empirical erosion data collected from rainfall simulator 35 feet (10.7 meter) erosion plots located primarily in Indiana (USDA-NRCS, 1984). The nomograph should not be extrapolated beyond the range of input values shown on the nomograph. For example, a value for organic matter greater than four percent is not recommended or allowed in USLE, DUSLE.

3) Soil erodibility factor doesn’t account rock cover in USLE. Rock cover on the soil surface acts as ground cover and reduces erosion much like plant litter, crop residue, and applied mulch, except the rock does not decompose and add organic matter to the soil (NASIS, 2003).

6.1.3. Calculation of the slope length factor

Table 13. Computation the LS for all segments of the catchment

Segment No	Area (Km^2)	Slope m/m	$\phi=\tan^{-1}$ slope	Sin ϕ	$\sin^2\phi$	λ	m	LS
1	2.65	0.11	6.27	0.11	0.012	300	0.5	4.93
2	5.08	0.12	6.84	0.12	0.014	300	0.5	5.65
3	4.60	0.13	7.40	0.13	0.016	300	0.5	6.34
4	0.54	0.12	6.84	0.12	0.014	300	0.5	5.65
5	4.31	0.17	9.60	0.17	0.028	300	0.5	9.66
6	3.83	0.14	7.90	0.14	0.019	300	0.5	7.06
7	3.16	0.13	7.40	0.13	0.016	300	0.5	6.34
8	1.29	0.12	6.84	0.12	0.014	300	0.5	5.65
9	2.34	0.11	6.27	0.11	0.012	300	0.5	4.93
10	1.30	0.08	4.50	0.08	0.006	300	0.5	3.02
11	1.80	0.09	5.14	0.09	0.008	300	0.5	3.64
12	2.41	0.01	0.57	0.00	0.000	300	0.5	0.26
13	6.06	0.11	6.27	0.11	0.012	300	0.5	4.93
14	6.43	0.13	7.40	0.13	0.016	300	0.5	6.34
15	1.69	0.11	6.27	0.11	0.012	300	0.5	4.93
16	2.78	0.09	5.14	0.09	0.008	300	0.5	3.64
17	3.23	0.10	5.71	0.10	0.010	300	0.5	4.26
18	3.60	0.14	7.90	0.14	0.019	300	0.5	7.06
19	1.53	0.10	5.71	0.10	0.010	300	0.5	4.26
20	1.10	0.11	6.27	0.11	0.012	300	0.5	4.93
21	2.84	0.13	7.40	0.13	0.016	300	0.5	6.34
22	6.21	0.10	5.71	0.10	0.010	300	0.5	4.26
23	4.22	0.10	5.71	0.10	0.010	300	0.5	4.26
24	2.89	0.11	6.27	0.11	0.012	300	0.5	4.93
25	4.86	0.14	7.90	0.14	0.019	300	0.5	7.06
26	2.16	0.11	6.27	0.11	0.012	300	0.5	4.93
27	4.91	0.13	7.40	0.13	0.016	300	0.5	6.34
28	2.99	0.12	6.84	0.12	0.014	300	0.5	5.65
29	1.29	0.12	6.84	0.12	0.014	300	0.5	5.65
30	1.33	0.14	7.90	0.14	0.019	300	0.5	7.06
31	1.03	0.16	9.10	0.16	0.025	300	0.5	8.90
32	4.38	0.11	6.27	0.11	0.012	300	0.5	4.93
33	2.66	0.13	7.40	0.13	0.016	300	0.5	6.34
34	2.17	0.14	7.90	0.14	0.019	300	0.5	7.06
Average		0.12						5.51

Note: Slope lengths greater than 305 m (1000 ft.) should not be used in this model because concentration usually occurs before the end of segments of this distance (Renard et al., 1997).

6.1.4. Calculation of the cover management factor (CM)

According to the information given by Leihner et al., 1996, Roose, E.J. 1977. & David, W.P. (1987) as shown in the table 4, the CM factor was 0.1 as the average value for the whole segments of the catchment. This because the watershed contains 40 % pasture without grazing, 10% primary forests, 20% bare soil and 30% diversified crops, using average value of the weighted percentage the value of CM factor is approximately equal to 0.1. The photograph below represents some parts of the catchment area which was taken during the data collection processes.

6.1.5. Calculation of the support practice factor

According to the information given by the United States Department of Agriculture- Natural Resources Conservation Services (USDA-NRCS, 1983) as shown in table 5, the value of P-factor is 0.5 for contour practices as average value for the whole segments of the catchment.

Table 14. Total annual eroded soil using USLE

Total annual eroded soil =	R	K	LS	CM	P
Total annual eroded soil=	3009.3	0.055	5.51	0.1	0.5
Total annual eroded soil in (ton /ha) =	45.92				
Since the catchment area is 103.67 km2, which is equal to 10367 hectare ; total annual eroded soil for (103.67 km^2) t/year=	476094.87				

6.1.6. Soil loss classification using USLE

Permissible soil loss is the maximum soil loss that allows an acceptable level of crop productivity to be sustained economically and indefinitely (Burrough et al., 1992). It is generally accepted as 12 t/ha/year (Wischmeier and Smith, 1978), but 5 t/ha/year is considered as the limit for shallow soils. In the present studies five classes of soil erosion (EC1–EC5) are adopted (Sehgal and Abrol, 1994). The ranges of soil erosion corresponding to these classes are given in Table 15. According to Wischmeier and Smith (1978), total eroded soil from the catchment is greater than 40 (t/ha/year), which is classified under EC5 classes.

Table 15. Standard soil erosion classes and ranges of soil loss

Class	EC1 very slight	EC2 slight	EC3 Moderate	EC4 Severe	EC5
Range t/ha/y	0.0-5.0	5.0 - 10.1	10.0-20.0	20.0-40.0	> 40.0

6.1.7. Eroded soil for each sub-catchment

The catchment is classified in to four sub-catchments, this classification based on the land use type and soil characteristics including grasslands, bare soils, croplands and forests. For each division the percentage of area was calculated as shown in the Table 10.

Table 16. Estimating total eroded soil and inflow sediment from different landuse sectors by USLE model

Type of landuse	Area Km^2	Area Percentage	Soil Loss t/y	Soil Loss m^3/y
Grasslands	33.18	32.01%	152376.1	84653
bare soil	33.31	32.13%	152973.1	84985
Annual crop	26.00	25.08%	119402.6	66335
Forest	11.18	10.78%	51343.1	28524
Total	103.67	100.00%	476094.9	264497

6.2. Estimating soil loss using DUSLE

As indicated by literature review, the DUSLE method is exactly the same as USLE, but different values of cover management and support practice factors are applied to each agro-climatic zone as shown in Table 6.

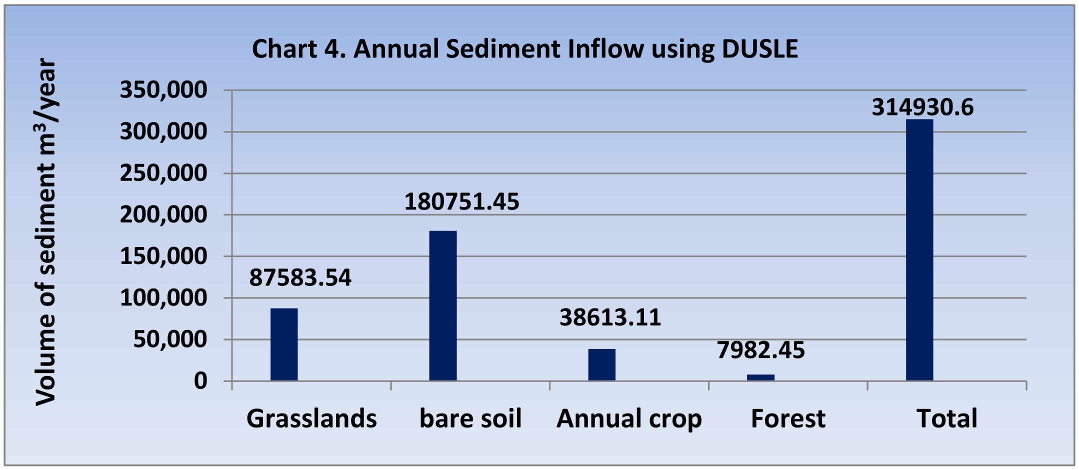
Table 17. Estimation of soil loss for discretized segments (Sub-catchment)

Grasslands	Area (Km^2)	R	K	LS	CM	P	Soil Loss t/ha/y	Soil Loss t/y
4	0.54	3009	0.055	5.65	0.1	0.5	46.75	2524.63
5	4.31	3009	0.055	9.66	0.1	0.5	79.93	34451.59
13	6.06	3009	0.055	4.93	0.1	0.5	40.79	24721.48
14	6.43	3009	0.055	6.34	0.1	0.5	52.46	33733.01
22	6.21	3009	0.055	4.26	0.1	0.5	35.25	21890.52
23	4.22	3009	0.055	4.26	0.1	0.5	35.25	14875.68
31	1.03	3009	0.055	8.90	0.1	0.5	73.65	7585.46
32	4.38	3009	0.055	4.93	0.1	0.5	40.79	17868.00
Sub-total 1	33.18			6.12				157650
Bare soil	Area (Km^2)	R	K	LS	CM	P	Soil Loss t/ha/y	Soil Loss t/y
2	5.08	3009	0.055	5.65	1.00	0.25	233.76	48077.30
6	3.83	3009	0.055	7.06	1.00	0.25	292.10	45293.03
7	3.16	3009	0.055	6.34	1.00	0.25	262.31	33558.63
11	1.8	3009	0.055	3.64	1.00	0.25	150.60	10974.93
15	1.69	3009	0.055	4.93	1.00	0.25	203.97	13956.02
16	2.78	3009	0.055	3.64	1.00	0.25	150.60	16950.17
20	1.1	3009	0.055	4.93	1.00	0.25	203.97	9083.80
24	2.89	3009	0.055	4.93	1.00	0.25	203.97	23865.62
25	4.86	3009	0.055	7.06	1.00	0.25	292.10	57473.67
29	1.29	3009	0.055	5.65	1.00	0.25	233.76	12208.61
33	2.66	3009	0.055	6.34	1.00	0.25	262.31	28248.72
34	2.17	3009	0.055	7.06	1.00	0.25	292.10	25662.11
Sub-total 2	33.31			5.57				325353

Annual crop	Area (Km^2)	R	K	LS	CM	P	Soil Loss t/ha/y	Soil Loss t/y
1	2.65	3009	0.055	4.93	0.20	0.37	60.38	6477.57
8	1.29	3009	0.055	5.65	0.20	0.37	69.19	3613.75
9	2.34	3009	0.055	4.93	0.20	0.37	60.38	5719.82
10	1.3	3009	0.055	3.02	0.20	0.37	36.98	1946.57
17	3.23	3009	0.055	4.26	0.20	0.37	52.17	6822.31
18	3.6	3009	0.055	7.06	0.20	0.37	86.46	12601.63
19	1.53	3009	0.055	4.26	0.20	0.37	52.17	3231.62
26	2.16	3009	0.055	4.93	0.20	0.37	60.38	5279.83
27	4.91	3009	0.055	6.34	0.20	0.37	77.64	15434.42
28	2.99	3009	0.055	5.65	0.20	0.37	69.19	8376.05
Sub-total 3	26.0			5.06				69504
Forest	Area (Km^2)	R	K	LS	CM	P	Soil Loss t/ha/y	Soil Loss t/y
3	4.6	3009	0.055	6.34	0.05	0.75	39.35	7327.68
12	2.41	3009	0.055	0.26	0.05	0.75	1.61	157.44
21	2.84	3009	0.055	6.34	0.05	0.75	39.35	4524.04
30	1.33	3009	0.055	7.06	0.05	0.75	43.81	2359.26
Sub-total 4	11.18			5.29				14368
Total = Sub-total 1 + Sub-total 2 + Sub-total 3 + Sub-total 4								566875

Table 18 . Estimating soil loss and yield sediment from different landuse sectors by DUSLE- Summary of the results

Type of landuse	Soil Loss t/y	Soil Loss m^3/y
Grasslands	157650	87583.54
bare soil	325353	180751.45
Annual crop	69504	38613.11
Forest	14368	7982.45
Total	566875	314930.6



As demonstrated from chart 4, it has been revealed that landuse condition has the major impact on the amount of eroded soil over the whole watershed area. As a result, landuse management is vitally important for conserving the soil from erosive forces.

