UNIVERSITE DES SCIENCES ET TECHNOLOGIES DE LILLE

Année : 2007 N° d'ordre : 4005

THESE DE DOCTORAT

Préparée au
Laboratoire de Mécanique de Lille (UMR 8107)
Ecole Polytechnique Universitaire de Lille

Spécialité
Génie civil

Titre

Modélisation de l'érosion en zone montagneuse semi-aride

Par
Issa ALBARADEYIA

Président:

Jacky MANIA	Professeur Emérite, USTL, Lille

Rapporteurs:

Abdellatif OUAHSINE	Professeur à l'Université des Technologies de Compiègne
Mohamed ROUAINIA	Professeur à l'Université de Newcastle (UK)

Examinateurs:

Eric CARLIER	Professeur, Université d'Artois, Lens
Shang-Hong CHEN	Professeur, Wuhan University, Wuhan (China)

Directeurs:

Isam SHAHROUR	Professeur, USTL, Lille

Soil Erosion modelling in Mountainous Semi Arid Zone

No. 4005

A THESIS SUBMITTED TO THE UNIVERSITY OF LILLE FOR SCIENCE AND TECHNOLOGY LABORATORY OF MECHANICS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN THE FACULTY OF CIVIL ENGINEERING

JULY 2007

By

Issa M. ALBARADEYIA
Department of Civil Engineering

Acknowledgements

I am profoundly grateful to Almighty Allah, who granted me all the capabilities that I possess and used throughout my life especially to enable me complete this dissertation.

I am very grateful to Prof. Isam SHAHROUR the vice president of Lille University of science and Technology, for his friendly supervision throughout my study. Prof Shahrour is a very motivating and goal oriented supervisor. He encourages his students to put ideas into practice. I wish I could learn from him more, especially the way he manage the time and the abilities to assists and guides others.

I am very thankful to Prof. Abdellatif OUAHSINE, Prof. Mohamed ROUAINIA whom agreed to be the reporters. Many thanks also go to Prof. Jacky MANIA president of the examination committee, and Prof. Eric CARLIER and Prof. Shang-Hong CHEN members of the committee. Their suggestion and discussion during the oral examination were very useful in improving the final version of the dissertation.

I owe a lot of thanks to Dr. Yousef Abu Safieh, Palestinian Minister of Environment, for his kind support and assistance. I feel humble in front of him because without his assistance I may not have been able to complete my dissertation.

I would like to express my gratitude to the Regional Initiative for Dry land Management (RIDM), for the financial support provided during the research. I am very thankful to Dr. Habib Hulila and Dr. Abelardo Rodreiguze of ICARDA and Matthias Grueniner of the World Bank for their support and assistance.

Many thanks go to Mr. Bassem Dudeen from LRC, for the useful data and information provided to me. Special thanks go to Imad ALBaba, Ibrahim AlQuoqa, Nedal Katbah, Ahmad Abu Thaher and Khalid Salam from the Palestinian Environmental Quality Authority for the useful information and assistance they provided.

I am thankful to all friends I met at the USTL. All of themes were very supportive, friendly and helpful during my study. Special thanks go to Dr. Said Jalala, Dr. Khamis AlMahallawi, Dr. Mohammed Eila, Dr. Rred Jafar, Dr. Marwan Sadik, Dr. Ihssan Dawood, Dr.Bassem Ali, and Dr. Ahmad Arab.

I am very thankful to my mother, for here support throughout my academic life. My late father would have been proud of me if he were alive.

Last but not least, I am grateful to my beloved wife, Yafa Adwan, for countless kinds of support and comfort throughout my research.

Dedication

To Yafa and Musa

Résumé

L’objectif du présent travail a été de déterminer les facteurs majeurs à l’origine de l'érosion des sols affectant la région des montagnes centrales située dans les territoires palestiniens. Ainsi, nous avons étudié l'effet de l'utilisation des différents terrains sur les propriétés du sol et choisi les meilleurs outils de modélisation pour prédire l’érosion des sols dans la région.

L’analyse des paramètres pluviométriques a été effectuée ainsi que le calcul des paramètres pris en compte dans la modélisation de l’érosion des sols : érodibilité des sols et érosivité des précipitations. De même, l'analyse statistique a été réalisée pour vérifier l'effet des différents types d'utilisation de terrains sur les propriétés de sol, l'écoulement et l’érosion ainsi que pour définir la relation qui les relie. Deux logiciels "Hillslope" du projet de prévision d'érosion par l'eau (WEPP) et Réseau de Neurones Artificiels (RNA) ont été utilisés pour simuler l’écoulement et l’érosion des sols en s’appuyant sur divers scénarii. Concernant le RNA, une étude approfondie à base d’analyses de sensibilité utilisant la capacité de sensibilité d'analyse de RNA et d'analyse statistique, a été réalisée pour choisir les variables d’entrée les plus influentes.

L'étude a montré que l'érosion dans le secteur d'étude dépend fortement de taux et de la durée des précipitations ainsi que son intensité comme souvent mentionnée dans la littérature. Les résultats obtenus par le modèle WEPP sont faibles en comparaison aux valeurs observées. Par contre, le modèle RNA donne des résultats très satisfaisants. Ainsi, le modèle global RNA, incluant l’ensemble des données issues des différents terrains utilisés, représente le meilleur modèle en raison des résultats obtenus très proches de ceux mesurés.

Le travail de thèse comporte cinq chapitres qui présentent successivement une synthèse bibliographique sur l’érosion des sols, la zone d’étude, une analyse des données de pluie, une analyse des mesures effectuées sur cinq parcelles et enfin la vérification de différents modèles sur les données collectées.

Mots clés: Propriétés des sols; écoulement, érosion; érodibilité; érosivité; WEPP; Réseau de Neurones Artificiels (RNA), Modélisation; Palestine.

Abstract

The study aims to analyse the factors affecting the soil erosion in the central highland mountainous area, of the Palestinian territories. Also to study the effect of different land use types on soil properties. In addition to select the best modelling techniques for soil loss prediction in the area. The rainfall characteristics were studied and analyzed. The soil erodibility and rainfall erosivity parameters which are considered in soil erosion modelling were calculated. The statistical analysis performed to check the effect of different land use types on soil properties, runoff and soil loss, and to find the relation between the rainfalls, runoff and soil loss under each land use types. The hillslope version of the water erosion prediction project (WEPP), evaluated for the prediction of runoff and soil loss under the different management scenarios.

The artificial neural network (ANN) was used for the simulation of runoff and soil loss as a new type of modelling approach. The input variables to ANN were carefully studied. The sensitivity analyses were performed by means of the ANN analysis sensitivity ability and statistical correlation analysis to select the most influential variables. The study showed that the erosion in the study area is highly dependent on the rainfall depth and rainfall event duration, rather than on the rainfall intensity as mostly mentioned in the literature. The results obtained from WEPP model for soil loss and runoff was very different from the observed values. The WEPP under estimates both the runoff and soil loss. Application of ANN for soil loss and runoff prediction agrees well with the observed values. Also the global network models developed from the combined data set of all the land use type show a relatively unbiased estimation for both runoff and soil loss. The study showed that the ANN model can be used as a management tool for predicting runoff and soil loss.

This report includes five chapters, which present successively a literature review on the soil erosion process, the study area and the methodology used in data collection, analysis of rainfall characteristics, analysis of the vegetation cover, soil loss, runoff and soil properties under the five different land use types, and evaluation of different model on the colleted data.

Keywords: Land use; Soil properties; Runoff, Water erosion; Erodibility; Erosivity; WEPP; Artificial Neural Network(ANN); Modelling; Palestine.

Table of contents

Résumé *I*
Abstract *II*
Table of contents *III*
List of tables *V*
List of Figures *VII*

General Introduction *1*

Chapter One
Literature review

1.1 soil erosion concept *4*
1.1.1 Definition of soil Erosion *4*
1.1.2 Types of soil erosion *4*
1.1.3 Soil erosion causes *5*
1.1.4 Water erosion processes *6*
1.1.5 Water erosion factors *6*
1.2 Environmental and Economic impact of soil erosion *9*
1.2.1 Effect of soil erosion *9*
1.2.2 Global States of soil erosion *10*
1.3 Costs of Soil Erosion *12*
1.4 Soil Erosion Research *13*
1.4.1 History of erosion research *13*
1.4.2 Soil erosion research methodology *15*
1.5 Water Erosion modelling *17*
1.5.1 Empirical models *18*
1.5.2 Conceptual models *26*

1.5.3 Physically-based model *26*
1.6 Artificial Neural Network Models *31*
1.7 Soil erosion Research in the Palestinian territories *34*
1.8 Conclusion *35*

Chapter 2
Study area and data collection

2.1 Introduction *38*
2.2 General description of the study area *40*
2.2.1 Location *40*
2.2.2 Topography *40*
2.2.3 Geology *40*
2.2.4 Vegetation and Land use *40*
2.2.5 Soil *41*
2.2.6 Runoff and Infiltration *42*
2.2.7 Climate *42*
2.3 Field Study *45*
2.3.1 Field Experiments *45*
2.3.2 Topography *46*
2.3.3 Rainfall *47*
2.3.4 Vegetative cover and land use *47*

2.3.5 Soil physical and hydraulic properties *48*
2.3.6 Runoff *50*
2.3.7 Soil loss *51*
2.4 Conclusion *52*

Chapter 3
Rainfall erosivity and soil erodibility in the study area

3.1 Introduction *54*
3.2 Rainfall characteristics *54*
3.2.1 Rainfall Depth and Duration *54*
3.2.2 Rainfall size and intensity *56*
3.2.3 Rainfall Erosivity *59*
3.3 Soil Erodibility *61*
3.4 Conclusion *65*

Chapter 4
Analysis of soil Erosion

4.1 Introduction *66*
4.2 Data Presentation *66*
4.3 Vegetation under different land use types *67*
4.4 Soil Properties under Different Land Use Type *68*
4.5 Effect of Land Use on Runoff *72*
4.6 Effect of Land Use on Erosion *77*
4.7 Interaction between Runoff -Erosion and potential cause factors *83*
4.7.1 Correlation matrix *83*
4.7.2 Rainfall-Runoff Relationships *84*
4.7.3 Regression Analysis *86*
4.7.3.1 Linear Regression between Runoff and Rainfall Depth *87*
4.7.3.2 Linear Regression between Erosion and Runoff *89*
4.8 Conclusion *90*

Chapter 5
Soil Erosion Modeling

5.1 Introduction *92*
5.2 Validation of the hillslope WEPP model *93*
5.2.1 Model description and mechanism *93*
5.2.2 Input data for the model *94*
5.2.3 Evaluation Criteria *95*
5.2.4 WEPP Results *95*
5.3 Validation of the Artificial Neural Network (ANN) *101*
5.3.1 ANN description and mechanism *101*
5.3.2 ANN Program *105*
5.3.3 Evaluation Criteria *105*
5.3.4 Network Development *106*
5.3.5 Artificial neural network results *108*
5.3.5.1 Global networks *108*
5.3.5.2 Individuals networks *115*
5.3.6 Conclusion *117*
Conclusion General and Recommendation *119*
Refrence *121*
Annex *135*