6.3. Estimating soil loss using MUSLE

$E= R_w * K.LS.CM.P$ Eq.17

$R_w= 11.8 * (V * q_p)^{0.56}$ Eq.18

$V = Q \times A$ Eq.19

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$ Eq.20

$$S = \frac{1000}{CN} - 10$$ Eq.21

$q_p= CIA$ Eq.22

6.3.1. Methodologies for determining the Curve Number (CN)

AMC II (Antecedent Moisture Condition type II) curve number was chosen for the calculation of daily runoff data. Many samples were taken from Shewasur watershed area and tested in the College of Engineering Soil lab-University of Sallahaddin in order to classify them. The results are illustrated in Table 4, and Appendix A. The geotechnical investigation report shows that the classification of the soil type is (Sandy Loam). For this reason Group (B) curve number was used in the calculation as shown in (Table 7). From many investigations for Shewasur watershed area it is found that the land use could be classified in to four types as:

1- A percentage area about (32%) of non-cultivated agricultural land pasture with no mechanical treatment practice and poor hydrological condition.(CN=79), (Table 7).

2- A percentage area about (32%) of fallow poor condition with no mechanical treatment practice and good hydrological condition, (CN=86).

3- A percentage area about (25%) of cultivated with conservation tillage and good hydrological condition. (CN=71)

4- A small percentage area about (11%) of forest agricultural land with diversified trees and good hydrological condition (CN=66).

On the basis of the above explanation and computation the Curve Number (CN) is chosen approximately (CN=75), for the entire catchment area.

6.3.2. Calculation of volume of runoff (V)

The average annual surface runoff can be estimated with aid of monthly rainfall taken from Koya Meteorological Station (table 10). The data shows the rainfall of eighteen years from 1987-2008, and average annual rainfall was calculated, now using the curve number CN=75, and the average annual rainfall (P= 664 mm) which is equal to 0.072 in/day, The depth of runoff is calculated using SCS (Soil conservation Service) method, as illustrated in the Eq. 20 , the following results obtained for the volume of surface runoff in the sub-catchments.

Table 19. Daily and annual surface runoff for discretized segments and entire catchment

Discretized segments	CN	S (in)	P in/d	Q (in)	Area Km^2	V (m^3/day) = A(m2)*Q(m)	Annual runoff in (m^3/year) =V*365
Grass Land	79	2.7	0.072	0.096	33.18	80986.67	29,560,134
Bare soil	86	1.6	0.072	0.047	33.31	39587.08	14,449,285
Diversified crops	71	4.1	0.072	0.166	26	109725.98	40,049,983
Forest	66	5.2	0.072	0.219	11.18	62191.98	22,700,074
Entire catchment	75	3.3	0.072	0.129	103.67	340012.46	124,104,547

6.3.3. Peak discharge calculations

For determining the maximum rate of flow, maximum daily precipitation was proposed as a critical point since 1987 to 2008. For this purpose, the maximum daily rainfall was identified which is 127.5 mm occurred in 8^{th} April 1993, which has been recorded by the Koya Meteorological Station (Table 20). Using of maximum rainfall instead of average annual rainfall belongs to the maximum design flood which is effectively depending on the critical point of precipitation during a historical period of time.

Table 20. Maximum Daily Rainfall Data for Shewasur area (Koya Meteorological Station, 2010)

Year	Day	Max. 24 hour rainfall (mm)	P in mm/hr	P in (in/hr)
1987-1988	5/12/1987	93.6	3.90	0.154
1988-1989	12/27/1988	64.2	2.68	0.105
1989-1990	11/13/1989	121	5.04	0.198
1992-1993	4/8/1993	127.5	5.31	0.209
1993-1994	4/10/1993	54.8	2.28	0.090
1995-1996	3/19/1996	58	2.42	0.095
1996-1997	3/2/1997	59	2.46	0.097
1997-1998	2/11/1998	41.7	1.74	0.068
1998-1999	2/7/1999	35.4	1.48	0.058
1999-2000	12/20/2000	40.5	1.69	0.066
2000-2001	3/8/2001	70.2	2.93	0.115
2001-2002	1/28/2002	55.5	2.31	0.091
2002-2003	1/5/2003	71	2.96	0.116
2003-2004	12/15/2004	70	2.92	0.115
2004-2005	1/23/2005	53	2.21	0.087
2005-2006	1/25/2006	40	1.67	0.066
2006-2007	1/5/2007	50	2.08	0.082
2007-2008	3/13/2008	39	1.63	0.064

For determining the runoff coefficient C, Rational Method Runoff Coefficients have been used as highlighted in (Table 21.).

Table 21. Runoff Coefficient for Agricultural Watersheds [Soil Group B] by Schwab et al., 1993.

Crop and hydrologic condition	Coefficient C for Rainfall Rates of		
	25 mm/hr	100 mm/hr	200 mm/hr
Row crop, poor practice	0.63	0.65	0.66
Row crop, good practice	0.47	0.56	0.62
Small grain, poor practice	0.38	0.38	0.38
Small grain, good practice	0.18	0.21	0.22
Meadow, rotation, good	0.29	0.36	0.39
Fallow condition	0.14	0.18	0.2
Pasture, permanent, good	0.2	0.35	0.45
Woodland, mature, good	0.02	0.1	0.15

Input the data to q=CiA, the following results will be obtained as shown in the Table 22.

Table 22. Peak discharge calculations (qp) for different land conditions

Discretized segment	C	I (mm/hr)	A (km^2)	q (m^3/s)= CiA
Grass Land	0.20	5.31	33.18	9.79
Bare soil	0.14	5.31	33.31	6.88
Diversified crops	0.29	5.31	26.00	11.12
Forest	0.02	5.31	11.18	0.33
Entire catchment				28.12

Now applying the above data in connection with soil loss parameters in Table 17, one can find the following results as shown in Table 23.

Table 23. Estimating soil loss by Modified Soil Loss Equation-MUSLE

Discretized segments	V (m^3)	qp m^3/s	Rw	K SI Unit	LS (Av)	CM	P	Soil Loss t/y	Soil Loss m^3/y
Grass Land	29560134	9.79	646054	0.055	6.12	0.10	0.50	10873	6040.6
Bare soil	14449285	6.88	355135	0.055	5.57	1.00	0.25	27199	15110.5
Diversified crops	40049983	11.1	822542	0.055	5.06	0.20	0.37	16940	9410.9
Forest	22700074	0.33	83461	0.055	5.29	0.05	0.75	911	505.9
Total									31068

6.4. Calculation of sediment deposited in the reservoir using SDR

As indicated by literature review, applying Vanoni's equations (Eq.23 & 24), the following results are acquired (Table 24.), for both predicted annual eroded soil by USLE and DUSLE. **Note:** MUSLE doesn't need applying SDR model for the purpose of deposition.

$SDR = 0.42\ Ar^{-0.125}$ Eq.23

$SY = SDR * E$ Eq.24

Table 24. Total volume of annual sediment using SDR method

Segment	Ar (mi^2)	E in m^3/year		SDR	SY (m^3/year) = E*SDR	
		USLE	DUSLE		USLE	DUSLE
Grass Land	12.81	84653	87583.54	0.305	25849.37	26744.11
Bare soil	12.86	84985	180751.45	0.305	25938.01	55166.57
Diversified crops	10.04	66335	38613.11	0.315	20882.08	12155.35
Forest	4.32	28524	7982.45	0.35	9977.54	2792.22
Total					82647	96858

Table 25. Summary of the results of annual sediment yield using USLE, DUSLE, MUSLE

Models	Final delivery sediment yield (m^3 / year)
USLE	82647
DUSLE	96858
MUSLE	31068
Average	70191

6.5. Estimation of Trap Efficiency

$$TE = 100 * (0.97)^{0.19^{\log\left(\frac{V}{I}\right)}}$$ ....**Eq.25 Brune's Formula**

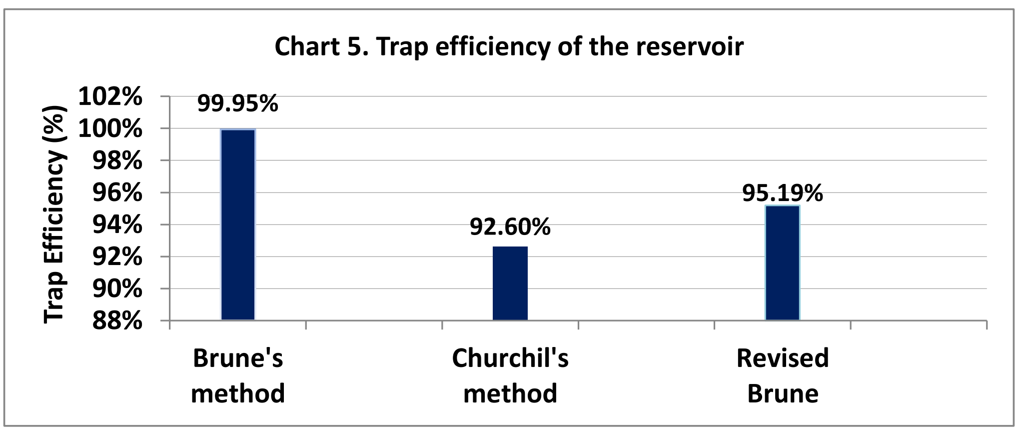
$$TE = 100 * \left[1 - \frac{1}{0.0021 * \frac{D * V}{W}}\right]$$ ....**Eq.26 Churchil's method**

$$TE = -22 + \left[\frac{119.6 * \frac{V}{I}}{0.012 + (1.02 * \frac{V}{I})}\right]$$ ....**Eq.27 Revised Brune's Formula**

Applying equations 25, 26, 27 to the data obtained by each method of USLE, DUSLE and MUSLE, one can get the following results.

Table 26. Trap Efficiency (TE) of the reservoir using three different models

Methods	Inflow Sediment m^3/y	Volume of reservoir m^3	Trap Efficiency (TE)		
			Brune's method	Churchil's method	Revised Brune
USLE	82647	6,689,956	99.96%	92.60%	95.26%
DUSLE	96858	6,689,956	99.80%	92.60%	95.23%
MUSLE	31068	6,689,956	99.95%	92.60%	95.19%



6.6. Useful Life and ful life calculation

The following equations by Gill (1979) as reviewed from the introduction were used to determine useful life after the relationship between sedimentation rates, TE, specific weight of sediment deposited, the storage available after sedimentation for a given period useful life in years was estimated.

$$T_L = \left(\frac{\lambda I}{G}\right) * (0.4935\frac{C0}{I} + 0.3 * 10^{-5}\frac{I}{C0} + 0.00436)$$ **Eq.28 Coarse grained sediments**

$$T_L = \left(\frac{\lambda I}{G}\right) * (0.008 + 0.51\frac{C0}{I})$$ **Eq.29 Medium sediment**

$$T_L = \left(\frac{\lambda I}{G}\right) * [0.51328\frac{C0}{I} - 0.133 * 10^{-3}\frac{I}{C0} + 0.153 * 10^{-5}(\frac{I}{C0})^2 + 0.018167] \quad \text{.......Eq.30}$$

According to the particle size distribution Appendix A, The percentage of clay, silt and sand are 2%, 21% and 77% respectively. Though, assume that inflow sediments are submerged moderately for duration of two years as the project has been finished since 2012. Thus, the value of λ can be calculated on the basis of data illustrated from Table 8.

λ sand = 1550+0ln(2)=1550

λ silt = 1120+91ln(2)=1183

λ clay = 416+256ln(2)=593

Now two methods can be applied to determine λ including average and weight percentage.

1. Average method: The average λ of materials is considered as follows;

λ = (λ sand + λ silt + λ clay)/3

λ = (1550+1183+593)/3=1108.67

2. Weighted percentage method: Based on the results which have been obtained from particle size analysis of all soil samples were taken from the boreholes. This method is predicted to have more precision as the deposited sediment represents the eroded soil consisted of sandy loamy materials.

λ = (0.77 λ sand) + (0.21 λ silt) + (0.02 λ clay) , the numbers 0.77, 0.21, 0.02 are representing material percentages in the reservoir.

λ = 1465.6

Using average data from total volume of annual sediment and eroded soil from each sub-catchment by different methods of soil loss estimation as shown in Table 26. Assuming sediments are generally medium-grained in nature (i.e. a mix of silt sand and clay), the results of the useful life of the reservoir by applying the above approaches are presented in the Table 27.

Table 27. Three approaches of estimating useful life of reservoir

Approaches	λ	I m^3/y	G kg/y	C_0 m^3	TL in Years	Capacity loss %
Eq.28	1466	70191	126343873	6689956	38.30	1.05%
Eq.29	1466	70191	126343873	6689956	39.58	1.05%
Eq.30	1466	70191	126343873	6689956	39.58	1.05%

6.7. Actual measurement of reservoir sedimentation

The methodology to assess the volume of sediments stored in a reservoir was determined directly by comparison of the initial height of reservoir base at the moment of dam construction (obtained from the construction plans) with the present height after one year (at the moment of the capacity assessment). The initial height of reservoir bed level was already determined by taking 20 readings from the entire area of the reservoir surface area as shown in the Figure 14. The present volume of deposited sediments is calculated by the product of reservoir surface area by the subtraction of the average initial level of reservoir bed level from the present top level of deposited sediment. The volume of deposited sediment is mathematically expressed as given:

Vs = Reservoir surface area (A) x Thickness of deposited sediment (T)

Where Vs is volume of deposited sediments in (m^3) at an age of one year, and T is the thickness of deposited sediment in the reservoir determined by a level apparatus in the reservoir.

Figure 14. Reservoir area and bottom level. Source: Ministry of Agriculture and Water Resources- Iraq-KRG. (MAWR, 2010).

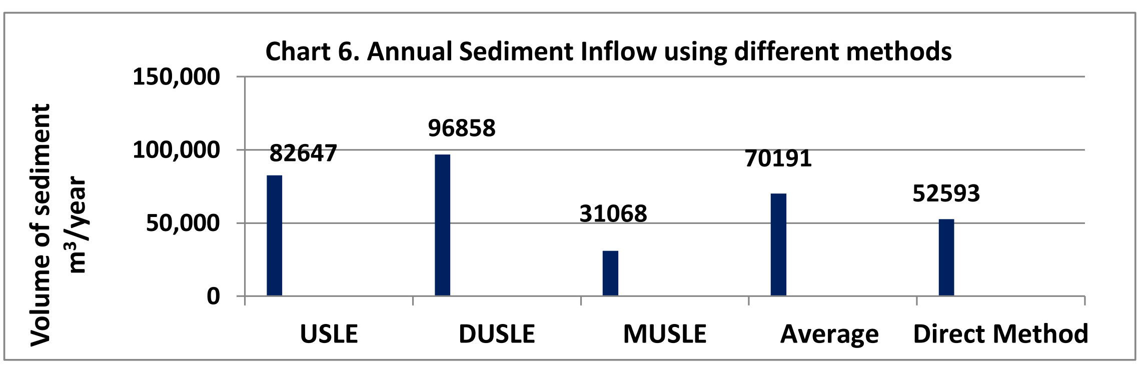
Figure 15. Reservoir area during preconstruction phase (MAWR, 2010).

Table 28. Measuring of reservoir sedimentation-Direct Method

Point	X	Y	Botom Elevation of the reservoir (m)	Staff reading after operational phase (m)	thickness of deposited sediment (T) in m
1	460362.5	3960369	450	450.05	0.05
2	460361.5	3960370	450	450.11	0.11
3	460362.4	3960368.5	450	450.13	0.13
4	460362.3	3960369.5	450	450.11	0.11
5	460361.1	3960370.5	450	450.08	0.08
6	460361.35	3960371.25	450	450.07	0.07
7	460360.5	3960369.65	450	450.09	0.09
8	460362.15	3960370.8	450	450.06	0.06
9	460361.05	3960369.15	450	450.05	0.05
10	460361.05	3960370.55	450	450.11	0.11
11	460362.45	3960370.35	450	450.10	0.10
12	460361.15	3960370.7	450	450.05	0.05
13	460360.05	3960378.5	450	450.13	0.13
14	460363.25	3960369.65	450	450.14	0.14
15	460359.5	3960370.5	450	450.11	0.11
16	460368.05	3960371.15	450	450.03	0.03
17	460361.45	3960369.45	450	450.15	0.15
18	460360.25	3960370.25	450	450.18	0.18
19	460371.05	3960369.6	450	450.06	0.06
20	460361.25	3960368.25	450	450.12	0.12
Volume of sediment in (m^3)			52592.5	545000	0.10

Table 29. Summary of the results of annual sediment yield using USLE, DUSLE, MUSLE and Direct Method

Models	Final delivery sediment yield (m^3 / year)
USLE	82647
DUSLE	96858
MUSLE	31068
Average	70191
Direct Method	52593



6.8. Cost analysis of erosion control techniques

6.8.1. Bill of quantity for constructing check dam

Table 30. Bill of quantity for construction 100 check dams

Item	Description	Unit	Qty	Price US$	Amount US$
1	Site preparation: including cleaning the site and removing all the debris to a designated area.	LS	1	120	120
2	Opening access road (minimum 3 m width) for the whole check dams to facilitate transportation between reservoir area and check dams in the sub-catchment.	M.L	100	54	5400
3	Excavation for foundation of the check dam (10 m length, 3m width and 0.5m depth) Includes excavation in all types of soil (even rock layers).	m^3	15	26	390
4	Supplying and transporting large stones with a minimum diameter of 25 cm to construct the check dam. (10 m width, 3m base width and 2 m height).	m^3	30	40	1200
5	Check dam wall: including supplying and placing the material (Rocks) to construct the wall of the dam, the weight of each individual rock shall not be less than 30 kg according to the ASTM and instructions of site engineer.	m^3	30	63	1890
Total cost of constructing one Checkdam					9000
Total cost of constructing 100 Checkdam over the entire area					**900,000**

6.8.2. Cost analysis of continuos types of terraces (Bench Terraces)

The cost of terracing per unit area depends on the following factors: slope, soil, width of bench, presence of rocks or tree stumps, and tools to be used for construction (USDA, 1980) . The cost of constructing terraces is calculated by the following formula:

C= V/T * R

Where:

C= Cost of construction terraces

V= Volume of cut and fill

T = Output per man-day or per machine hour

R = Wage per man-day or rate per hour for machines like Caterpillar or Bulldozer

To calculate the construction cost for (33.31 Km^2 =3331 ha) of 3.5 m wide bench terraces on a 12 % slope using the topsoil preservation method

Step 1. The volume for 0.5 ha is 719 m3, according to Sheng, T.C. (2000) the design specification of bench terraces, therefore, the volume for 3331 ha is 4,789,978 m^3.

Step 2. Expected output for the proposed site is 1000 m^3 per machine-day (for example Bulldozer) for the proposed site (under average conditions).

Step 3. Expected wage for the proposed site is 200 US$ per machine-day for the proposed site (under average conditions).

Cost of construction terraces= (4789978/1000) * 200

Cost of construction terraces= 957,996 US$

Maintenance cost = 2000 per year for two worker

Grand cost= Cost of construction + Cost of top soil preservation + Maintenance cost

Grand cost= Cost of construction + Cost of top soil preservation + Maintenance cost

Grand cost= 957,996 + 20,000 + 2000= 1,000,000 US$

From the cost benefit analysis it is found that both construction of small check dams and terraces can be selected as a control measure of soil erosion. Construction of check dam has more suitability than other techniques to choose as an instrument to control the annual sediment income. This is because, in addition to presence of local construction materials and labour force, relatively inexpensive and easy to construct. Moreover, check dams are effective at reducing erosion and sediment transport off site. As well as, check dams have secondary design benefits including removal of pollutants in the catchment such as nutrient loading, heavy metals, floatables, biochemical oxygen demand (BOD), total suspended sediments (TSS) and nitrogen and phosphorus contents (Mecklenburg, 1996).

6.8.3. Effectiveness of check dams on reducing sediment yield

The upstream hydrological effects of dams differ from the downstream effects. Channel aggradation gradually takes place upstream, because of the increase in base level (García Ruiz and Puigdefabregas, 1984). As a consequence the dams are rapidly filled up with sediment, especially in semiarid environments, where sediment yield is high (Poesen and Hooke, 1997). In the Rogativa catchment the conjunction of important land-use changes during the last 40 years, the installation of check dams has led to a significant reduction of the sediment supply with visible consequences in the hydrology of the sub-catchment (Castillo et al., 2007).

Now the tolerable sediment yield in the sub-catchment (bare lands) can be noticeably reduced on the basis of assumptions that have been made in the cost benefit analysis about the number of check dams and it's dimensions. The volume of sediment stored behind the dams is computed as a rectangular channel with trapezoidal cross section (Lien, 2003 and May and Gresswell, 2003).

$V= 1/2\ L * W * Ds$

$W= 1/2(Wb+W)$

$V= 1/4 * L*(Wb+W)* Ds$

Where:

V = Volume of deposited sediment carried by the suggested check dam in m^3

L = Longitudinal length of check dam as shown in the (Figure 16)

W= surface width of deposited sediment above NGL in m

Wb= bottom width of deposited sediment

Ds= Maximum depth of deposited sediment in the dam

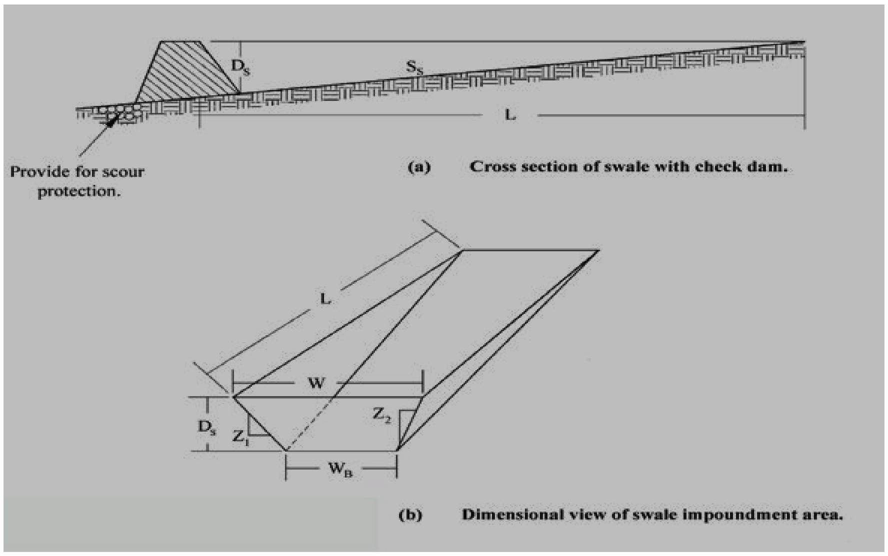


Figure 16. Profile section of assumed check dam

Now input L=20m, Wb=10m and Ds=2m, one can find out the volume of sediment obstructed by the check dam is 220m^3, then the overall volumes of 100 check dams as proposed earlier will be 22000 m3, which is a huge capacity to reduce the sediment discharge during high rainfall intensity in particular, from December to April as there has been chronologically huge precipitation in the area. Now, input the above data to find out the percentage of sediment reduction by the proposed check dams.