List of tables

Figure	Title	pages
1.1	Global extent of land affected by wind and water erosion (Oldeman, 1992)	10
1.2	Distribution of susceptible dry-land areas to soil erosion by water and wind in the world (Middleton and Thomas, 1992).	11
1.3	Estimates of global land areas vulnerable to water and wind erosion.	12
1.4	Global soil loss due to water erosion in relation to population density (Reich et al, 2005)	12
1.5	Erosion and sediment transport models	18
2.1	Description of experimental plots.	45
3.1	Analysis of rainfall events number, duration and depth.	55
3.2	Frequency analysis of rainfall size classes for 2003-2004 and 2004-2005 seasons.	57
3.3	Frequency analysis of rainfall events intensity classes for 2003-2004 and 2004-2005 rainy seasons.	58
3.4	Frequency analysis of maximum thirty minute (I30) intensity classes for each rainfall even for 2003-2004 and 2004-2005 rainy seasons.	59
4.1	Percentage values of vegetative cover under the five land use types	68
4.2	Analysis of variance of the surface soil aggregate stability under the different land use types.	69
4.3	Analysis of variance of the surface soil physical properties under the different land use types.	70
4.4	Analysis of variance of the surface soil hydraulic properties under the different land use types	71
4.5	Summary of the runoff under the five land use during the two years.	73
4.6	Analysis of variance of runoff under the different land use type for the year 2003-2004.	73
4.7	Analysis of variance of different years in runoff under land use types	77
4.8	Summary of the erosion under the five land use during the two years.	78
4.9	Analysis of variance of different years in erosion under each land use types.	81
4.10	Correlation Matrix of runoff and soil erosion and selected influential cause parameters.	84
4.11	Runoff to rainfall ratio (R_0/R_f) % under the five land use during the two years.	85
4.12	The analyses of variance of (R0/Rf) ratio for each land us of the two years.	86
4.13	Regression fits for the rainfall depth (x_1) vs. runoff (y) for the year 2003-2004.	87
4.14	Regression fits for the rainfall depth (x_1) vs. runoff (y) for the year 2004-2005.	88
4.15	Regression fits for the runoff (x_1) vs. erosion (y), for the year 2003-2004.	89
4.16	Regression fits for the runoff (x_1) vs. erosion (y), for the year 2004-2005.	90
5.1	Summary statistics of the WEPP model validation for runoff according to the land use types.	98
5.2	Measured ($_M$) and simulated ($_S$) total runoff (R_O) and soil loss (SL) for the period 2003-2005	98
5.3	Summary statistics of the WEPP model validation for soil loss according to	100

the land use types.
5.4 Effect of some of the parameters considered by WEPP in ANN networks 107
5.5 Significance of the selected parameters on the NET1 performance 108
5.6 NET1 testing phase with different architecture and neuron in the hidden layer. 108
5.7 Global networks optimal model architecture 109
5.8 Summary statistics of the global NET1 and NET2 of observed versus predicted runoff. 109
5.9 Summary statistics of the global NET1 and NET2 of observed versus predicted soil loss 112
5.10 Individuals land use type optimal network architecture 115
5.11 Summary statistics of the NETLU1 of observed versus predicted runoff and soil loss. 115
5.12 Summary statistics of the NETLU2 of observed versus predicted runoff and soil loss. 116
5.13 Summary statistics of the NETLU3 of observed versus predicted runoff and soil loss. 116
5.14 Summary statistics of the NETLU4 of observed versus predicted runoff and soil loss. 117
5.15 Summary statistics of the NETLU5 of observed versus predicted runoff and soil loss. 117

Liste of figures

Figure	Title	Page
1.1	Types of soil erosion (Lal, 1990)	5
1.2	Soil particles and aggregates that have been detached by raindrops are transported down the slope by runoff	6
1.3	Factors controlling soil erosion by water, as considered by the universal soil loss equation (in ton/ha/yr). (Ponce-Hernandez, 2004)	7
1.4	Relationship between soil erosion rates and slope gradients. (Xinbao et al., 2003).	8
1.5	Effect of residue cover on reduction of soil erosion. (Dickey et al., 1997).	9
1.6	Soil erodibility monograph (after Wischmeier and Smith 1978). For conversation to SI divide K value of this monograph by 7.59. K is in U.S customary units.	22
1.7	Layers and connections of a feed-forward back propagating artificial neural network.	33
2.1	Geographical Projection of the study area (Source UNEP, 2003)	39
2.2	Average Monthly Rainfall in mm for Hebron Metrological station (1975-2002)	43
2.3	Average Monthly Maximum and Minimum Temperature in Degree Celsius for Hebron Metrological station (1975-2002).	43
2.4	Average Monthly Relative Humidity for Hebron Metrological station (1975-2002)	44
2.5	Average Monthly Evaporation for Hebron Metrological station (1975-2002)	44
3.1	Rainfall distribution during the study (2003-2004, and 2004-2005) and that based on long term data (1975-2002).	56
3.2	a and b. Kinetic energy of rainfall events, figure A for 2003-2004 and figure B for 2004-2005 rainy seasons	60
3.3	a and b. Kinetic energy of maximum thirty minute intensity I_{30} , of each rainfall events, figure A for 2003-2004 and figure B for 2004-2005 rainy seasons.	61
3.4	The derived interrill erodibility (K_i) under the studied land use types.	63
3.5	The derived rill erodibility (K_r) values under the studied land use types.	64
3.6	The derived critical shear stress values under the studied land use types.	65
4.1	Normality test and data transformation for events rainfall depth and duration parameters.	67
4.2	Analysis of variance of runoff under the different land use type for the year 2003-2004 (Means and 95% LSD intervals).	74
4.3	Analysis of means plot of runoff under the different land use type for the year 2003-2004.	75
4.4	Analysis of variance of runoff under the different land use type for the year 2004-2005 (Means and 95% LSD intervals).	76
4.5	Analysis of means plot of runoff under the different land use type for the year 2004-2005.	76
4.6	Analysis of variance of erosion under the different land use type for the year 2003-2004 (Means and 95% LSD intervals)	79

4.7 Analysis of means plot of erosion under the different land use type for the year 2003-2004. 79

4.8 Analysis of variance of erosion under the different land use type for the year 2004-2005 (Means and 95% LSD intervals) 80

4.9 Analysis of means plot of erosion under the different land use type for the year 2004-2005. 81

4.10 Analysis of means plot of (R_0/R_f) % under the different land use type for the year 2003-2004 85

4.11 Analysis of means plot of (R_0/R_f) under the different land use type for the year 2004-2005. 86

5.1 WEPP Windows Interface 94

5.2 Observed vs.WEPP Predicted runoff under the five land use types 97

5.3 Observed vs. WEPP predicted soil loss under the five land use types. 100

5.4 Typical three layered feed forward neural networks with a back propagation training algorithm 103

5.5 Sigmoid transfer function 104

5.6 Measured versus predicted runoff values by Global NET1 model. 110

5.7 Measured versus predicted runoff values by Global NET2 model. 111

5.8 Measured versus predicted soil loss by Global NET1 model. 113

5.9 Measured versus predicted soil loss by Global NET3 model. 114

General Introduction

General Introduction

The aim of the present study is to assist in developing suitable soil conservation strategies for the central highland mountains in Palestine. The study area located within Mediterranean climates is characterized by winter rains, with some months of excess rainfall over evatranspiration, warm and dry summer months with moisture deficits, drying out soils and their annual vegetation (xeric moisture regime) (Arij., 1995). Characteristic landscape attributes are the high proportion of mountains with steep slopes, and a large proportion of limestone and other calcareous rocks as soil parent materials (LRC., 2000).

In the central highlands, soil erosion constitutes a key land degradation factors affecting the productivity of rain fed agriculture (Ministry of Agriculture, 2004). The Central Highlands Region extends the length of the West Bank with mountains ranging from 400 to 1020 meters above sea level, rainfall varying from 300 mm in the southern foothills to 600 mm in the north (Ministry of Agriculture, 2004). Field inspection of the Palestinian territories shows that soil erosion is present almost everywhere, and is particularly severe on bare, compact ground near residences and other buildings (Soil and Water Conservation Society, 1994; Basim Dudeen, 1999; Abu Hammad et al, 2004). Water erosion is the most important type taking place in all of its types depending on the geomorphology and rain intensity (LRC, 2000).

One of the main important pillars of the Palestinian Environmental Quality Authority (EQA) is to control and limit the degradation of natural resources, and combat desertification and soil erosion. Land degradation in the form of soil erosion ranked as one of the highest priority by the Palestinian Environmental Strategy that need to be addressed and require an immediate action by the Palestinian authority, through mobilizing different methodology to lower from the effect of this hazard (Ministry of Environmental Affairs, 2000). Based on the Palestinian Agricultural Strategy, the Palestinian Ministry of Agriculture (MOA) should assess the extent of soil erosion and desertification and identify priority actions and areas where mitigation measures are most needed. The MOA should also give high priority to set up an effective mechanism for the regular monitoring of soil erosion and desertification (Ministry of Agriculture, 2004).

To explore the problem in the central highland mountains accurately, detailed data related to study area physical characteristics; soil erosion, runoff and soil properties are required. The present study has mainly relied on a very important project (Regional Initiative for Dry land Management, DIM), executed by the Palestinian Ministry of Environment and International Centre for Agricultural Research in Dry Area (ICARDA), under the auspice of the World Bank. Therefore field experiment and survey were conducted utilizing the grant of the above mentioned project.

There are five main factors that influence the soil erosion processes: soil type, topography, landuse, climate and human activities (Nelson, 2002). The intensity of precipitation affects soil erosion which is heavily dependent on climate (Nelson, 2002). Soil erosion occurs under different environmental conditions which mean the variables involved vary spatially. The accurate prediction of soil erosion is therefore a challenge due to this intricacy of the factors influencing this process. Several modeling approaches have been developed for a range of temporal and spatial scales (Bhuyan *et al.*, 2002). Soil erosion modeling has been identified as a useful tool in conservation and planning practices (Lu *et al.*, 2004). Implementation of these models has proven to be a cost effective method for erosion prediction over large areas (Lu *et al.*, 2004). However, of the many available models developed for soil erosion, many require specific and detailed data or are only applicable to certain types of regions. To identify which approaches are most robust for area under study, models need to be compared using datasets from a field experiment. Experimental and monitoring data are essential to calibrate, initialise, validate and improve soil erosion models under new situation and condition different form the original environment under which the model was developed (Wischmeier and Smith, 1978; Bhuyan *et al.*, 2002).

The methodology commenced by investigation all the variables that could contribute to the soil erosion process. The present erosion conditions and Processes are described from a detailed study of the following aspects: (i) physical characteristics of the study area (ii) effects of land use types on runoff and soil erosion, (iii) effects of land use types on physical and hydraulic properties of soil, (iv) the relationship between rainfall-runoff and erosion under different land use practices. Deep survey of water erosion modeling with emphasises to the models that consider the mountains and hillslope component. Evaluation of selected soil erosion models using field data collected during the study carried out. The most accurate simulating erosion model is recommended for soil erosion prediction and land conservation.