Table 31. Computation storage volume of sediment by proposed check dams

Discretized segment	Area (Km^2)	V (m^3)	Volume of inflow sediment before constructing check dams in (m^3)	Volume of inflow sediment after constructing check dams in (m^3)	Percentage of sediment reduction
Bare soil	33.31	22000	70191	48191	31%

6.8.4. Effectiveness of check dams on reducing water flow rate and velocity

While the dams are suggested to be constructed, the water flow rate should be reduced in the channel, in particular, the bare lands where the discharge of surface water was 6.987 $m^3.s^{-1}$, as it was calculated previously from the peak discharge estimation (Table 22). For this purpose, two methods have been used to calculate flow rate of water in the catchment including Gover's Empirical Equation and Manning's Formula for designing open channels.

$$V = \frac{R^{\frac{2}{3}} S^{\frac{1}{2}}}{n}$$ **……………………………………………………Eq.32**

$$v = 3.52\, Q^{0.294}$$ **……………………………………………………Eq.33**

Where:

Q is peak discharge in m^3/s , R is the hydraulic radius (area (A)/wetted perimeter (P)) in metres, S=slope (sine of slope angle), v=average velocity (m/s) and n is the Manning's roughness coefficients varies according to the physical properties of the bed material where water discharges. The general approach for estimating n values consists of the selection of a base roughness value for a straight, uniform, smooth channel in the materials involved, then, through a consideration of various factors, modifying values are added to the base n value to obtain the n value for the channel under consideration (Chow, 1959; Cowan, 1956). The value of n is determined by the following equation:

$n = (n_0+n_1+n_2+n_3+n_4)m$

Where:

no: is the base value for a straight uniform channel

n1: is the additive value due to the effect of cross-section irregularity

n2: is the additive value due to variations of the channel

n3 is the additive value due to the relative effect of obstructions

n4: is the additive value due to the type and density of vegetation

m: represents a value for the degree of meandering

Although the base and modifying values are interrelated to some extent, it is important that each factor be examined and considered independently and the effects not duplicated. Cowan (1956) indicates this method has not been verified on channels where hydraulic radius exceeds 15 ft. Alternatively, the main parameter which validates the practicality of Manning's Formula is the hydraulic radius. As a result, it is vitally important to calculate the value of hydraulic radius for designing the best cross sectional channel before making any preliminary design procedures using manning's roughness coefficient. The methodologies for determining hydraulic radius are based on the assumption that the cross section has a side slope angle of 45^0 degrees as shown in Figure 17.

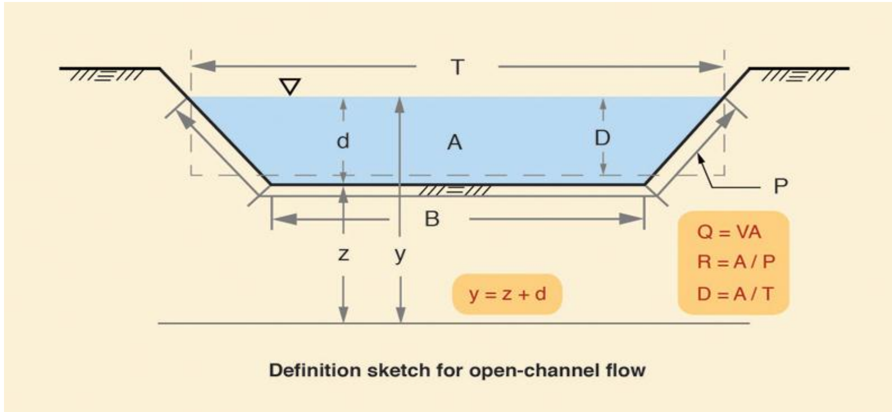


Figure 17. Cross sectional area of typical trapezoidal open channel

Area of the trapezoidal cross section (A) =d*(B+T)/2

Hydraulic Radius = A/P

P: is the perimeter of the wetted area= B + 2* Dcosϕ For ϕ=45, P= Wb+1.41D

According to Cowan (1956) this method can be verified on the channel as hydraulic radius doesn't exceed 15 ft. (4.57m) Table 32. Therefore Manning's equation is valid for determining the velocity of water and water flow rate in the flood plain. The value of n can be determined from Table 30 which has been empirically explored for a wide range of land use conditions.

Table 32. Typical values of Manning's Roughness coefficient.(n). **Source:** Hessei, R., Jetten, V. & Guanghui, Z. (2003). Estimating Manning's n for steep slopes. Catena, 54(1-2), 77-91.

Channel type	Surface material and form	Manning's (n)
	Earth straight	0.02-0.025
	Earth meandering	0.03-0.05
	Gravel straight (75mm-150mm)	0.03-0.04
	Gravel winding (75mm-150mm)	0.04-0.08
Unlined canal	Earth straight	0.018-0.025
	Rock straight	0.025-0.045
	Earth, smooth	0.018
	Earth channel - clean	0.022
	Earth channel - gravelly	0.025
	Earth channel - weedy	0.030
	Earth channel - stony, cobbles	0.035
	Floodplains - pasture, farmland	0.035
	Floodplains - light brush 0.050	0.050
	Floodplains - heavy brush 0.075	0.075
Lined canal	Concrete	0.012-.017

To find out the coefficient of roughness one can find a relation between the channel type and surface materials, which is shown in Table 32. According to Hussei et al., 2003 it can be predicted that the value of n ranges from 0.018 to 0.035 for the proposed sub-catchment. Take the value of n =0.30, as the channel bed contains stone, gravel, light brush and cobbles. For determining the slope of the channel, data from EDM was selected to each discretised portion of the sub-catchment. According to the EDM, the average slope of bare lands is equal to 0.12 which was shown in Appendix C . Assume that the channel has the average slope equals to the average overland slope 0.12 and applying Manning's equation the following results will be obtained.

Table 33. Hydrological data on the subcatchment

Bare soil	Area (m^2)	land use type	n	S	qp m^3/S	$V=3.52Q^{0.294}$	$R=[n*v/(s^{1/2})]^{3/2}$
2	2	Fallow	0.03	0.12	6.879	6.205	0.3940
6	2	Fallow	0.03	0.14	6.879	6.205	0.3510
7	2	Fallow	0.03	0.13	6.879	6.205	0.3710
11	2	Fallow	0.03	0.09	6.879	6.205	0.4888
15	2	Fallow	0.03	0.11	6.879	6.205	0.4205
16	2	Fallow	0.03	0.09	6.879	6.205	0.4888
20	2	Fallow	0.03	0.11	6.879	6.205	0.4205
24	2	Fallow	0.03	0.11	6.879	6.205	0.4205
25	2	Fallow	0.03	0.14	6.879	6.205	0.3510
29	2	Fallow	0.03	0.12	6.879	6.205	0.3940
33	2	Fallow	0.03	0.13	6.879	6.205	0.3710
34	2	Fallow	0.03	0.14	6.879	6.205	0.3510
Average							0.4m

Assume the cross sectional area of the channel is 2 m^2, from the above calculations by manning's formula, the results obtained for hydraulic radius is 0.4 m, there are many possibilities to choose the cross sectional geometry for the channel. As a result, making trials and errors the following results will be obtained. As it is shown from Table 34, the trial no 10 has more appropriateness to select the channel on the basis of the assumptions that have been made for the trapezoidal channel.

Table 34. Trial and assumption approach to determine the open channel dimensions

No	R (m)	Side slope angle 45°	d (m)	B(m)	T(m)	P (m)= B+1.41D	A in m^2 =d*(B+T)/2
1	0.472	45	0.500	3.00	4.00	3.705	1.75
2	0.478	45	0.500	4.00	5.00	4.705	2.25
3	0.432	45	0.450	4.00	4.90	4.635	2.00
4	0.424	45	0.440	4.20	5.08	4.820	2.04
5	0.414	45	0.430	4.15	5.01	4.756	1.97
6	0.405	45	0.420	4.19	5.03	4.782	1.94
7	0.400	45	0.415	4.20	5.03	4.785	1.92
8	0.398	45	0.412	4.23	5.05	4.811	1.91
9	0.398	45	0.412	4.24	5.06	4.821	1.92
10	0.404	45	0.419	4.35	5.19	4.941	2.00

6.8.5. Limitations of the Manning's equation to determine water flow rate

Several limitations of the Manning's equation and hydraulic calculations include streams subject to debris flow, very high-gradient streams, and modification of the channel during a flood. For instance, in the Manning's equation, specifically bare land floodplain, the cross section geometry has been constant for overall channel stations. This results in uncertainty in validation of Manning's equation, since the channel cross section is changing from a point to another one due to variation in soil properties and sediment load alterations by contributing gully erosion in steeper valleys.

Moreover, the hydraulic characteristics of debris flows and mudflows are such that the selection of n values for them and subsequent conventional hydraulic analyses probably are not applicable because of the large sediment load, channel scour and deposition, and a lack of a well-defined channel (Hergarte and Neugebaue, 1997). These hazard areas can be identified from geomorphic and sedimentologic evidence that remains in the flood plain and generally are found in small, steep watersheds and at the confluence of these watersheds with larger streams (Costa and Jarrett, 1981). Consequently, homogenisation of Manning's Formula can increase the percentage of errors in the calculations of water discharge and velocity.

7. Results

The results as shown in Table 29 & Chart 7, are focusing on that soil loss estimated by MUSLE is closer to the observed soil loss by actual measurement than those values predicted by USLE and DUSLE. This reason is belonging to: Firstly, a direct consideration of runoff was evident for a preferable soil loss prediction via MUSLE (Kinnell, 2005; Seyed et al., 2007). Secondly, in addition to divide the area in terms of hydrogeological conditions, it was also referred to consider the curve number and initial abstraction and peak discharge as an input for MUSLE model. William (1975) stated that runoff produced from single storm events is a better indicator than rainfall for sediment prediction. More specifically, in the proposed catchment, according to the meteorological data, there is no rainfall in summer seasons as illustrated in (Chart 3.), in other words, there are no eroded soil due to water erosion from June to September.

Hence, the results obtained by USLE are depending on average values which may be uncertain in particular to sensitive analyses like design of dams and hydraulic structures. Consequently, runoff from individual storm events has more validity than USLE and DUSLE, applied by MUSLE. According to the products as presented in Tables 23 & 24, the highest soil loss was simulated in non-cultivated soils. Since the value of cover management factor and support practice factor for this distinct part were higher than the contour practices. Similarly, it is evident that one of the areas where a phenomenal increase in erosion has been particularly focused on is the bare lands, in which the amount of eroded soil has reached its maximum rate. Contrastingly, minimum and moderate rate of erosions were recorded from the segments contained natural local trees and permanent pasture respectively.

On the basis of this analysis and from the hydrological and economical perspectives, a number of erosion control approaches have been proposed. The results as shown in the cost effective analysis were justified to suggest construction of check dam for the purpose of reducing sediment discharge in the basin. It can be summarised from Table 31 that after completion of check dams the annual eroded soil in bare lands significantly decreased from 70191 m3 to 48191 m^3. Then, as highlighted from the TE calculations in Table 26 and Chart 6, it can be discerned Revised Brune's approach has approximately an average value of trap efficiency. The outcomes of TE by this approach show that under all circumstances, only 5% of total annual sediment will release to the downstream part of the reservoir. Consequently, many environmental and geomorphological alterations experience to the shadow part which suffering from lack of sediments in the downstream part of the dam.

Physically based numerical modelling techniques can provide more accurate estimates of TE and using this approach it is possible to directly estimate the effects of sinking, particle aggregation, and diffusive transport on sediment dynamics [Casamitjana and Schladow, 1993]. Table 26 shows that trap efficiency of the studied reservoir ranges between 92% and 99% with a mean of 95%. The classic empirical equation of brune overestimated the trapping efficiency of the reservoir as the TE approaches from 100% which is very high in terms of the catchment characteristics and size of the dam. In comparison, applying of the modified Churchill's equation can provide a rapid and relatively perfect assessment of reservoir sediment trapping which only depends on the availability of daily inflow data. Due to having a great discrepancy between Brune and Churchil's formula in the TE of the reservoir, Revised Brune's equation, which was approximately equal to the mean value of the whole empirical results was taken in to account. This was due to overestimation of TE by Brune's approach and underprediction of TE by Churchill's formula.

As a result, one of the main environmental impacts of lack of sediments in the downstream will be the channel incision. Moreover, lack of sediments affects the gravel quarries and mining extraction companies. This is because, high amount of deposited sediments contained gravel are lost due to reservoir sedimentation deposition. Finally, a dramatic reduction of gravel and sand yield will be arisen due to deposition enormous amount of sediments in the reservoir. As it can be seen from Table 27, it is found that the reservoir will lose approximately more than 1 % of it's initial capacity annually. As well, according to the useful life estimation, the reservoir will be completely filled up over the next 78 years with the current trap efficiency and same hydrogeological conditions. The results acquired in this study will detract from the preliminary design criteria of the reservoir (i.e. 500 years, which was confirmed in both the Environmental Impact Assessment (EIA) and Strategic Environmental Assessment Report as a complementary part of the project design).

Correspondingly, the figures of trap efficiency estimation restrain the number of years required for the reservoir capacity to be partially depleted by sedimentation which is called useful life of reservoir. Full life of the reservoir, on the other hand, starts directly after the useful life can no longer serve it's primary purposes. However, until the year of 2050, the sediment deposits does not prevent the reservoir from achieving it's intended primary purposes such as wildlife, irrigation and flood control. But, due to replacing half of the reservoir capacity by sediment the water level raises by 50% which has a negative impact on the dam structure and flood control. Subsequently, in spite of increased water turbidity, numerous environmental and geomorphological implications will occur due to lack of sediments in the downstream part of the reservoir.

8. Discussions

Indirect measurements of inflow sediment due to water erosion play an important role to the hydrological knowledge of river basins and catchments. When estimating soil erosion indirectly by Universal Soil Loss Equations (USLE), one of the greatest difficulty lies in the estimation of eroded soil from different sub-catchments, since the USLE method generalises average values of parameters over the whole catchment area. In contrast, DUSLE discretised the catchment in to four discrete sub-catchments with different soil characteristics and land use types. For instance, factor 'vegetation cover' played a crucial role in the actual amount of soil loss or the rate of erosion. Similarly, the types of conservation measures (support practices) further determine the extent of actual erosion.

Hence, the latter model of erosion gives a better real-world picture of erosion rates when all the factors R, K, L, S, C, and P are considered in a discrete sub-catchment. As indicated from the literature review, The land use, soil texture, gradient steepness and management parameters are the principal agents governing soil erosion potential at specific location to the erosive power of rainfall. Although, the USLE predicted annual soil loss from sheet and rill erosion, gully erosion was disregarded. Furthermore, according to Foster (1988) the USLE doesn't account for deposition nor does it predict sediment yield. Relatedly, USLE is mainly associated with the SDR principles for the purpose of deposition. However, as it was reported by Walling (1983), the magnitude of sediment delivery ratio for a particular basin will be highly impacted by a wide range of geomorphological and environmental dynamics including the nature, extent and location of sediment sources, relief and slope characteristics, the drainage pattern and channel condition, vegetation cover, land use and soil texture.

The USLE estimates erosion for moderate slopes and medium soil textures. The results obtained by USLE may be overestimated or inaccurate at extreme slopes and texture. Moreover, according to Robinson (1979) the annual sediment load obtained by USLE is frequently low in regions where the erosive forces are primarily from overland flows. USLE generalised a specific support practice and cover management factor upon the whole catchment area which resulted in inaccuracy of the outcomes obtained. Lastly, a major limitation of the model is that it neglects certain interactions between factors in order to distinguish more easily the individual effect of each. For example, it does not take into account the effect on erosion of slope combined with plant cover, nor the effect of soil type on the effect of slope. As a result, the USLE overestimated soil losses in comparison with those predicted by MUSLE and direct measurement approaches (Table 29).

As seen from Table 23, the MUSLE has performed well enough in prediction sediment yield from individual storm event. However, the individual storm events are not representing the real climatic condition of the catchment, because the MUSLE depends mainly on the rainfall intensity and duration of the rainfall since each storm event. In the proposed catchment, the average annual precipitation was considered to calculate the sediment yield for the whole 365 days in a year. This calculation may be correct in a mathematical perspective, but from a hydrological point of view, it is frequently far from the real condition of the area because there has been no rainfall in June, July, August and September since 1987 to 2008 according to the data presented in Table 10. Therefore, calculation of the total annual sediment yield on the basis of summing up 365 equal storm event with respect to the nature and climatic conditions, may have given less precise results. Consequently, sediment yield determination on the basis of using individual storm events and summing the results for all the events provide a better understanding and accurate result to the catchment for making decisions and feasibility studyings.

The data of Table 31 have two important implications. First, they indicate that check dams can reduce the amount of annual sediment yield from areas with high soil erosion as suggested by erosion control measures. Second, the application of either land use changes agroforestry, terracing or check-dams to reduce sediment yield depends on the intention of the management and the particular environmental conditions. For instance, terracing can control the sedimentation in the area, while requires huge inputs of machinery and labour forces to construct and maintain as calculated from the cost analysis section of different land use alternatives. Specifically, in sandy soils, which compose the majority of Shewasur flood plain, unretained terraces can lead to mudslides, making of large gullies and increased soil erosion. Therefore, land use alternatives are highly evaluated by the Environmental Impact Assessment before starting implementation processes and making decisions on it.

In terms of the useful life of the reservoir and trap efficiency estimation there may have been uncertainty in the results. Brune (1953) had considered only two parameters in his formulation namely, capacity and average annual inflow while many other factors influence on the reservoir sedimentation. For example, angle of internal friction between soil particles affects on soil stabilisation, erosion and land degradation. In addition, Brune (1953) had used only normally ponded reservoirs for deriving this empirical relationship. However, this method found to be not accurate enough for reservoirs where a highly variable inflow can be observed, as trapped sediment weight is very much influenced by sediment inflow rate. Churchill (1948) also had taken limited number of parameters in to account such as, detention time and mean velocity, omitting others parameters which affects the reservoir sedimentation. But Trimble et.al (1990) concluded that the Churchill method provides a more realistic computation of sediment yields than the Brune method, for reservoirs receive sediments from an upstream reservoir.

The obtained data suggest that the two most commonly used methods to predict reservoir TEs, the Brune and Revised Brune's equations [e.g., Verstraeten and Poesen, 2000], considerably overestimate trapping in the Shewasur Reservoir Dam. There are several potential reasons, related to water transit time and sediment sinking velocity, that make the

Brune's formula not reliably predict sediment trapping in the Shewasur Reservoir. These include (1) differences in dam stratification; (2) variability of the inflows; and (3) particle size. The Shewasur Reservoir receives most of its inflow during the winter period when the water column is temperature stratified [Chudek et al., 1998; Faithful and Griffiths, 2000]. Under such conditions inflows with similar temperatures, lower ionic strength and higher TSS concentrations than the dam resident water, flow through either the surface layer or metalimnion [see Faithful and Griffiths, 2000] as an interflow.

Another possible mechanism why the Brune and Revision's methods overestimate TE could be that the incoming sediments to the Reservoir are relatively finer and sink more slowly than those upon which the empirical relationships were based (Lewis et al., 2013). The results obtained by Borland (1971) also verified that the Churchill formula is estimating trap efficiency more adequately than Brune's equation, according to results obtained from his experiments on reservoir sedimentation. Verstraeten et.al (2000) have stated that although the use of the Churchill method may give a better prediction of TE compare to Brune's method, but it is very difficult to obtain the input data for calculating the sedimentation index (SI) for Churchill formula which is defined as the ratio of detention time to mean velocity .

The major limitations of this study are created throughout the methods of data collection, because a substantial part of the study relies on the secondary data which might influenced the application and/or interpretation of the results obtained. It is expected that, the results would have been more reasonable, if the primary data had been used through the whole approaches of soil loss estimation. Following are some examples of major limitations that they possibly impacted the findings.

1) Lack of rainfall information after 2007 may impacted the results, as the study dealing with the current situations and future prospects of the reservoir.

2) The soil samples used to generate the geotechnical investigation reports may be small with respect to the size of the catchment.

3) The results for erosion control measures, are based on the assumptions and trials that have been made as a mitigation processes of sedimentation, it doesn’t represent the real situation of the catchment because the check dams have not been constructed yet.

9. Recommendations

Methods of soil loss estimation are important component of soil management services and sediment controllin strategies, in particular in the designing of reservoir and hydraulic structures.Therefore, it can be recommended that while estimating soil loss from a catchment using USLE or MUSLE, it is important to carry out qualitative and quantitative analyses of site specific and regional hydrological, meteorological and geological data. Selection of primary data rather than relying on secondary research enable designers and engineers decide on the most appropriate approach of soil loss estimation, especially dams and reservoirs which require more precision in designing live storage and dead storage, spill way, diversion channel and bottom outlet. There are numerous sediment strategies to reduce deposition in the reservoir. A reduction of sediment yield by soil stabilization in the catchment area can be very effective, and can solve the reservoir sedimentation problem in a sustainable way (Sumi et al., 2004). Where the climatic conditions promote vegetation practices, the soil can be kept from erosive forces by reforestation or vegetation screens. In catchment areas without vegetation, as for example the bare lands, erosion protection can only be succeeded with engineering projects such as construction of retaining walls, check dams, gully control , as well as slope and bank protection works on rivers.

Sediment deposition can be reduced naturally, through saving water during seasons of low precipitation because the amount of eroded soil is less than during high intensity rainfalls. In other words the saving water has less turbidity as compared to the water inflow during high rainfall intensity. Secondly, making extra diversion channels to pass sediment inflow around the reservoir in order not to accumulate in reservoirs.

Sediment Replenishment Technique By Mechanical Dredging or Hydrulically: Sediment replenishment method is one of new measures of sediment management that can be recommended for the reservoir. In this method, deposited sediment is periodically dredged out by excavators and then transported to be placed temporarily downstream of the dam. This technique can be completely achieved through proceduring four steps including, extracting mechanically the accumulated sediment at check dam. Then, transporting it by truck to downstream river. After that, placing the sediment with specific geometry and finally, monitoring flow, sediment, and environmental parameters.

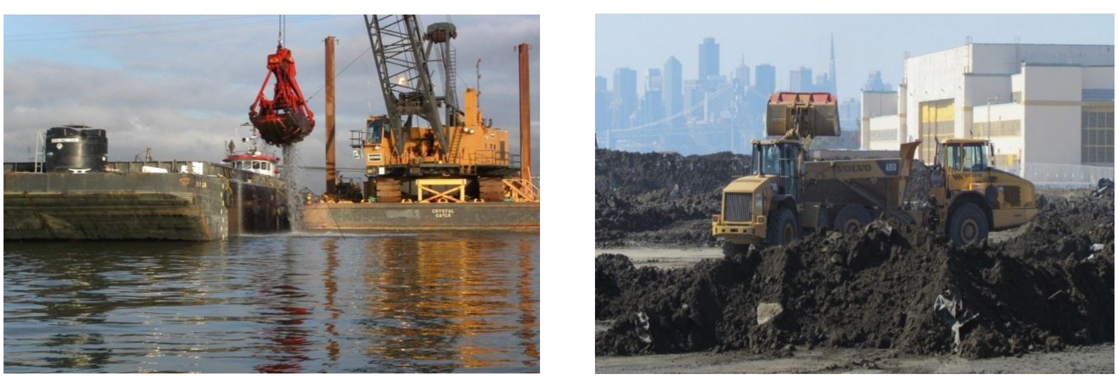


Figure 18. Dredging out sediment by excavation method

10. Conclusions

Monitoring soil loss by USLE, DUSLE and even MUSLE is technically impractical, because soil erosion events are highly variable, both temporally and spatially. These empirical erosion prediction technologies have important limitations when used to analyse the impact of soil erosion on reservoirs and dams. Actual measurements of sediment discharge provides better understandings than empirical approaches since soil loss by wind erosion for instance is extensively neglected by the aforementioned models of erosion prediction. It has been found that runoff and peak discharge calculations are a better indicator than rainfall for sediment prediction for the agroclimatic condition of Iraq. This has been examined through a case study, which was carried out in the Shewasur catchment in the North Iraq.

A review of the literature indicated that many hydrological analyses underestimate annual soil loss from a specific area of the watershed and overestimate of annual sediment flux in the reservoir. Because many parameter's value like CM and P factor, based on current guidance documents are considered too small as the average value of factors calculated by the USLE and DUSLE. It can be also concluded that considering contour practices as average value for the whole catchment portions made the results have a great inconsistency obtained by three different approaches of soil loss calculation. This paper has shown that an informed selection of soil loss estimation models is a prerequisite task in determining the annual inflow sediment and may be one of the most important procedure for developing sustainable land management and water resources.