This report is divided into five chapters. The first chapter introduces the soil erosion process by water and gives a deep overview about the soil erosion modeling and research methodology used in studying the soil erosion problem. The second chapter presents the study area and the methodology used to gather the needed data for conducting the research. The third chapter presents the analysis of rainfall characteristics and the calculation of rainfall erosivity and soil erodibility parameters. The fourth chapter tackles analysis of the vegetation cover, soil loss, runoff and soil properties under the five different land use types. Furthermore it explores the relation between runoff-erosion and potential causes factors. The fifth chapter examines and evaluates the efficiency of the selected models (WEPP and ANN) in simulating the runoff and erosion under the five different land use types. The last section deals with general conclusion and recommendation.

Chapter 1---

Literature review

1. Literature review

This chapter gives a brief description of the water erosion, sediment transport, deposition processes, and water erosion factors. Soil erosion research history and methodology are highlighted. Review of the types of erosion and sediment transport models that are available are presented. Models types are distinguished in terms of how the physical processes of sediment detachment, transport and deposition are represented by the model, as well as the spatial and temporal resolution of the model types. Emphasis and details are given to the models considering the hillslope erosion process. Capabilities of the Artificial Neural Network Modelling presented, and finally the state of soil erosion research in the Palestinian territories reviewed.

1.1 Soil erosion concept

1.1.1 Definition of soil erosion

Soil erosion is “the physical removal of topsoil by various agents, including falling raindrops, water flowing over and through the soil profile, wind velocity and gravitational pull” (Lal, 1990, Laflen and Roose, 1997). The Soil Conservation Society of America formally defined soil erosion as “the wearing away of the land surface by running water, wind, ice or other geological agents, including such processes as gravitational creep” (SCSA, 1982). Quantitatively, soil erosion is expressed in terms of “depth or weight of soil per unit area and unit time”. Soil sediment refers to “solid material that is detached from the soil mass by erosion agents and transported from its original place by suspension in water or air or by gravity” (Lal, 1990).

1.1.2 Types of soil erosion

Soil erosion is generally classified as geologic soil erosion and accelerated soil erosion. Geologic erosion is the natural and inevitable process, and it doesn’t always adversely affect soil or environment (Lal, 1990). This is slow and constructive geologic process acting over a long geologic time scale, causing the wearing away of the mountains and building up of flood plains and coastal plains (SCSA, 1982).

Accelerated erosion, on the other hand, is caused by human activities and is far beyond the threshold value of compensatory rate of new soil formation (Morgan, 2005). Soil erosion due to the agricultural activities, erosion from the construction sites, reclaimed land and mine land, erosion due to deforestation, vegetative inundation etc are the examples of accelerated soil erosion (Lal, 1990). Soil erosion rates considered “natural” are not without controversy;

however “acceptable” rates of soil erosion (FAO, 1979) range from 0.4 tons ha^{-1} yr^{-1} for shallow soils to 1.8 ton ha^{-1} yr^{-1} for deep soils. These “acceptable“ rates are also a point of argument and some experts agree that there is no uniform natural rate of soil erosion, nor a solid basis for a tolerance rate On the basis of causes of erosion, it may be classified as the erosion caused by fluid and erosion caused by gravity (Lal, 1990) (Figure 1.1).

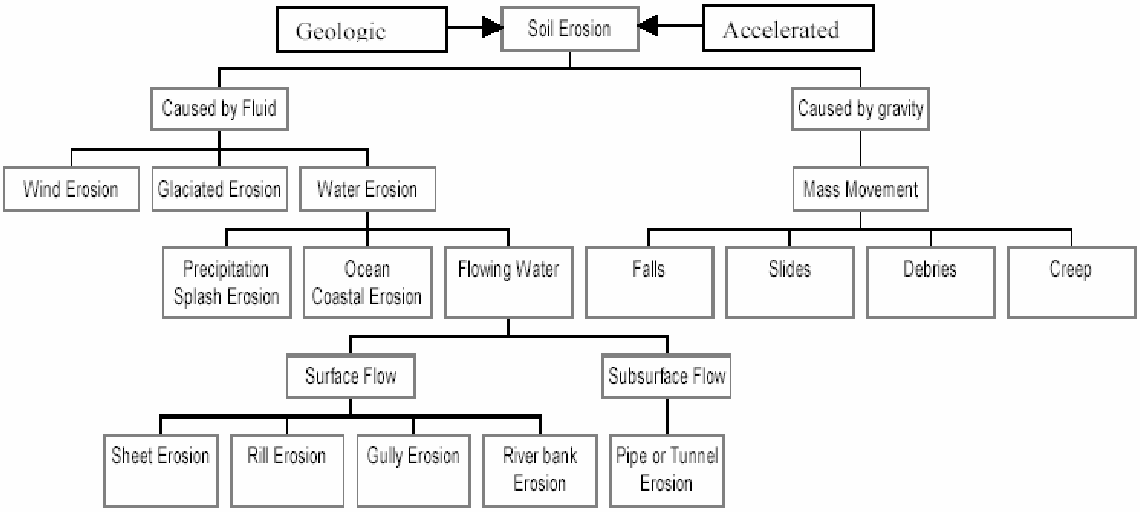


Figure 1.1 Types of soil erosion *(Lal, 1990)*

1.1.3 Soil erosion causes

Erosion can be caused by wind (wind erosion), by rainfall (rainfall erosion), or by runoff (runoff erosion) (Nill *et al.*, 1996). Runoff erosion can happen in unconcentrated flow (sheet erosion), in rills (rill erosion), or gullies (gully erosion) (Nill *et al.*, 1996, Laflen and Roose 1997). Rills are such small concentrations of running water that they can be completely removed by normal cultivation methods, whereas gullies cannot be. Erosion in the channel is called channel erosion. Precipitation is the main source of flowing water. Rainfall initiates surface and subsurface flow.

Soil eroded from a given area is defined in terms of rate of erosion. Total sediment outflow from a watershed per unit time is called sediment yield. It is obtained by multiplying the sediment loss by a delivery ratio (Novotny and Chesters, 1989). The transported portion of the eroded sediment (ratio of yield to the total eroded material) is called sediment delivery or sediment delivery ratio.

1.1.4 Water erosion processes

Water erosion is a two-part process involving: a) the detachment of soil particles due to splash caused by kinetic energy of raindrops, and b). overland transport of these soil particles through runoff.According to Rose (1988), soil erosion by water can be regarded as a result of four processes:

- detachment by raindrop impact;
- transport by raindrop impact (splash erosion);
- detachment by the shearing forces of flowing water; and
- transport in surface runoff (sheet or interill erosion, rill and gully erosion).

During rainstorms, a two-fold problem often occurs. The rate of rainfall may exceed the rate at which water can enter the soil. The excess water either collects on or runs off the soil surface. Secondly, raindrop impact forces can result in a partially sealed soil surface, thus reducing infiltration of water into the soil which causes more runoff. If all the water could always enter the soil, detachment and splashing of soil particles would be of minor concern and soil loss would be minimal. However, when the rainfall rate exceeds the soil's infiltration rate and the soil surface storage is filled, runoff will begin. This runoff will travel downhill, carrying soil particles with it (Figure1.2).

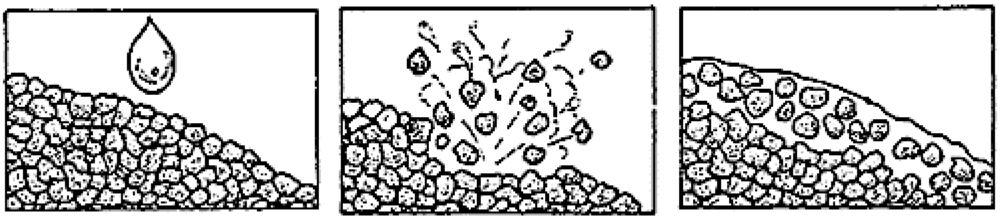


Figure 1.2 Soil particles and aggregates that have been detached by raindrops are transported down the slope by runoff.

1.1.5 Water erosion factors

Factors affecting water erosion are climate, topography, soil, vegetation and anthropogenic activities such as tillage systems and soil conservation measures. Large amounts of precipitation and runoff occurring during winter could cause high erosion rates if the soil cover is minimal (ASCE Task Committee, 1977). This fact was observed by Emmett (1970) who concluded, based on nearly 10-year experimental data, that sediment concentration in overland flow is negatively correlated with vegetation cover of the region.

The four major factors affecting water erosion are: (1) climate, (2) soil, (3) topography, and (4) land use (Foster, 1982). They are well presented as considered by the universal soil loss estimating equation (in ton/ha/yr) (figure 1.3), are listed below:

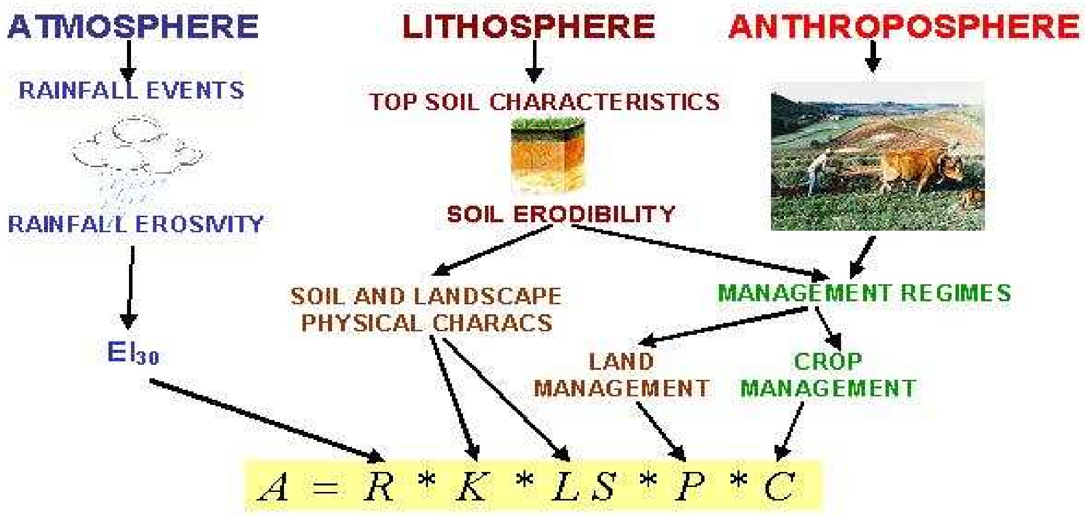


Figure 1.3 Factors controlling soil erosion by water, as considered by the universal soil loss equation (in ton/ha/yr). (Ponce-Hernandez, 2004).

Climate

The climatic factors that influence erosion are rainfall amount, intensity, and frequency. During periods of frequent rainfall, a greater percentage of the rainfall will become runoff. This is due to high soil moisture or saturated conditions. Temperature is another climatic factor influencing erosion.

Soil

Some soils are naturally more erodible than are other soils. Erosion by raindrop impact is not easily seen, but varying degrees of rilling indicate differing erodibility among soils.

Physical characteristics of soil have a bearing on erodibility. Soil properties influencing erodibility include texture, structure and cohesion. For example, soils high in clay and sand have low erodibility while soils high in silt have high erodibility.