Alternatively, validation of the USLE/ MUSLE models for estimating annual sediment yield, trap efficiency and useful life of reservoir was examined at the Shewasur Watershed in Northern Iraq. The MUSLE application was better to estimate soil loss than the USLE and DUSLE at the overall segments of the watershed. This was due to runoff and peak discharge calculations which were considered as an input for MUSLE model, and was a better indicator than rainfall for sediment prediction because of interacting many hydrological parameters to the model analysis. The first parameter was the Curve Number which has reduced the total precipitation to runoff potential, after losses such as evaporation, absorption, transpiration and surface storage. Therefore, the higher the CN value the higher the runoff potential was.

References

Ahamed, N., Rao, K., & Murthy, R. (2000). Fuzzy class membership approach to soil erosion modelling. *Agricultural Systems, 63* (2), 97-110.

Annandale, G.W. (1987). *Reservoir Sedimentation.* New York: Elsevier Science Publishers.

Armanini, A. and Larcher, M. (2011). Rational criterion for designing opening of slit-check dam. *Journal of Hydraulic Engineering, 127* (2), 94-104.

Arnoldus, H M J.(1977). Methodology used to determine the maximum potential average annual soil loss due to sheet and rill erosion in Morocco. FAO/UNEP Expert Consultation on Assessing Soil Degradation. Rome (Italy), soil bulletin 34:39-48.

Arnoldus, H.M.J., 1980: An approximation of the rainfall factor in the Universal Soil Loss Equation. In: M. deBoodt and D. Gabriels (Eds.), *Assessment of erosion* . Wiley, chichester.

Arora, P.K. and Goel, M.P. (1994). Estimating Life of a Reservoir. Proceedings of Workshop on Reservoir Sedimentation held in Mysore, Karnataka, on May 17- May -19 , 1994, pp. 4-11, India.

Bashar, K.E. and Ahmed, E. (2010). Sediment Accumulation in Roseires Reservoir. *Nile Basin Water Science & Engineering Journal,3* (3),46-55.

Basson, G. (2008). Reservoir sedimentation- An overview of global sedimentation rates , sediment yield and sediment deposition prediction.*The International Workshop on Erosion, Transport and Deposition of Sediments. University of Bern- Switzerland.* UNESCO-ISI.

Bhattarai, R. & Dutta, D. (2007). Estimation of soil erosion and sediment yield using GIS at catchment scale. *Water Resources Management, 21,* 1635-1647.

Bonda, F., Mlava, J., Mughogho, M. & Mwafongo, K. (1999). Recommendations for future research to support erosion hazard assessment in Malawi. Malawi Environmental Monitoring Programme. University of Arizona.

Borland, W.M. (1971). Reservoir Sedimentation. In Shen, H.W., editor, *River mechanics* . Vol. II, Fort Collins, CO: Colorado State University.

Brune, G.M. (1953). Trap efficiency of reservoirs. *Transactions of American Geophysical Union, 34* (3), 407–418.

Burrough, P.A., Macmillan, R.A. & Van Deursen, W.(1992). Fuzzy classification methods for determining land suitability from soil profile observation and topography. *European Journal of Soil Sciences, 43* (2),193–210.

Casamitjana, X. & Schladow, G. (1993). Vertical-distribution of particles in stratified lake. *Journal of Environmental Engineering, 119,* 443–462.

Castillo, M., Mosch, M., García, C., Barbera, G. Navarro, A. & Lopez, F. (2007). Effectiveness and geomorphological impacts of check dams for soil erosion control in semiarid Mediterranean catchments, SE Spain. *Catena, 20* (3), 416–427.

Castillo, C., Perez, R. & Gomez, A. (2014). A conceptual model of check dam hydraulics for gully control: Efficiency, optimal spacing and relation with step-pools. *Hydrology and Earth System Sciences, 18* (1)1705–1721.

Chow, T.L., Rees, H.W., and Daigle, J.L. (1999). Effectiveness of terraces grassed waterway systems for soil and water conservation: a field evaluation. *Journal of Soil and Water Conservation, 54* (3), 577-583.

Chow, V.T. (1959). *Open Channel Hydraulics.* New York: McGraw-Hill.

Cogo, D., Moldenhauer, C. & Foster, R. (1984). Soil loss reduction from conservation tillage practices. American Journal of Soil Science Society, 48, 368-373.

Cowan, W.L. (1956). Estimating hydraulic roughness coefficients. *Agricultural Engineering, 37* (7), 473-475.

David, W.P. (1987). *Soil erosion and land classification* . Report for World Bank Farm Mission.

Department for Environment, Food and Rural Affairs (DEFRA), (2004). *Developing measures to promote catchment-sensitive farming. A Joint Defra-HM Treasury Consultation* . DEFRA, London.

Evans, R. & Boardman, J. (1994). Assessment of water erosion in farmers' fields in the UK. In: Rickson, R.J. (Ed.), *Conserving Soil Resources: European Perspectives.* CAB International, Wallingford, UK, pp. 13–24.

Food and Agricultural Organisation (FAO). (2000). *Manual on integrated soil management and conservation practices* . *Land and Water Bulletin* , 8 (pp. 230). Italy: Rome.

Ferro,V. (2010). Deducing the USLE mathematical structure by dimensional analysis and self-similarity theory. *Biosystems Engineering, 106* (2), 216-220.

Ferro,V.&Minacapilli,M.(1995). Sediment delivery processes at basin scale. *Hydrological Sciences Journal, 40* (6),703-717.

Ferro,V., Porto, P. &Tusa, G.(1998).Testing a distributed approach for modelling sediment delivery. *Hydrological Sciences Journal* , 43(3), 425-442.

Gallart, F., Liorens, P. & Latron, J. (1994). Studying the role of old agricultural terraces on runoff generation in a small Mediterranean mountainous basin. *Journal of Hydrology, 159* (1-4), 291-303.

Garg, V. and Jothiprakash, V.(2008). Estimation of useful life of a reservoir using sediment trap efficiency. *Journal of Spatial Hydrology, 8* (2), 2-12.

Goldman S.J., Jackson K. & Bursztynsky T.A. (1986). *Erosion and sediment control handbook.* New York: McGraw Hill.

Gover, G. (1992). Relationships between discharge, velocity and flow area for rills eroding loose, non-layered materials. *Earth Surface Processes and Landforms, 17* (5),515–528.

Graf, W.L. (2005). Geomorphology and American dams: the scientific, social, and economic context. *Geomorphology, 71* (1–2), 3–26.

Gray, D. & Sotir, R. (1996). *Biotechnical and bioengineering-Slope stabilisation: A practical guide for erosion control.* New York: John Wiley & Sons, Inc.

Gregori E., Andrenelli, M.C. & Zorn G. (2006). Assessment and classification of climatic aggressiveness with regard to instability phenomena connected to hydrological and morphological processes. *Journal of Hydrology, 329* (3-4)*,* 489- 499.

Haan, C.T. (1982). Hydrologic modeling of small watersheds. American Society of Agricultural Engineers. United States Department of Agriculture.(1982).

Haan, C.T., B.J. Barfield, and J.C. Hayes (1994). Design hydrology and sedimentology for small catchments. USA. California, San Diego: Academic Press. Pp. 588.

Hadley, R.F., Lal, R., Onstad, C.A., Walling, D.E. & Yair, A. (1985). *Recent developments in erosion and sediment yield study* . UNESCO, IHP. Paris: France.

Harbor, J., Bhaduri, B., Angelakis, L. and Snyder, J. (1997). *Sediment basins, using modified stormwater management basins and sediment basins to reduce water pollution from construction sites in Ohio* . Kent, OH Department of Geology, Kent State University.

Hessel, R., Jetten, V. & Guanghui, Z. (2003). Estimating Manning's n for steep slopes. *Catena, 54* (1-2), 77-91.

Hergarten, S. & Neugebaue, H. (1997). Homogenization of Mannings formula for modeling surface runoff. *Geophysical Research Letters, 24* (8), 877-880.

Jain, S., Kumar, S. & Varghese, J. (2001). Estimation of soil erosion for a Himalayan Watershed using GIS technique. *Water Resources Management, 15,* 41–54.

Johnson, C. W., Gordon, N. D. & Hanson. C. L. (1985). Northwest rangeland sediment yield analysis by the MUSLE. *Transactions of the American Society of Agricultural Engineers* , 28 (6), 1889-1895.

Khanbilvardi, M., & Rogowski, S. (1984). Quantitative evaluation of sediment delivery ratios. *Journal of the American Water Resources Association, 20 (6),* 865-874.

Kinnell, P.I.A. (2005). Why the universal soil loss equation and the revised version of it do not predict event erosion well? *Hydrological Processes, 19,* 851-854.

Kothyari, U.C, and Jain, S.K. (1997). Sediment yield estimation using GIS. *Journal of Hydrological Sciences* , 42(6), 833-843.

Kulkarni, D.N., Shukla, S.Y. & Oka, V.S. (1994). Sedimentation of Reservoirs in Maharashtra. *Proceedings of Workshop on Reservoir Sedimentation held in Mysore, Karnataka, on May 17- May 19 1994, pp. 158-165,* India.

Lal, R. (1998). Soil erosion impact on agronomic productivity and environment quality. Critical *Reviews in Plant Sciences* 17, 319–464.

Lane, L., Hernandez, M. & Nicholas, M. (1997). Processes controlling sediment yield from watershed as functions of spatial scale. *Environmental Modelling & Software, 12* (4), 355-369.

Lara, J.M. & Pemberton, E.L. (1965). Initial unit weight of deposited sediments. In A.R.S. USDA (Eds.), *Federal Interagency Sedimentation Conference* . New York: Prentice Hall.

Lasanta, T., Arnaez, J., Oserin, M. & Ortigosa, L.M. (2001). Marginal lands and erosion in terraced fields in the Mediterranean mountains. *Mountain Research and Development, 21* (1) 69-76.

Lewis, S., Bainbridge, Z., Kuhnert, P., Sherman, B., Henderson, B., Dougall, C., Cooper, M. & Brodie, J. (2013). Calculating sediment trapping efficiencies for reservoirs in tropical settings: A case study from the Burdekin Falls Dam, NE Australia. *Water Resources Research, 49* , 1017–1029.

Lien, H.P. (2003). Design of slit dams for controlling stony debris flow. *International Journal of Sediment Research, 18* (1), 74–87.

Lundgren, B. O. & Raintree, J.B. (1982). Sustained Agroforestry. In B. Nestel (Ed.) *Agricultural research for development: Potential and challenges in Asia* . ISNAR, The Hague, Netherlands. Pp. 37 - 49.

Marone, C. (1998). Laboratory-derived friction constitutive laws and their application to seismic faulting: *Annual Review of Earth Planetary Sciences. 26* (1), 643–696.

May, C. & Gresswell, R. (2003). Processes and rates of sediment and wood accumulation in headwater streams of the Oregon coast range, USA. *Earth Surface Processes Landforms, 28* (4),409–424.

McHugh, M., Wood, G., Walling, D.E., Morgan, R., Zhang, Y., Anthony, S. & Hutchins, M. (n.d). Prediction of sediment delivery to watercourses from land-Phase II. Environmental Agency R&D- Technical Report. pp. (2-209).

Meadow croft, I. C., Bettess, R., Reef, C.E. & Wellingford, H.R. (1992). Numerical modelling of reservoir sedimentation. In Noel, M., Parr, J., Charles, A., & Walker, S. (Eds.), *Water Resources and Reservoir Engineering: Proceedings of the seventh conference of the British Dam Society held at the University of Stirling, June 1992.* (pp. 211-219). London: Thomas Telford, Redwood Press.

Mecklenburg, D. (1996). Rainwater and land development. Division of Soil and Water Conservation. Ohio Department of Natural Resources. Columbs,

Ministry of Agriculture and Water Resources- Kurdistan Regional Government-Iraq. 2010. *Shewasur Dam Final Report: Hydrology and Hydraulics. Volume 5.* Erbil: MAWR Printing Office.

Montgomery, D.R. (2007). Soil erosion and agricultural sustainability. *Proceedings of the National Academy of Sciences,4* (13), 268-272.

Morgan, C. (1986). *Soil erosion and conservation.* London: Longman Group UK, Ltd.

Morgan, C. (1995). *Soil Erosion and Conservation.* London: Longman Group UK, Ltd.

Morris, G.L., and Fan, J. (1998). *Reservoir Sedimentation Handbook* . New York: McGraw Hill.

Murthy, B.N. (1980). *Life of Reservoir.* Technical Report No. 19, Central Board of Irrigation and Power (CBIP): New Delhi, India.

Mutua, B. & Klik, A. (2006). Estimating spatial sediment delivery ratio on a large rural catchment. *Journal of Spatial Hydrology, 6* (1), 64-80.

Nair, P. K. R. (1993). *An Introduction to Agroforestry* . Kluwer, Boston.

Newson, M.D. (1980). The erosion of drainage ditches and its effect on bed load yields in mid-Wales: reconnaissance studies. *Earth Surface Processes and Landforms, 5,* (275-90).

Panagos, P., Meusburger, K. ,Ballabio, C., Borrelli, P. & Alewell, C. (2014). Soil erodibility in Europe: a high-resolution dataset based on LUCAS. *Science of the total environment, 479-480(1)* 189-200.

Parsons, A., Wainwright, J., Powell, D., Kaduk, J. & Brazier, R. (2004). A conceptual model for determining soil erosion by water. *Earth Surface Processes and Landforms, 29* (10), 302-1293.

Ran, L., Lu, X., Xin, Z. & Yang, X. (2013). Cumulative sediment trapping by reservoirs in large river basins: A case study of the Yellow River basin. *Global and Planetary Change, 100* , 308-319.

Reaney, S.M., Lane, S.N., Heathwaite, A.L. & Dugdale, L.J. (2011). Risk-based modelling of diffuse land use impacts from rural landscapes upon salmonid from abundance. *Ecological Modelling, 222* (4), 1016-1029..

Renard, G., Foster, R., Weesies, A., McCool, K. & Yoder, C. (1997). *Predicting soil erosion by water: A Guide to conservation planning with the revised Universal Soil Loss Equation* —USDA Agric. Handb. 703. U.S. Gov. Print. Office, Washington, D.C.

Robinson, D.A. (1999). Agricultural practice, climate change and the soil erosion hazard in parts of southeast England. *Applied Geography,19* (1)*,* 13–27.

Roose, E.J. (1977). Application of the Universal Soil Loss Equation of Wischmeier and Smith in West Africa. In: D.J. Greenland and R. Lal (Eds.). *Soil Conservation and Management in the Humid Tropics* . John Wiley and Sons. New York, USA. Pp. 177-187.

Sanchez, P. A. (1995). Science in Agroforestry. *Agroforestry Systems, 30* (1 & 2), 5 - 55.

Soil Conservation and Protection in Europe(SCAPE). (2000). The way ahead.

Schawb, G., Fangmeier, D., Elliot, W. & Frevert. R. (1993). *Soil and water conservation engineering* . New York: John Wiley & Sons, Inc.

Sehgal, J., I.P. Abrol, I.P. (1994). Soil Degradation: Status and Impact. NBSS&LUP (ICAR)Oxford and IBH Pub. Co. Pvt. Ltd, New Delhi, India.

Seyed H.S, Takahisa, M. & Babak, G.V (2007). Conformity of MUSLE estimates and erosion plot data for storm-wise sediment yield estimation. *Terrestrial Atmospheric and Oceanic Sciences ,(18)* , 117-128.

Sheng, T. C. (2000). Terrace system design and application using computers. In Laflen et al., (Eds.), *Soil erosion and dryland farming.* Florida: CRC Press. pp.381-390.

Singh, M.J. & Khera, K.L. (2009). Nomographic estimation and evaluation of soil erodibility under simulated and natural rainfall conditions. *Land Degradation and Development, 20 ( ),* 471-480.

Stocking, M.A. (1980). Soil loss estimation for rural development: a position for geomorphology. *Geomorphology, 36,* 264-273.

Sumi, T. & Hirose, T. (2000). *Water storage, transport and distribution: Accumulation of sediment in reservoirs.* Department of Civil Engineering, Kyoto- Japan.

Sumi, T., Murasaki, M., Fujinaga, K., Nagura, Y. and Tamaki, H., (2004): Study on measurement of erosion-deposition process of reservoir sediment during flushing operation, annual. *Journal of Hydraulic Engineering, 48* , 1147-1152.

Takken, I. & Govers, G. (2000). Hydraulics of interrill overland flow on rough, bare soil surfaces. *Earth Surface Processes and Landforms, 25* (13),1387–1402.

Toniolo, H. & Schultz, J. (2005). Experiments on sediment trap efficiency in reservoirs. Lakes & reservoirs: *Research and Management, 10* , 13–24.

Trimble, S.W. and Carey, W.P. (1990). *A comparison of the Brune and Churchill methods for computing sediment yields applied to a reservoir system* . USGS Water Supply Paper 2340, 195–202.

Tripathi, M.P., Panda, R.K., Pradhan, S.& Das, R.K. (2001). Estimation of sediment yield from a small watershed using MUSLE and GIS. *Journal of the Institution of Engineers ,1(82),* 40-45.

U.S. Dept. of Agriculture. Soil Conservation Service. Soil Survey Staff. (1980). *Save soils with terraces.* U.S. Dept. of Agric. U.S. Government. Printing. Office. Washington.

USDA-NRCS. (1983). *Sediment sources, yields, and delivery ratios* . Chapter 6 in
National Engineering Handbook, Section 3, Sedimentation. U.S. Department Agriculture, Natural Resources Conservation Service formerly Soil Conservation Service (SCS), 6.2-6.19. U.S.A: Washington, D.C.

U.S. Dept. of Agriculture. Soil Conservation Service. Soil Survey Staff. (1992). *Soil Taxonomy: A Basic System of Soil Classification for Making and Interpreting Soil Surveys* . U.S. Dept. of Agric. Handb. 436. U.S. Government. Printing. Office. Washington, DC. 754 pp.

Van Dijk, A.I.J.M. & Bruijnzeel, L.A. (2003). Terrace erosion and sediment transport model: a new tool for soil conservation planning in bench-terraced steeplands. *Environmental Modelling & Software, 18,* 839-850.

Van Remortel, R., Hamilton, M. & Hickey,R. (2001). Estimating the LS factor for RUSLE
through iterative slope length processing of digital elevation data. *Cartography, 30* (1), 27-35.

Vanoni, V. (1975). *Sedimentation engineering.* In ASCE Manuals and reports on engineering practice. No.54.

Vente, J., Poesen, J., Arabkhedri, M. & Verstraeten, G. (2007). The sediment delivery problem revisited. *Progress in Physical Geography,31* (2), 155–178.

Verstraeten, G. and Poesen, J. (2000). Estimating Trap Efficiency of Small Reservoirs And Ponds: methods and implications for the assessment of sediment yield,. *Progress in Physical Geography, 2* (24), 219-251.

Vörösmarty, C.J., Meybeck, M., Fekete, B., Sharma, K., Green, P. & Syvitski, J.P.M. (2003). Anthropogenic sediment retention: major global impact from registered river impoundments. *Global and Planetary Change, 39* (1-2), 169 – 190.

Walling, D.E. (1983). The sediment delivery problem. *Journal of Hydrology, 65,* 209-37.

Walling, D.E. (1988). Erosion and sediment yield research : Some recent perspectives. *Journal of Hydrology, 100,* 113-141.

Walling, D.E., Russell, M.A., Hodgkinson, R.A & Zhang, Y. (2002). Establishing sediment budgets for two small lowland agricultural catchments in the UK. *Catena, 47* , 53-323.

Walling, D.E. and Fang, D. (2003). Recent trends in the suspended sediment loads of the world's rivers. *Global and Planetary Change, 39,* 111–26.

Walling, D.E. (2008). Global change and the sediment loads of the world's rivers. *Proceedings of the Tenth International Symposium on River Sedimentation, 1,* 112–30.

World Commission on Dams (WCD). (2000). Dams and developments: A new framework for decision making: The Report of the World Commission on Dams. London: Earthscan Publication.

Williams, J. R. (1995). The EPIC model. In Singh, V. P. (Ed.), *Computer model of watershed hydrology,* Water Resource Publications, Highland Ranch, Colorado.

Williams, J. R. & Berndt, H. D. (1972). Sediment yield computed with universal equation. *Journal of the Hydraulics Division,98* (12),2087-2098.

Williams, J. R. & Berndt, H. D. (1977). Sediment yield prediction based on watershed hydrology. *Transactions of the ASAE, 20* (6), 1100-1104.

Wilson, J.P. (1986). Estimating the topographic factor in the universal soil loss equation for watersheds. *Journal of Soil and Water Conservation, 41* , (3), 179-184.

Wischmeier, W.H., Johnson, C.B. & Cross, B.V. (1971). A soil erodibility nomograph for farmland and construction sites. *Journal of Soil and Water Conservation, 26,* 189-193.

Wischmeier, W.H. & Smith, D.D. (1978). *Predicting Rainfall Erosion Losses - A Guide to Conservation Planning.* Agriculture Handbook No. 537. Agriculture Science and Education Administration, Washington, District of Columbia USA.

Wisner, P.E. & Lam, A. (1983). *Twin models for Sstorm water management mainframe computers and microcomputers* , ASCE Engineering Foundation Conference on Emerging Computer Techniques in Stormwater and Flood Management, Niagara-on-the-Lake, Ontario, Canada, Oct. 30 - Nov. 4, 1983.

Young, A., 1989. *Agroforestry for Soil Conservation.* CAB International, Oxford, U.K.

APPENDICES

APPENDIX A - Geotechnical Investigation Report of Shewasur Watershed (MAWR,2010)

Table 1. Borehole No : D1 , Depth=40m , Location : (x=460362, y=3960369)

Sample type	Depth (m)		Index property %		SPT (N)	Particle size distribution - weight (%)				Classification symbols	Chemical tests		
	From	To	Wl	Wp		G	S	M	C		RQD %	PH	OC
D	0.0	2.0	27.0	17.0		31.0	35.0	28.0	6.0	SC			
S.P.T	2.0	2.5			71.0								
D	2.5	5.0										8.9	0.20
S.P.T	5.0	5.5			61.0								
D	5.5	10.0	39.0	21.0		1.0	17.0	77.0	5.0	CL		8.5	0.22
S.P.T	10.0	10.5			80.0								
D	10.5	14.0											
S.P.T	14.0	14.5			50/10 cm								
D	14.5	16.0										8.4	0.23
S.P.T	16.0	16.5			50/6 cm								
C	16.5	18.0									75.0		
C	18.0	24.0									70.0		
C	24.0	29.0									0.0		
C	29.0	31.0									50.0		
C	31.0	34.0									0.0		
C	34.0	36.0									13.0		
C	36.0	40.0									0.0		
D= Disturbed , U= Undisturbed sample, SPT= Standard Penetration Test, C= Rock Core													

Table 2. Borehole No : D2 , Depth=40m , Location : (x=460363, y=3960370)

D	0.0	1.5											
S.P.T	1.5	2.0			21.0								
D	2.0	3.0	41.0	20.0		6.0	27.0	59.0	8.0	CL			
S.P.T	3.0	3.5			21.0								
D	3.5	5.0										8.8	0.2
S.P.T	5.0	5.5			52.0								
D	5.5	7.5	40.0	25.0		5.0	25.0	60.0	10.0	CL			
S.P.T	7.5	8.0			41.0								
D	8.0	9.5										8.5	0.3
S.P.T	9.5	10.0			50/11cm								
C	10.0	14.0									55.0		
C	14.0	18.0									12.0		
C	18.0	26.0	28.0	17.0		45.0	30.0	15.0	10.0	GC	0.0		
C	26.0	31.0									70.0		
C	31.0	33.0									0.0		
C	33.0	40.0									75.0	9.2	0.2

Table 3. Borehole No : D3 , Depth=40m , Location : (x=460365, y=3960365)