Topography

Slope length, steepness and roughness affect erodibility (Figure 1.4). Generally, the longer the slope, the greater the potential for erosion. The greatest erosion potential is at the base of the slope, where runoff velocity is greatest and runoff concentrates. Slope steepness, along with surface roughness, and the amount and intensity of rainfall control the speed at which runoff flows down a slope. The steeper the slope, the faster the water will flow. The faster it flows, the more likely it will cause erosion and increase sedimentation.

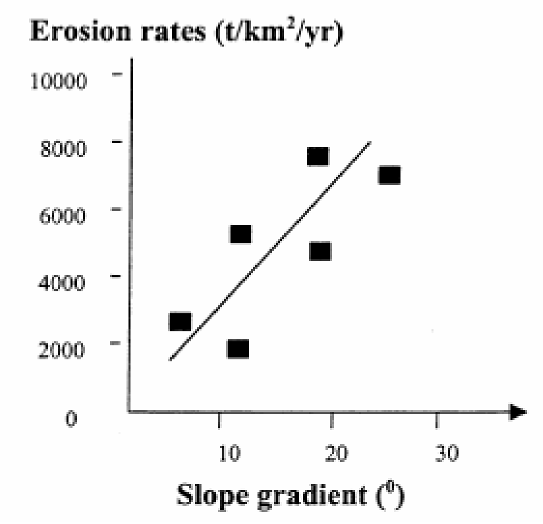


Figure 1.4 Relationship between soil erosion rates and slope gradients. (Xinbao et al., 2003).

Land use

Erosion occurs when soil is left bare and exposed to raindrop impact and surface runoff. Vegetation is probably the most important physical factor influencing soil erosion. A good cover of vegetation shields the soil from the impact of raindrops. It also binds the soil together, making it more resistant to runoff. A vegetative cover provides organic matter, slows runoff, and filters sediment. On a graded slope, the condition of vegetative cover will determine whether erosion will be stopped or only slightly halted (Figure 1.5). A dense, robust cover of vegetation is one of the best protections against soil erosion.

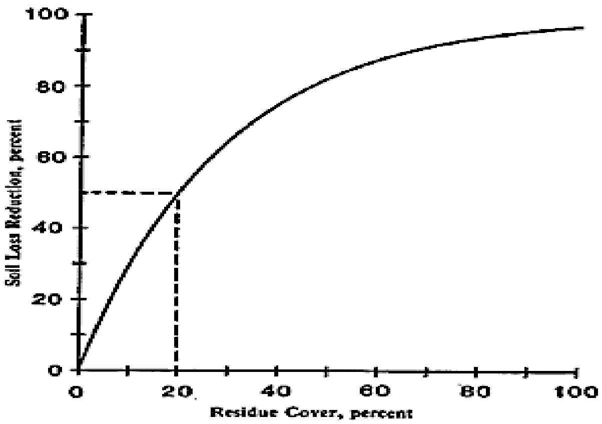


Figure 1.5 Effect of residue cover on reduction of soil erosion. (Dickey et al., 1997).

1.2 Environmental and economic impact of soil erosion

1.2.1 Effect of soil erosion

Soil erosion has both off-site and on-site effects. Important on-site and off-site impacts of soil erosion by water summarized by Bojo (1996) are presented below.

On-site effects of soil erosion by water

- Reduced crop productivity and the economic losses associated with crop failure and loss of seed and fertilizer.
- Soil removal by sheet erosion; land deformation by rill and gully erosion; reduced traffic ability.
- Stream bank and ditch bank erosion.
- Undermining of built structures (e.g. washout of roads, fences and undermining of bridges).
- Removal of valuable topsoil and loss of natural nutrients and applied chemicals (fertilizers and pesticides).
- Important changes in soil quality as structure, stability and texture are affected by soil loss. Removal of smaller particles or entire layers of soil or organic matter may weaken structure and may result in a change in texture, which in turn affects the water-holding capacity of the soil, increasing its susceptibility to drought (nexus to desertification) and/or increased risk of flooding

Off-site effects of soil erosion by water

- Deposition of sediments down slope causing obstruction (roads, stream channels, silt in reservoirs).
- Accelerated stream bank erosion
- Reduction of downstream water quality (eroded soil and transported chemicals end up in streams and reservoirs).
- Effects on fish ecology by polluting and affecting water quality.
- Effects on human health by affecting the quality of water consumption

1.2.2 Global states of soil erosion

The first global assessment of human-induced water and wind erosion was made by Oldeman et al. (1991) in the framework of the Global Assessment of Land Degradation (GLASOD) Project of the United Nations Environment Program (ISRIC, 2003). Oldeman's (1992) shows that more than 1600 million hectares of land is already affected by soil erosion (Table 1.1). The contribution of Asia region to soil erosion is 663 million hectares; it is the highest proportion when compared with other part of the world. Data show that the water-induced erosion is more in comparison to wind induced erosion. These data support that the water-induced soil erosion is a greater problem facing the humankind and all the region of the globe.

Table 1.1 Global extent of land affected by wind and water erosion *(Oldeman, 1992)*

REGION	LAND AREA AFFECTED BY EROSION (10^6 HA)	
	Water erosion	Wind Erosion
Africa	227	186
Asia	441	222
South America	123	42
Central America	46	5
North America	60	35
Europe	114	42
Oceania	83	16
World Total	1094	548

Middleton and Thomas, (1992) used the maps and information from the GLASOD study, with minor modifications, in the Atlas of Desertification. Their estimates of land area susceptible to wind and water erosion are given in Table 1.2. Despite of all its limitation, the GLASOD assessment is the only estimate of human-induced degradation available.

Table 1.2 Distribution of susceptible dry-land areas to soil erosion by water and wind in the world (Middleton and Thomas, 1992).

REGION	WATER EROSION (MILLION HA)			WIND EROSION (MILLION HA)		
	Dry Sub-humid	Semiarid	Arid	Dry Sub-humid	Semiarid	Arid
Africa	25.1	59.2	34.8	1.6	30.7	127.5
Asia	54.9	69.9	32.7	15.1	52.1	85.9
Australasia	4.1	26.3	39.3	0	6.4	9.5
Europe	34.7	12.8	0.6	17.4	17.3	4.0
N. America	10.7	24.4	3.3	6.8	27.3	3.7
S. America	11.5	20.6	2.5	5.9	16.4	4.6
Total	141.0	213.2	113.2	46.8	150.2	235.2
TOTAL	467.4			432.2		

A global assessment of wind and water erosion was carried out recently by Reich et al (2005) of the USDA Natural Resources Conservation Service, employing a simplified model considering only soil and climatic variables. Population density in combination with these soil and climatic attributes is used to make estimates of rates of soil loss. This is achieved by overlaying through a GIS a population density data on maps depicting vulnerability to wind and water erosion. The annual potential yield of sediment through water erosion from 72.5 million km^2 of global land area considered in the study is about 130 billion Mega grams (Mg). In the arable lands of the world, water erosion may contribute about 67 billion Mg of sediment. In the susceptible dry lands, which are the areas most prone to desertification, water erosion could yield about 92 billion Mg, which are about 71% of the total global soil loss.

Further to the figures in table 1.2 by Middleton and Thomas (1992), the assessment by Reich et al (2005) provides data on the global land areas subject to wind and water erosion. These are summarized in table 1.3. Globally, there are about 56 million km^2 (43% of ice-free land mass) of land vulnerable to water erosion in the slightly arid to humid areas of the world. The hyper-arid and cold regions are excluded in this estimate.

Table 1.3 Estimates of global land areas vulnerable to water and wind erosion.

EROSION VULNERABILITY CLASS	WATER EROSION		WIND EROSION	
	Area Million Km^2	Percent	Area Million Km^2	Percent
Low	17.33	13.3	9.25	7.1
Moderate	15.39	11.8	6.32	4.8
High	10.97	8.4	7.80	5.9
Very high	12.21	9.3	9.33	7.1
Total vulnerable area	55.91	42.8	32.70	25.0
Dry	37.77	28.9	37.77	28.9
Depositional/minimal	16.59	12.7	40.00	30.6
Cold	20.36	15.6	20.36	15.6
Total Ice-free land area	130.63		130.63	

The amounts of potential soil loss were calculated by Reich et al (2005) to map out risk of water erosion arising from land use, by overlaying the water erosion vulnerability map with a population density map. An estimate of amounts of soil loss that can be expected for each population density class is obtained and shown in Table 1.4.

Table 1.4 Global soil loss due to water erosion in relation to population density (Reich et al, 2005)

POPULATION DENSITY PERSONS/SQ. KM	VULNERABILITY TO EROSION				
	Low	Moderate	High	Very High	Total
	Erosion amount (million Mg)				
<2	392	842	717	1,935	3,886
2-10	1,633	2,247	2,429	15,341	21,650
11-40	1,878	4,092	5,589	9,978	21,537
41-100	3,025	4,465	5,116	8,696	21,302
101-500	3,460	5,280	9,636	10,375	28,751
>500	1,029	873	2,148	1,779	5,829
Total	11,418	17,799	25,634	38,103	91,953

1.3 Costs of soil erosion

There is a wide range of estimates on yield and economic losses caused by soil erosion.UN Environmental Program reports that crop productivity on about 20 million hectares each year is reduced to zero or become uneconomical because of soil erosion or soil induced degradation (UNEP, 1991). It has been estimated that the world’s croplands are currently losing 23 billion tons of soil in excess of new soil formation each year (Brown, 1984). An

ISRIC/UNEP survey on global assessment of soil degradation indicates that more than one-fourth of the world's soils have lost a substantial amount of their natural fertility over the past 45 years (UNEP, 1992).Globally, the current economic costs of the on-site and off-site impacts of erosion of agricultural land have been estimated to amount to some US$ 400 billion per year (Bernard and Iiavri, 2000).Soil erosion from productive farmlands decreases soil quality and crop production, diminishes on-site land value, and causes off-site environmental damage. For example, in the USA, the cost of off-site soil erosion damages amounts to >US$2 billion per year (Clark, 1985).

den Biggelaar et al. (2004a) estimated the impact of soil erosion on productivity by collating, synthesizing and comparing the results from published site-specific soil erosion-productivity experiments on a global scale. The studies were grouped based on soil type and the crops grown and in total 329 studies were reviewed. The methodology used was similar to an earlier study of soil based estimates of production losses due to water and wind erosion in North America that revealed potential losses of 235000 tons/yr of maize, 60000 tons/yr of soybeans, 75000 tons/yr of wheat and 2000 tons/yr of cotton. Economic value of these production losses were estimated to at US$56 million in the USA and US$3 million in Canada (den Biggelaar et al., 2001). The results of the 329 studies showed that average crop yields and effects of past erosion on yields differed greatly by crop, continent and soil order. The absolute yield loss of grain and leguminous crops ranged between -0.49 and 1.44 kg/ha per ton of soil lost to erosion, and between 0.69 to 127.0 kg/ha for root crops. Overall, the loss was less than 0.1% of the yield for each ton of soil erosion, but differences were site-specific (den Biggelaar et al., 2004a). The authors subsequently extrapolated the yield losses per ton of soil erosion to the annual impact of crop yield on various scales. Losses vary widely between crops, soil orders and regions and is substantial in several areas but little is known about the losses for many important crops in many developing countries (den Biggelaar et al., 2004b). Most estimated crop losses are small in relation to the off-site effects, which underscores the importance of continued policy measures to encourage soil conservation.

1.4 Soil erosion research

1.4.1 History of erosion research

According to Baver (1939), the first scientific investigation of erosion was carried out by the German soil scientist Wollny, between 1877 and 1895 (Hudson, 1995). He had used small plots to measure wide range of effects, such as that of vegetation and surface mulch on the interception of rainfall and deterioration of soil structure. He had also studied the effect of soil type and slope in runoff and erosion. Organized research started in the United States of America when US Department of Agriculture declared an official policy of land protection in 1907. The results of field plot experiments were first published in 1923 after the works of Forest Service in 1915 in Utah and that of Miller in 1917 in Missouri (Hudson, 1995). The first detailed study of natural rain was carried out by Laws in 1941 and the first analysis of the mechanical action of raindrops on the soil was studied by Ellison in 1944. Ellison was the first who realized that the falling raindrop was a complete erosion agent within itself (Hudson, 1995). The first mathematical expression of erosion was established by Zingg (1940) to evaluate the effect of the length and steepness of slope in erosion. Smith (1941) introduced the concept of permissible soil loss and evaluated the effect of crop factor and mechanical protection over erosion. Browning and his co-workers worked in Iowa to find soil erodibility and evaluated the effect of crop rotation and management in erosion around the same time (Hudson, 1995). Musgrave and co-worker developed an empirical equation in 1947 known as Musgrave equation or Slope Practice equation, given as (Hudson, 1995):

$$E_r = T_p \times S_l \times L_n \times A_p \times M_p \times R_f \qquad \textbf{1.1}$$

Where E_r = Erosion, T_p = Type of soil, S_l = Slope, L_n = Length, A_p = Agronomic practice, M_p = Mechanical protection, R_f = Rainfall

This equation was exclusively implemented for nearly ten years before it was replaced with more realistic Purdue product, Universal Soil Loss Equation (USLE), in 1958. Wischmeier and Smith (1965) published the Agricultural Handbook 282 to use it as erosion planning tool for farmers and conservation planners. Continuous experimentation and research extended the scope of its application and the Agricultural Handbook 537 was subsequently published with more experimental results and improvement in the existing parameter estimation methods (Wischmeier and Smith, 1978). Different models have been developed based on USLE in different countries to suit their particular requirements between the decade of late 1980s and early 1990s. The Soil Loss Estimation Model for Southern Africa, SLEMSA (Elwell, 1981) developed in South Africa, INDEROSI (Gnagey, 1991) developed in Indonesia and SOILOSS (Rosewell, 1993) developed in Australia are some of the examples of such models.

Mayer and Wischmeier (1969) defined four basic steps in erosion process: detachment by raindrop splash, transportation by raindrop splash, detachment by surface runoff and transportation by surface runoff. After splitting erosion process into rill and interrill parts, Foster and his co-workers developed a semi empirical model called CREAMS (1980). EUROpean Soil Erosion Model (EUROSEM) was developed around the same time in Europe (Morgan et al., 1992). ANSWERS model was developed in late 1970s to assess sediment yield from watersheds (Beasley et al., 1980). Erosion/Productivity Impact Calculator (EPIC) was developed to assess the effect of soil loss in agricultural productivity. In the early 1980's teams of USDA Agricultural Research Service (ARS) Soil Conservation Service (SCS), and Economic Research Service (ERS) scientists developed EPIC to quantify the costs of soil erosion and benefits of soil erosion research and control in the United States.

In 1985, USDA initiated a ten-year research project in cooperation with other Federal agencies including Agricultural Research Service (ARS), Soil Conservation Service (SCS), the Forest Service and Bureau of Land Management (BLM). The Project was named Water Erosion Prediction Project (WEPP) that had the principal objective of developing a new generation of erosion prediction technology based on the current understanding of erosion processes and applicable to wide range of scale and land use possibility so as to replace the existing USLE technique. The result was the process based erosion prediction model WEPP, named after the project in 1995 (Foster et al., 1995).

1.4.2 Soil erosion research methodology

The existing methods for soil erosion research can be grouped into three categories: erosion modeling and prediction methods and erosion measurement methods, in both cases, there is a need for direct measurement of soil erosion. The third one is the assessment method.

Experimental methods

Water erosion can be measured using small plots, medium-sized plots (e.g. USLE plots) and/or large plots (unit-source watersheds) (Mutchler et al., 1994). The justification for small plots is that experiments performed under this condition provide insight into basic concepts and processes of soil erosion (e.g. sealing, aggregate stability, raindrop detachment and splash transport and erodibility). Next come the plots big enough to represent the combined processes of rill and interrill erosion (e.g. USLE plots) (Wischmeier and Smith, 1978). When this plot size is used, the effect of different conservation practices on soil loss can be compared with untreated land. Such plots should preferably be installed on a uniform sloping landscape element (e.g. hillside), to avoid deposition processes occurring in them. The third type of plot, unit-source watershed, combines the results of all the erosion processes and conservation measures, although this gives little opportunity to learn about the different parts of the erosion process (Mutchler et al., 1994).

Additionally, rainfall simulation has played an important role in the development of new erosion prediction technologies. These include the Water Erosion Prediction Project (WEPP; Elliot et al., 1989) and the European Soil Erosion Model (EUROSEM; Morgan et al., 1992).Field measurements are the most reliable if realistic data is needed on soil loss, whereas laboratory tests, in which the effects of many factors can be controlled, are designed to lead to explanation (Morgan, 1995).

Assessment methods

- ***The use of environmental radionuclides as tracers in soil erosion investigations***

The quest for alternative techniques for assessing soil erosion to complement existing methods has directed attention to the use of radionuclides, in particular fallout ^{137}Cs as tracers to obtain estimates of soil erosion and deposition on agricultural land (*Ritchie and Mc Henry, 1990).*The worldwide fallout ^{137}Cs, associated with the atmospheric testing of nuclear weapons during 1950s and 1960s, was released into the stratosphere by the testing of above ground thermonuclear weapons and deposited as fallout has provided a valuable man-made tracer for studies of soil erosion and sediment delivery *(Ritchie & MeHenry, 1990*). It is an artificial radionuclide with a half-life of 30 years. Since Its high affinity to fine soil particles, relatively long half-life, and world-wide distribution, the ^{137}Cs technique has widely applied in water erosion leading to profound accomplishments *(Ritchie & Ritchie, 1996).* The ^{137}Cs technique provides a means of assembling retrospective information on long term (about 35 year) rates of soil loss for an area and the spatial pattern of erosion and deposition involved, based on a single site visit (*WALLING & QUINE, 1991, Felipe Zapata, 2003).*

- ***Aerial photography***

Several people in order to show the distribution of soil erosion in agricultural or other environments have used aerial photographs. Example includes Bergsma (1980). Though the use of aerial photographs in the assessment of soil erosion has assisted in distinguishing the land areas with occurrences of visible erosion, they have not been able to show the extent of erosion that goes on below the plant canopy cover. This is mainly due to obscurity of below-canopy phenomena to above ground observation in remote sensing or aerial photography.

- ***Digital elevation model and spatial prediction***

The term digital elevation model was first used by Miller and Laflamme (1958), who defined it as the statistical representation of the continuous surface of the ground by large number of selected points with known x, y and z coordinates in an arbitrary coordinate field. Accurate elevation data may be obtained from ground surveys, maps, interferometry and aerial photographs. A Digital Elevation Model (DEM) is the most powerful spatial representation from which to construct a mathematical model of landform. A DEM allows z values, representing elevation, to be interpolated for any x, y (horizontal and vertical) coordinates in the model.

To compute the model, three methods (grid-based, triangulated irregular networks and vector or contour lines) may be used. The grid-based model is the original approach to building a DEM. This method uses data that have been sampled or structured using a regular grid. A DEM is a raster representation of a continuous surface, usually referring to the surface of the Earth. These data can be used as input to a software package of Geographical Information System (GIS), to quantify the characteristics of the land surface. The DEM therefore provides the spatial attributes of hydrologic characters, such as elevation, slope, aspect, curvature, drainage, flow direction, flow accumulation, and contributing catchment area, for catchments and sub-catchments to model effects on soil erosion.

1.5 Water erosion modelling

The intention of this section is to provide a brief overview of the concepts and models that have been used to simulate aspects of water erosion, sediment generation and sediment movement and most commonly used and applicable to hillslope or mountains erosion. The advantage and disadvantage of the various approaches is highlighted. Simulation models have become important tools for the analysis of hillslope and watershed processes and their interactions, and for the development and assessment of watershed management scenarios (He, 2003).

Scientific planning for soil conservation and water management requires knowledge of the relations among parameters that cause the soil loss or reduce it (Renard et al., 1996). Modelling soil erosion involves mathematically describing soil particle detachment, transport and deposition processes on land surfaces (Nearing et al., 1994). There are various reasons for modelling erosion, some of these are:

• Erosion models can be used as prediction tool for conservation planning, project planning and regulation.

• Erosion models give the idea of erosion process, as well as the time and amount of possible erosion at the area of interest so as to allow planners divert resources to reduce erosion. The erosion models differ greatly in terms of their complexity, their inputs and requirements, the processes they represent and the manner in which these processes are represented, the scale of their intended use and the types of output information they provide (Table1.5). Numbers of erosion models are in use and suit different land and weather conditions. The classification system used by Wheater et al. (1993) for describing the process representation of the model (empirical, conceptual and physics-based) is adopted in this section.

Table 1.5 Erosion and sediment transport models

MODEL	TYPE	SCALE
AGNPS	Conceptual	Small catchment
ANSWERS	Physical	Small catchment
CREAMS	Physical	Field 40-400 ha
EMSS	Conceptual	Catchment
HSPF	Conceptual	Catchment
IQQM	Conceptual	Catchment
LASCAM	Conceptual	Catchment
SWRRB	Conceptual	Catchment
GUEST	Physical	Plot
LISEM	Physical	Small catchment
USLE	Empirical	Hillslope
RUSLE	Empirical	Hillslope
WEPP	Physical	Hillslope/Catchment
EUROSEM	Physical	Catchment

1.5.1 Empirical models

Empirical models are developed from long-term measurements requiring large capital investments in research. Statistical technique is an appropriate tool when there is an extensive amount of data obtained from runoff plot and watershed accessible for analysis, and when the involved physical processes are not yet fully understood (Meyer, 1980).Different erosion models have been developed in the past to estimate the rate of soil erosion from the agricultural land as a guide for the conservation planning. Universal Soil Loss Equation, USLE (Wischmeier and Smith, 1978), later revised as Revised USLE or RUSLE (Renard et al., 1996) is one such model developed in the USA with more than 10,000 plot years of research data and experience of soil scientists. Model developers have suggested that the model could not be used outside USA without proper calibration of its parameters for the particular hydro-meteorological, geologic and topographic condition. The Soil Loss Estimation Model for Southern Africa (SLEMSA) (Elwell, 1981) and SOILOSS (Rosewell, 1993) are the examples of the model derived from the concept of USLE (Hudson, 1995).