Sample type	Depth (m)		Index property %		SPT (N)	Particle size distribution - weight (%)				Classification symbols	Chemical tests		
	From	To	Wl	Wp		G	S	M	C		RQD %	PH	OC
D	0.0	1.5	36.0	18.0		2.00	19.0	70.0	9.0	CL			
S.P.T	1.5	2.0			50/11cm								
D	2.0	3.0	25.0	15.0						CL			0.3
S.P.T	3.0	3.5			50/2cm								
C	3.5	12.5									0.0		0.2
C	12.5	22.5									25.0		
C	22.5	33.0									65.0		
C	33.0	40.0									0.0		

Table 4. Borehole No : D4 , Depth=40m , Location : (x=4600385, y=3960372)

D	0.0	3.5	40.0	25.0		2.0	19.0	75.0	4.0	CL			
S.P.T	3.5	4.0			53.0								
D	4.0	6.0	25.0	15.0		38.0	32.0	20.0	10.0	GC		8.50	0.24
S.P.T	6.0	6.5			64.0								
D	6.5	8.0											
S.P.T	8.0	8.5			79/28cm								
D	8.5	10.0											
C	10.0	16.3									70.0		
C	16.3	22.0									10.0		
C	22.0	30.0									85.0	9.20	0.11
C	30.0	34.0									70.0		
C	34.0	40.0									0.0		

Table 5. Borehole No : D5 , Depth=40m , Location : (x=4600387, 3960387)

D	0.0	5.0	38.0	22.0		3.0	17.0	72.0	8.0	CL			
S.P.T	5.0	5.5			64.0								
D	5.5	7.0										8.80	0.16
S.P.T	7.0	7.5			51.0								
D	7.5	10.0	25.0	15.0		35.0	30.0	30.0	5.0	GC			
S.P.T	10.0	10.5			50/13cm								
D	10.5	13.0											
S.P.T	13.0	13.5			70/29cm								
D	13.5	16.0	27.0	15.0						GC			
S.P.T	16.0	16.5			33.0								
D	16.5	20.0											
S.P.T	20.0	20.5			58.0								
C	20.5	30.0											
C	30.0	33.0											
C	33.0	35.0										9.00	0.15
C	35.0	40.0											

Table 6. Borehole No : D6, Depth=40m , Location : (x=4600350, y=3960492)

Sample type	Depth (m)		Index property %		SPT (N)	Particle size distribution - weight (%)				Classification symbols	Chemical tests		
	From	To	Wl	Wp		G	S	M	C		RQD %	PH	OC
D	0.0	4.0	35.0	20.0		3.0	16.0	70.0	11.0	CL			
S.P.T	4.0	4.5			32.0							8.80	0.12
D	4.5	5.5											
S.P.T	5.5	6.0			32.0								
D	6.0	11.0	25.0	15.0		31.0	67.0	2.0	0.0	SP			
S.P.T	11.0	11.5			80/29cm								
D	11.5	12.5										8.50	0.11
S.P.T	12.5	13.0			84.0								
D	13.0	15.5	29.0	15.0		30.0	50.0	15.0	5.0	SP			
S.P.T	15.5	16.0			50/9cm								
C	16.0	26.0									32.0		
C	26.0	31.0									72.0		
C	31.0	34.0									12.0		
C	34.0	40.0									0.0		

Table 7. Borehole No : B1 , Depth=20m , Location : (x=4600421, 3960415)

D	0.0	1.5	25.0	17.0		30.0	35.0	25.0	10.0				
S.P.T	1.5	2.0			85.0								
D	2.0	4.0	38.0	18.0		2.0	18.0	72.0	8.0			8.60	0.10
S.P.T	4.0	4.5			50/12cm								
D	4.5	11.0	35.0	20.0		3.0	16.0	71.0	10.0				
S.P.T	11.0	11.5			50/10cm								
D	11.5	18.0	27.0	17.0		32.0	38.0	21.0	9.0			8.50	0.12
S.P.T	18.0	18.5			80.0								

Table 8. Borehole No : B2 , Depth=10.5m , Location : (x=4600436, y=3960425)

D	0.0	4.0	25.0	17.0		30.0	57.0	10.0	3.00				
S.P.T	4.0	4.5			50/5cm								
D	4.5	10.0	27.0	19.0		29.0	59.0	10.0	5.00			8.90	0.12
S.P.T	10.0	10.5			50/2cm								

Table 9. Borehole No : B3 , Depth=20m , Location : (x=4600452, y=3960455)

D	0.0	1.5	48.0	27.0		0.0	4.0	67.0	29.0			8.90	0.12
S.P.T	1.5	2.0			11.0								
D	2.0	5.0	27.0	17.0		28.0	38.0	24.0	10.0				
S.P.T	5.0	5.5			13.0								
D	5.5	8.0											
S.P.T	8.0	8.5			82.0								
D	8.5	13.0	35.0	20.0		3.0	19.0	70.0	8.0			8.50	0.15
S.P.T	13.0	13.5			50/10cm								
D	13.5	19.5											
S.P.T	19.5	20.0			50/8cm								

Table 10. Summary of the geotechnical investigation results for all the boreholes

Borehole No	Hydraulic conductivity K * 10^{-6} (m/s)	WT (m)	Clay%	Silt%	Fine Sand%	Coarse Sand%	OM%	Soil structure code	permeability class
D1	5.00	8.5							
D2	4.49	8.3							
D3	4.36	7.5							
D4	5.26	4.0							
D5	4.18	11							
D6	3.78	14							
B1	3.25	1.8							
B2	2.36	4.6							
B3	3.56	4.5							
Average	4.03	7.1	2	21	61	16	2	1	1

APPENDIX B- Description of Basin Geometry (from WMS program)

Description	Unit	Value
Basin area	Km2	103.665
Reservoir area till the elevation of 479 m.a.s.l	Km2	0.545
Average overland flow length	m	499.96
Basin overland slope	m/m	0.123
Basin length along main channel from outlet to upstream boundary	m	17739.119
Basin slope along main channel from outlet to upstream boundary	m/m	0.039
Length along main channel from outlet to point opposite centroid	m	8176.8
Slope along main channel from outlet to point opposite centroid	m/m	0.014
Maximum flow watercourse length	m	15848
Maximum flow watercourse average slope	m/m	0.023

APPENDIX C- Climate Data Considered for Shewasoor Site (Koya Meteorological Station)

Months	Max T C	Min T C	Humidity %	Wind speed (Km/d)	Sunshine (hours)	Solar radiation MJ/m2/d	E To mm/d
January	7.6	-0.3	74	173	5.3	9.3	1.1
February	10.1	1.2	69	173	5.6	11.7	1.6
March	15.3	5.4	62	164	5.7	14.4	2.5
April	20.5	10.3	61	121	6.5	18	3.4
May	28	14.9	47	130	8.8	22.7	5.1
June	34.7	21	26	147	12	27.8	7.1
July	38.4	24.3	23	181	12.2	27.8	8.1
August	38.6	24.6	22	156	11.3	25.2	7.1
September	34.4	20.4	24	130	10.5	21.5	5.3
October	27.9	14.8	32	147	7.8	15	3.8
November	18.4	8.1	54	138	6.1	10.5	2
December	10.9	2.5	69	156	5.4	8.7	1.2
Average	23.73	12.27	46.917	151.333	8.100	17.72	4.03

APPENDIX D- RISK ASSESSMENT FORM

University of Hertfordshire UH

SCHOOL OF LIFE AND MEDICAL SCIENCES

DEPARTMENT OF HUMAN AND ENVIRONMENTAL SCIENCES

WATER AND ENVIRONMENTAL MANAGEMENT

Ref No:	
Date:	8-Sep-14
Review Date:	8-Sep-14

ACTIVITY INFORMATION	
Name of Assessor/ Contact details	Name: Majeed Kakarash Omar
	Email Address: majeedkakarash45@ymail.com
	Ext no: 07460270203-009647701566597
Location of Activity	GIS Laboratory and the LRC computers
Description of Activity	Using of Computers and Printers
Personnel Involved	No one involved

TYPES OF HAZARD LIKELY TO BE ENCOUNTERED					
	Animal Allergens		Hand Tools		Sharps
	Biological Agents		Ionising Radiation		Slips/trips/falls
	Chemical Compounds		Office Equipment		Stress
	Compressed/liquefied gases		Laboratory Equipment	●	Travel
●	Computers		Ladders		Vacuum systems
●	Electricity		Manual Handling		Pressure systems
	Falling Objects		Non-ionising Radiation	●	Vehicles
●	Farm Machinery		Hot or cold extremes		Aggressive response, physical or verbal
	Fire		Repetitive Handling		Workshop Machinery
	Glassware Handling	●	Severe Weather		
Explosions, airstriking danger, remenants of chemical weapons due to war legacy in iraq in particular Shewasur Dam Location					

APPENDIX D- RISK ASSESSMENT FORM

HAZARD ASSESSMENT						
Severity of Consequences	Score	Risk Classification				
No or minor injury/ health disorder Minor Damage or Loss Insignificant Environmental Impact Group 1 Biological agents	1	Trivial (1)	Trivial (2)	Trivial (3)	Trivial (4)	Tolerable(5)
Injury or Health Disorder – resulting in absence up to 3 days Moderate Damage or Loss Moderate Environmental Impact Group 2 Biological agents	2	Trivial (2)	Trivial (4)	Tolerable(6)	Tolerable(8)	Moderate (10)
Injury or Health Disorder – resulting in absence over 3 days Substantial Damage or Loss Serious Environmental Impact Group 3 Biological agents	3	Trivial (3)	Tolerable(6)	Moderate (9)	Moderate (12)	Substantial (15)
Long Term Injury or Sickness – resulting in permanent incapacity Extensive Damage or Loss Major Long Term Environmental Impact	4	Trivial (4)	Tolerable(8)	Moderate (12)	Substantial (16	Substantial (20
Death Serious Structural Damage Environmental Catastrophe Group 4 Biological agents	5	Tolerable(5)	Moderate (10)	Substantial (15)	Substantial (20)	Intolerable (25)
Note on Risk Classification: 1-4 Trivial 5-7 Tolerable 8-12 Moderate 13-16 Substantial >20 Intolerable	Likelihood	1 Almost Impossible	2 Unlikely-possible exposure every 1-3 yea	3 Harm is possible	4 Harm is likely to occur	5 Harm will occur or is very likely to occur

APPENDIX D- RISK ASSESSMENT FORM

University of Hertfordshire UH

SCHOOL OF LIFE AND MEDICAL SCIENCES

DEPARTMENT OF HUMAN AND ENVIRONMENTAL SCIENCES

WATER AND ENVIRONMENTAL MANAGEMENT

ASSESSMENT OF RISK CLASSIFICATION			
Hazard	Likelihood Score	Severity Score	Risk Classification
Computers	1	2	Trivial (2)
Electricity	1	3	Trivial (3)
Farm Machinery	1	2	Trivial (2)
Severe Weather	2	3	Tolerable(6)
Travel	2	4	Tolerable(8)
Vehicles	2	5	Moderate (10)

EFFECT OF RISK CLASSIFICATION	
Risk Classification	Action
Trivial	No further action required. Activity can begin.
Tolerable	No additional controls required. Current controls must be maintained and monitored.
Moderate	Reduce risks if cost effective. Implement new controls over an agreed period.
Substantial	Activity cannot begin without major risk reduction.
Intolerable	Activity must not begin.

RISK CONTROL MEASURES
Are the local code of practice and/or local rules adequate to control the risks identified? Yes/No Please list. Please list all additional measures required
Local Code of Practice and Local Rules applicable: No
Additional Measures: No

APPENDIX D- RISK ASSESSMENT FORM

University of Hertfordshire UH

SCHOOL OF LIFE AND MEDICAL SCIENCES

DEPARTMENT OF HUMAN AND ENVIRONMENTAL SCIENCES

WATER AND ENVIRONMENTAL MANAGEMENT

HEALTH SURVEILLANCE ISSUES	
Persons at Special Risk	No
Health Surveillance Measures (including symptoms and signs of exposure)	No
Exclusions	No

SIGNATURES				
	Staff/PhD student/MSc student/Undergraduate	Name (Print)	Signature	Date
Assessor	MSc Student	Majeed Omar		9/8/2014
Supervisor	Dr	Tim Sands		9/8/2014
Local Health and Safety Advisor / Laboratory Manager		Peter Coates Jenny Harman		9/8/2014