A number of proposed erosion models use some aspects of the USLE such as EPIC (Erosion Productivity Impact Calculator) of Williams, Jones and Dyke, 1984) which used a modified USLE developed by Onstad and Foster (1975). In addition, AGNPS (Agricultural Non-Point Source) of Young et al (1989) used USLE with a slope shape adjustment factor. ANSWERS (Areal Non-point Source Watershed Environment Simulation) of Beasley (1977) made use of the continuity equation of Foster and Meyer (1972a) and values of C_u and K determined for the USLE. CREAMS (Chemicals, Runoff and Erosion from Agricultural Management Systems) of Foster et al (1981) were a process-and event-based model that uses USLE soil erodibility values, “crop-storage-soil-loss ratios” (Foster, Lane and Nowlin, 1980 as cited by Nearing et al, 1989).

Erosion and sedimentation by water involve the process of detachment, transport and deposition of soil particles (Foster, 1982). The factors that affect the erosion process are (Renard and Foster, 1983):

$$E_r = f\left(C_l, S_{pr}, T_y, SS, H_a\right) \qquad \textbf{1.2}$$

where E_r = Erosion, C_l = Climate, S_{pr} = Soil properties, T_y = Topography, SS = Soil surface conditions, H_a = Human activities

On the basis of the above functional relationship, USDA (US Department of Agriculture) developed the empirical relationship (Wischmeier and Smith, 1965):

$$A = R \times K \times LS \times C \times P \qquad \textbf{1.3}$$

Where A = Average annual soil loss predicted (t/ha), R = Rainfall runoff erosivity factor (MJ mm/ (ha h)), K = Soil erodibility factor, (ton ha h/ (MJ ha mm)), L = Slope length factor and S = Slope steepness factor, C = Cover management factor and, P = Support practice factor

After a number of improvements in the parameters of the equation, USDA published Agricultural Handbook 703 (Renard et al., 1996) and the Eq.5 is called the Revised Universal Soil Loss Equation (RUSLE). Presentations on the parameters of RUSLE are presented below.

Rainfall runoff erosivity factor (R)

Rainfall runoff erosivity factor, R (MJ mm/(ha h)), represents the erosive potential of rainfall. Rainfall erosivity (R) is defined as the mean annual sum of individual storm erosion index values, EI_{30}, where E is the total storm kinetic energy and I_{30} is the maximum rainfall intensity in 30 minutes. To compute storm EI_{30}, continuous rainfall intensity data are needed. Wischmeier and Smith (1978) recommended that at least 20 years of pluviograph data be used to accommodate natural climatic variations. However, the spatial and temporal coverage of pluviograph data is often very limited. Mathematically, R is computed as:

$$R = \frac{1}{n}\sum_{i=1}^{n}\left[\sum_{j=1}^{m} E_j (I_{30})_j\right] \qquad \textbf{1.4}$$

where n = Total no. of years, m = Total number of rainfall storms in i_{th} year, I_{30} = Maximum 30 minutes intensity (mm/h), E_j = Total kinetic energy (MJ/ha) of j_{th} storm of i_{th} year and is given as:

$$E_j = \sum_{k-1}^{p} e_k d_k \qquad \textbf{1.5}$$

Where p = Total number of divisions of j_{th} storm of i_{th} year, d_k = Rainfall depth of k_{th} division of the storm (mm), e_k = Kinetic energy (MJ/ha/mm) of k_{th} division of the storm and is given as (Renard et al., 1996) :

$$e_k = 0.29\left(1 - 0.72e^{(-0.05 i_k)}\right) \qquad \textbf{1.6}$$

Where i_k = Intensity of rainfall of k_{th} division of the storm (mm/h)

Soil erodibility factor (K)

Soil erodibility (*K*) is a measure of the susceptibility of the soil to erosion. Soil erodibility is related to the integrated effect of rainfall, runoff, and infiltration on soil loss. The K factor in RUSLE accounts for the influence of soil properties on soil loss during storm events on upland areas. Soil-erodibility factors are best obtained from direct measurements on natural runoff plots. The major requirement in a study using a natural runoff plot is a database that is large enough and that was obtained over a sufficiently long period. For satisfactory direct measurement of soil erodibility, erosion from field plots needs to be studied for periods generally well in excess of 5 years (Loch *et al*., 1998). Very few studies exist for which long-term observations are available.

It is the rate of soil loss per rainfall erosion index unit (ton.ha.h./(MJ.ha.mm)). It represents both susceptibility of soil to erosion as well as rate of runoff. Soil with higher clay content will have smaller *K* value due to high cohesion where as sandy soil will again have less *K* value due to higher infiltration rate resulting in less surface runoff. Organic soils such as loam will have moderate value of *K* as they are moderately susceptible to detachment. Soils with high silt content will have high erodibility factor as they possess less cohesion and allow more runoff.

Wischmeier and Smith (1978) developed monograph to account the effect of particle size distribution, classes of structure and permeability of soil (figure 1.6). If the total of percentage of silt and percentage of very fine sand is less than 70, this nomograph mathematically approximated as (Renard et al., 1996):

$$K = 2.77\times 10^{-7}\,(12 - OM) \cdot M^{1.14} + 4.28\times 10^{-3}\,(s - 2) + 3.29\times 10^{-3}\,(p\text{-}3) \qquad \mathbf{1.7}$$

Where *K* = Soil erodibility factor (ton. ha. h/(MJ.ha.mm)), *s* = Classes of structure (1-4), *p* = Soil permeability class (1-6), *OM* = Percentage organic matter content, *M* = Product of primary particle size fraction given as (Rosewell, 1993)

$$M = (si + 0.7\,Fs)\,(si + Fs + Cs) \qquad \mathbf{1.8}$$

Where *si* = Percentage silt, *Fs* = Percentage fine sand, *Cs* = Percentage coarse sand, Classes of structure and soil permeability class are the functions of particle size and permeability of soil.

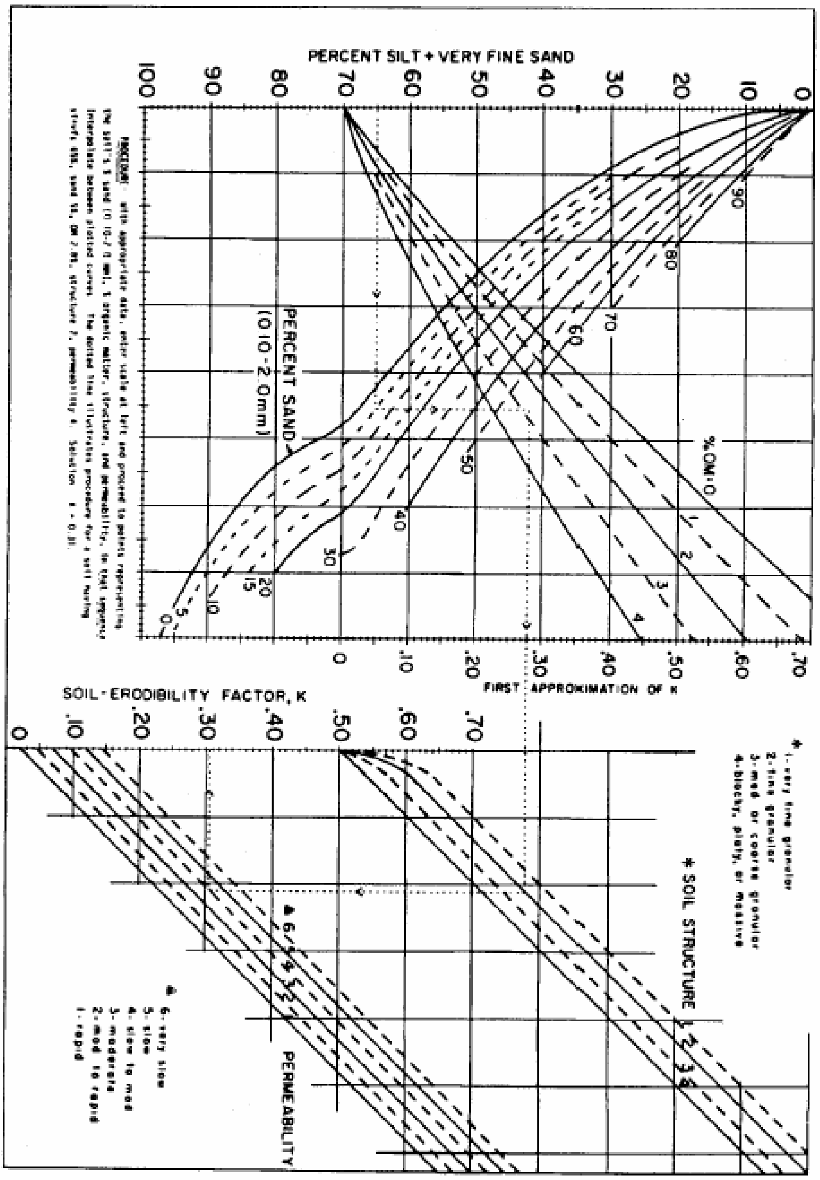


Figure 1.6 Soil erodibility monograph (after Wischmeier and Smith 1978). For conversation to SI divide K value of this monograph by 7.59. K is in U.S customary units.

Topographical factors (LS)

Slope length is defined as the horizontal distance from the origin of overland flow to the point where either the slope gradient decreases enough that deposition begins or runoff becomes concentrated in a defined channel (Wischmeier and Smith, 1978). The slope steepness factor (S) reflects the influence of slope gradient on erosion. Slope is estimated in the field by use of an inclinometer, Abney level, or similar device. Slope may be estimated from contour maps having 2-ft contour intervals if considerable care is used. These two factors have a substantial effect on the rate of soil erosion by water. They are combined into a single factor for convenience and simplicity.

Slope length of more than 305m is not recommended to use in RUSLE and usually shall not exceed 122m. If λ is the horizontal projection of the slope length, then *L* factor is given as,

$$L = \left(\frac{\lambda}{22.1}\right)^{m} \qquad \textbf{1.9}$$

m = Variable slope length exponent.

The value of slope length exponent depends upon the ratio of rill to interrill erosion. If β is the ratio of rill erosion to interrill erosion then *m* is given as

$$m = \frac{\beta}{(1+\beta)} \qquad \textbf{1.10}$$

For moderately susceptible soil in both rill and interrill erosion, McCool et al. (1989) suggested the equation:

$$\beta = \frac{11.1607 Sin\psi}{3.0(Sin\psi)^{0.8} + 0.56} \qquad \textbf{1.11}$$

ψ = Slope angle (degrees)

S factor is slope steepness factor and represents slope steepness in erosion. It is again the ratio of soil loss from the field gradient to that from a 9 % slope with other condition remaining the same. Soil loss increase more rapidly with slope steepness than it does with slope length. The slope steepness factor *S* is evaluated from (McCool et al., 1987).

$$S = \begin{cases} 10.8 Sin\psi + 0.03\ for slope < 9\% \\ 16.8 Sin\psi - 0.50\ for slope \geq 9\% \end{cases} \qquad \textbf{1.12}$$

The equation used to evaluate LS (e is a correction factor) is:

$$LS = (I/72.6)^{e}\left(65.41\sin^{2} q + 4.56\sin q + .065\right)$$

Where:
I = slope length in feet
e = 0.5 if percent slope is greater than 5
e = 0.4 on slopes of 3.5 to 4.5
e = 0.3 on slopes of 1 to 3 percent
e = 0.3 on slope of less than 1 percent
q = slope in degrees from horizontal

Cover and crop management factor (C)

The cover and crop management factor (*C*) measures the combined effect of all the interrelated cover and crop management variables. It is defined as the ratio of soil loss from land maintained under specified conditions to the corresponding loss from continuous tilled bare fallow. It is an estimate of the combined effects of prior land use, crop canopy cover, surface cover, surface roughness, and organic material below the soil surface. It is usually expressed as an annual value for a particular cover and crop management system but is calculated from the soil loss ratios for shorter periods of time within which cover and management effects are relatively uniform. The soil loss ratios are combined in proportion to the applicable percentages of erosivity (*R*) to derive annual *C* values. Estimation of *C* includes computation of *SLR* (Soil Loss Ratio) as:

$$SLR = PLU \times CC \times SC \times SR \times SM \qquad \textbf{1.13}$$

Where PLU = Prior land use sub-factor, *CC* = Canopy cover sub-factor, *SC* = Surface cover sub-factor, *SR* = Surface roughness sub-factor, *SM* = Soil moisture sub-factor

Details of estimation of SLR sub-factors and parameters are given in the *Agricultural Handbook 703* (Renard et al., 1996).

Support practice factor (P)

Support practice factor, *P*, is the ratio of soil loss with specific support practice to the corresponding loss with up and down slope tillage. Specific support practices affect erosion by modifying the flow pattern, grade and direction of surface runoff and by reducing the amount of runoff (Renard and Foster, 1983). For cultivated land, the support practices include contouring, strip cropping, terracing and subsurface drainage. On dry land or rangeland areas, soil-disturbing practices oriented on or near the contour that results in storage moisture and reduction of runoff are also termed as support practices.

Support practice factor, *P*, for contouring is computed from erosion theory and experimental data. When tillage is oriented along the contour, the flow will be redirected towards the tillage marks. Thus the runoff from the contoured field is often less than that from field tilled upslope and down slope (van Doren et al., 1950). Terracing reduces the sheet and rill erosion on the terrace interval by breaking the slope into shorter slope length. Proper subsurface drainage reduces runoff and thus the erosion from the hill slope (Formanek et al., 1987).

Support practice factor for individual support practice associated with the land of interest is calculated and incorporated to compute overall *P* factor. Details of calculation procedures are described in the Agricultural Handbook 703 (Renard et al., 1996).

Limitations

Empirical models have some limitations such as the use of USLE outside the US has been limited by the perceived lack of data for the parameters required to run the model under new conditions (e.g. Loch and Rosewell, 1992). Nearing et al. (1994) noted that the adaptation of USLE to a new environment requires a large investment of time and resources to develop the database required to run the model. According to Foster (1988) due to variability in climatic conditions, “at least 10 years of data be collected under the best of conditions to obtain an accurate measure of average annual erosion”. The methodology used in the derivation of USLE is not adopted for semi-arid areas because of the characteristic of large and infrequent storms in this region, a situation that necessitates long time experimentation (Edwards, 1987). Semi arid areas characterized principally by highly variable and erosive storm events need erosion estimates by individual storms to have accurate values of average annual soil loss (Foster, 1988).

In-spite-of the above limitations, RUSLE are used in erosion prediction worldwide. The simplicity of this equation and the availability of parameter values, at least in the United States, have made this model relatively easy to use (Loch and Rosewell, 1992).

1.5.2 Conceptual models

Conceptual models lie somewhere between physically based models and empirical models and are based on spatially lumped forms of the water and sediment continuity equation (Lane et al., 1988). These models use the concept of unit hydrograph to predict sediment yield. Rendon-Herrero (1974) was probably the first to use unit hydrograph concept to derive Unit Sediment Graph (USG) for a small watershed. Sediment Concentration Graph (Johnson, 1943), and Sediment Routing Model (William and Hann, 1978) are examples of conceptual models. According to De Hoop (1993), the conceptual model describes entities and the relationships among them, which are considered relevant for the intended application. Peuquet (1984) refers to the conceptual model as an abstraction of the real world, which incorporates only those properties, thought to be relevant to the application or applications at hand, usually a human conceptualisation of reality. All developed conceptual model are applicable at the catchment level.

LASCAM an example of the conceptual modelling is a continuous (daily time interval), conceptual sediment generation and transport algorithm was coupled to an existing water and salt balance model, LASCAM (Viney and Sivapalan, 1999). LASCAM was originally developed to predict the effect of land use and climate change on the daily trends of water yield and quality in forested catchments in Western Australia. The developed sediment transport algorithm does not discriminate between sediment size classes. It was found that the amount of runoff and sediment produced by the model was matched well in monthly and daily time intervals. Viney et al. (2000) later coupled a conceptual model of nutrient mobilisation and transport to the LASCAM.

1.5.3 Physically-based model

The lack of resources in most countries outside the USA to provide the widespread and sustained experimentation required by the empirically based USLE methodology (or its revisions) posed the question of possible alternatives (Ciesiolka and Coughlan, 1995).

A workshop of soil erosion scientists in Lafayette, Indiana in 1985 had came out with a realization that there existed an ability, “with some well-targeted research, to develop a new generation of erosion prediction technology” based on the contemporary understanding of erosion processes (Laflen, et al.,1991a). As a follow-up of the workshop, the USDA instituted a 10-year research and development program aimed to replace the USLE with the current improved erosion prediction technology. Thus, the Water Erosion Prediction Project (WEPP) was envisaged in 1986 by four U.S. federal agencies: the ARS, the SCS, the USDA-Forest Service and the U.S. Department of Interior-Bureau of Land Management (BLM). This model was designed to serve as the primary means of predicting soil erosion by the SCS (Foster and Lane, 1987). WEPP has the purpose "to develop new generation water erosion prediction technology for use by organizations involved in soil and water conservation and environmental planning and assessment" (Foster and Lane, 1987).

Physically-based models are intended to represent the essential mechanisms controlling erosion, they take into account physical characteristics as plant growth and climate. USDA-Water Erosion Prediction Project (WEPP) is an example of physically-based erosion model that combines a process-based hydrology model, a daily water balance model, a plant growth and residue decomposition model, a climate generator, and a soil consolidation model (Nearing et al., 1989) and based on numerical solutions (Lane et al, 2000).

Few process-based erosion models contain a winter hydrology routine. The EUROSEM model—the European Soil Erosion Model (Morgan et al., 1998), which simulates single runoff events is another model that contain hydrology routine. Unfortunately the EUROSEM has been suspended due to some technical difficulties being experienced by some users and to the lack of financial recourses to develop the code (EUROSEM web site).

Since the first version was released in 1995, the WEPP model has been in a maintenance and implementation mode. The Water Erosion Prediction Project WEPP model (Flanagan and Nearing, 1995) is one of the well-validated erosion prediction models that have been widely used (Merrit et al., 2003). Many authors have tested the performance of the WEPP hillslope model, finding adequate predictions for average runoff and soil losses (Zhang et al., 1996), but also less accurate predictions (Ghidy et al., 1995; Kramer and Alberts, 1995). However, WEPP predictions were better than the predictions by models like EPIC and ANSWERS, with reasonable degree of confidence for soil loss quantification under a specific condition Bhuyan et al., 2002). Still, few studies have been reported where the model has been applied outside the USA. Uses of the model have occurred in Spain (Soto and Di'az-Fierros, 1998), UK (Brazier et al., 2000), Australia (Yu and Rosewell, 2001) and Brazil (Bacchi et al., 2003). Discussion of the WEPP model parameter and structure are presented below:

Water Erosion Prediction Project (WEPP) Description

Model outputs

The hillslope version of WEPP outputs estimates of the spatial and temporal distributions of soil loss, sediment yield, sediment size characteristics, runoff volumes and the soil water balance. The WEPP profile also considers sediment deposition and is applicable from the top of a hillslope to a channel. The basic output contains the runoff and erosion summary on a storm-by-storm, monthly, annual and average annual basis.

Input data

The simulation model predicts soil loss, runoff and sediment deposition from surface flows on hillsides. The major inputs for running the WEPP hillslope version need four data files: a climate file, a slope file, a soil file, and a management file. The climate file requires daily values for precipitation, maximum and minimum temperature, and solar radiation. In addition to rainfall amount, the model requires three variables related to rainfall intensity, used to compute rainfall excess rates and thus runoff. The slope file consists of a sequence of slope elements with uniform properties with respect to overland flow: the so-called Overland Flow Elements (OFE). These are defined as “regions on a hillslope of homogeneous soil, cropping and management”, and are the basic units for modelling erosion. The soil file contains information on the physical (soil texture), chemical (CEC, organic matter content) of the topsoil and subsoil and hydrological characteristics (erodibility indexes, hydraulic conductivity) for the topsoil. The management file contains information needed to define initial conditions, tillage practices, plant growth parameters, residue management, and crop management (Flanagan and Nearing, 1995).

Model structure

WEPP uses mainly physics-based equations to describe hydrologic and sediment generation and transport processes at the hillslope and in-stream scales. The model operates on a continuous daily time-step.

Runoff modelling

The erosional processes result from the forces and energies developed in hydrologic processes (Laflen et al., 1991). The components of the hydrological processes are climate, infiltration and a winter component that accounts for snow accumulation and melt. On hillslopes, the soil water status is updated on a daily basis and is required to obtain infiltration and surface runoff volumes—the driving force in the detachment by flowing water in rills and channels (Laflen et al., 1991). The water balance component uses information about climate, plant growth and infiltration to estimate daily potential evapotranspiration and soil and plant evaporation. Rainfall excess is predicted using the Green-Ampt Mein-Larson (GAML) infiltration equation. The peak runoff rate can be simulated using either kinematics wave overland flow routing or simplified regression equations.

Erosion/transport modelling

The erosion processes represented in WEPP are limited to sheet and rill erosion and erosion occurring in channels where detachment is due to hydraulic shear. Through the erosional components of the model, the three stages of erosion (detachment, transport and deposition) are quantified using the rill–interill concept of describing sediment detachment (Laflen et al., 1991).

WEPP model uses steady state sediment continuity equations) to estimate net detachment in the hillslope (Foster et al., 1995).

$$\frac{dG}{dx} = D_f + D_i \qquad \textbf{1.14}$$

and

$$D_f = D_c\left(1 - \frac{G}{T_c}\right) \qquad \textbf{1.15}$$

Where G = Sediment load (kg/m/s) at distance x from the origin of hillslope, X = Distance down slope (m), D_i = Interrill sediment delivery rate to rill (kg/m^2/s), D_f = Rill erosion rate (kg/m^2/s), D_c= detachment capacity by rill flow (kg/m^2/s), T_c = Sediment transport capacity of the rill flow (kg/m/s)

Net deposition of sediment in the hillslope is give by the relation:

$$D_r = \frac{\beta_r V_f}{q_w}\left(T_c - G\right) \qquad \textbf{1.16}$$

Where D_r = Sediment deposition rate in the hillslope (kg/m^2/s), V_f = Effective fall velocity of the sediment (m/s), β_r = Raindrop induced turbulence coefficient (0-1), q_w = Flow discharge per unit width (m^2/s)

The model separately treats rill and interrill soil erosion as two major components of upland soil erosion. Soil sediment eroded from interrill areas is assumed to be transported to a rill, the distance between rills being taken as constant for the hillslope. The interrill detachment is presented as follows (Elliot et al, 1989):

$$D_i = K_i I_e^2 \qquad \textbf{1.17}$$

Where D_i - interrill detachment rate i.e., delivery of sediment from interrill areas to a nearby rill [kg/(s-m^2)], K_i - interrill erodibility [kg/ (m^4/s)], and I_e - effective rainfall intensity (m/s).

Since interrill erosion is a function of slope gradient towards a nearby rill, the complete expression for interrill soil erosion incorporating the effects of ground- and canopy-cover is as follows:

$$D_i = K_i I_e^2 G_a C_a S_a \left(\frac{R_s}{W} \right) \qquad \textbf{1.18}$$

$$S_a = 1.05 - 0.85 e^{-4 \sin S_r} \qquad \textbf{1.19}$$

Where G_a - ground cover adjustment factor, C_a - canopy cover adjustment factor, S_a - slope adjustment factor, R_s - rill spacing (m/rill), w - rill width (m) (Laflen et al, 1991), and S_r - slope of the land surface towards a nearby rill. The value of S_a “varies from 0.2 for a flat slope to 1.0 for a slope of 45°, to 1.05 for a slope of 90°”.

The erosion in rill (which can accept eroded soil sediments from the adjoining interrill area) is given as follow:

$$D_c = K_r (\tau - \tau_c) \qquad \textbf{1.20}$$

D_c - rill detachment capacity of the clear flowing water [kg/(s-m^2)];

K_r - rill erodibility parameter due to hydraulic shear (s/m);

τ - hydraulic flow shear stress acting on the soil particles (Pa); and

τ_c - shear stress below which there is no detachment or the critical hydraulic shear stress that must be exceeded before rill detachment can occur or threshold shear stress (Pa).

The hydraulic flow shear stress of flowing water τ (in Pa) acting on the soil particles is computed as follows:

$$\tau = \gamma R s_o \qquad \mathbf{1.21}$$

Where γ - specific weight of water (N/m^3); R - hydraulic radius (m); and s_o - hydraulic gradient or rill bottom slope.

1.6 Artificial neural network models

A neural network is a powerful data modeling tool that is able to capture and represent complex input/output relationships (Najjar et al., 1997).The NN is conceived to imitate the functioning of the human brain by acquiring knowledge through a learning process and finding optimum weights for the different connections between the individual nerve cells(Liu et al., 2003). Mathematically, a NN can be treated as a universal function approximator Hornik et al (1989).The NN is a non-linear model that makes use of a parallel programming structure capable of representing arbitrarily complex non-linear processes that relate the inputs and outputs of any system (Hsu et al., 1997). It provides better solutions than traditional statistical methods when applied to poorly defined and poorly understood complex systems that involve pattern recognition (Poff et al., 1996). Although NN do not provide a model that is readily physically explainable, it is a viable technique to develop input–output simulations and forecast models for situations when the objective is an accurate forecast (Uvo et al., 2000).

A minimum of three layers is required in an ANN: the input, hidden, and output layers (Figure1.8). An ANN consists of a set of processing elements, also known as neurons or nodes, which are interconnected (Najjar and Zhang, 2000). It can be described as a directed graph in which each node i performs a transfer function f_i of the form

$$y_i = f_i\left(\sum_{j=1}^{n} w_{ij} x_j - \theta_i\right) \qquad \textbf{1.22}$$

Where y_i is the output of the node i, x_j is the jth input to the node, and w_{ij} is the connection weight between nodes i and j . θ_i is the threshold (or bias) of the node. Usually, f_i is nonlinear, such as a heaviside, sigmoid, or Gaussian function.

ANN’s can be divided into feed forward and recurrent classes according to their connectivity. An ANN is feed forward if there a method which numbers all the nodes in the network such that there is no connection from a node with a large number to a node with a smaller number. All the connections are from nodes with small numbers to nodes with larger numbers. An ANN is recurrent if such a numbering method does not exist.

ANN’s is typically accomplished using examples. This is also called “training” in ANN’s because the learning is achieved by adjusting the connection weights in ANN’s iteratively so that trained (or learned) ANN’s can perform certain tasks. Learning in ANN’s divided into supervised, unsupervised, and reinforcement learning. Supervised learning is based on direct comparison between the actual output of an ANN and the desired correct output, also known as the target output. It is often formulated as the minimization of an error function such as the total mean square error between the actual output and the desired output summed over all available data. Reinforcement learning is a special case of supervised learning where the exact desired output is unknown. It is based only on the information of whether or not the actual output is correct. Unsupervised learning is solely based on the correlations among input data. No information on correct output is available for learning

Data move between layers across weighted connections. A node accepts data from the previous layer and calculates a weighted sum of all its inputs, *t*:

$$t_i = \sum_{j=1}^{n} w_{ij} x_j \qquad \textbf{1.23}$$

Where *n* is the number of inputs, *w* is the weight of the connection between node *i* and *j*, and *x* is the input from node *j*. A transfer function is then applied to the weighted value, t, to calculate the node output, *oi*.

$$o_i = f(t_i) \qquad 1.24$$

The most popular neural network model in use is the back-propagation feed-forward multilayer perceptron (MLP) with sigmoid-type transfer functions for the hidden and output layers and a linear transfer function is commonly used for the input layer due to its high performance compared to the other networks (Lippmann, 1987).This type of neural network is known as a supervised network because it requires a desired output in order to learn. The goal of this type of network is to create a model that correctly maps the input to the output using historical data so that the model can then be used to produce the output when the desired output is unknown.

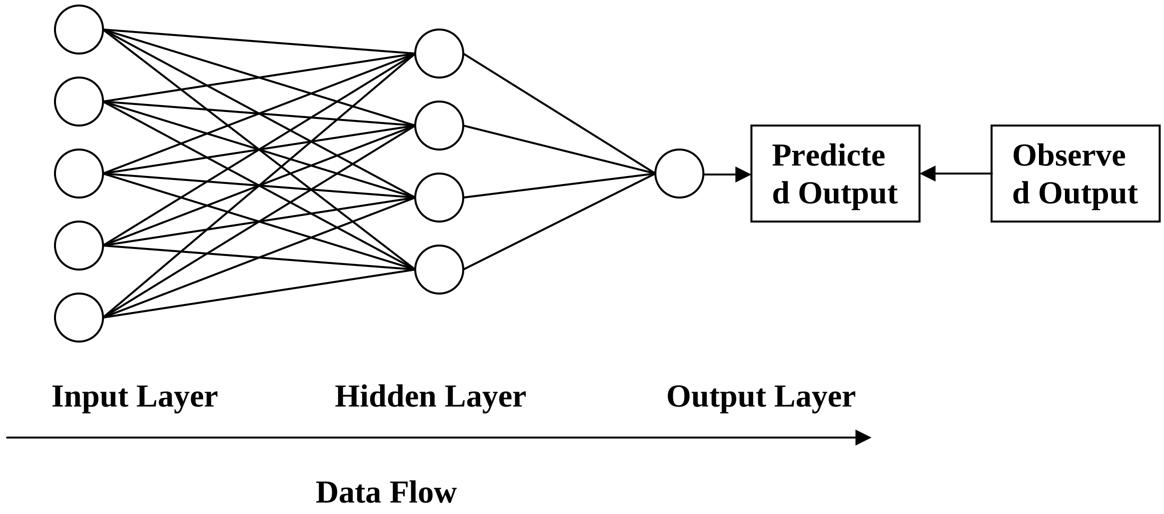


Figure 1.7 Layers and connections of a feed-forward back propagating artificial neural network.

The number of hidden nodes determines the number of connections between inputs and outputs. If too many nodes are used, then the ANN may become over-trained causing it to memorize the training data resulting in poor predictions (Lawrence, 1994). The learning rate determines the amount the weights change during a series of iterations to bring the predicted value within an acceptable range of the observed value. The training tolerance refers to the maximum error rate at which the network must converge during training. Once the network converges, an approximate function is developed and utilized for future predictions. The trained network is then tested with a separate data set with its output information omitted.

Artificial neural networks are being successfully used in many areas closely related to soil erosion. The American Society of Civil Engineers (ASCE) Task Committee on Application of

Artificial Neural Networks in Hydrology (2000a) reports applications for rainfall-runoff modeling, stream flow forecasting, ground water modeling, water quality, water management policy, precipitation forecasting, hydrological time series, and reservoir operations. Only a few articles describe results of artificial neural network in erosion research. In that area, artificial neural networks have been used mainly for classification of erosion processes. Rosa et al. (1999) captured interactions between the land and land management qualities and a vulnerability index to soil erosion in Andalucia region in Spain by means of expert decision trees and artificial neural networks. Harris and Boardmann (1998) used expert systems and neural networks as an alternative paradigm to mathematical process-based erosion modelling for South Downs in Sussex, England. However, we know of no publication describing quantitative prediction of soil loss and runoff at the hillslope scale. Licznar and Nearing (2003) used the neural networks to quantitatively predict soil loss from natural runoff plots, utilizing 2879 erosion events from eight locations in the United States, indicated that the neural networks performed generally better than the WEPP model in predicting both event runoff volumes and soil loss amounts. Pachepsky et al. (1996) reported ANN's estimated soil water content based on soil physical properties better than regression techniques. Starrett et al. (1996) reported that an ANN performed better (r^2 = 0.984) than a regression model (r^2 = 0.780) when predicting applied-nitrogen leaking below the root zone of turf grass.

1.7 Soil erosion research in the Palestinian territories

The erosion process is highly variable in the diverse ecosystems of the Palestinian highlands. As these highlands cover a wide range of geographical locations and a wide range of altitudes, it is difficult to consider the area as a homogeneous ecosystem. Palestinian territories are one of the Mediterranean region exhibiting different states of the erosion problem (Soil and Water Conservation Society, 1994). The first attempt to measure soil erosion rates in Palestine was made by Hammad et al. (2004). The study area located 6 km southeast of the Ramallah District in the central highland at 900 m above sea level with slope steepness of 2-3%. Using runoff plots, to study the effect of stonewalled terracing on soil erosion under wheat canopy to the nonterraced area for two rainy seasons. They found erosion rates of between 182 kg/ha and 3525 kg/ha during the first season, 1769 kg/ha and 5057 kg/ha during the second season for terraced and nonterraced plots, respectively. Despite the limitation of model and deficiency of data (Hammad et al., 2005) utilized field plots soil erosion measurements of the previous experiment to use and adopt the RUSLE model to the study area. They found that the model over estimate the actual soil loss by three times and by 14% before and after adjusting the RUSLE factors respectively. The authors recommended that for accurate and reliable validation of the model under this condition, it is advisable to conduct long term soil loss experimentation and measurement.

Since then, there have been no erosion investigations, and reference to soil erosion has often been criticized because of a lack of quantitative data. The causes of the erosion are the intensive land use, overgrazing of pastures, cultivation of annual crops on steep slopes; deforestation, built-up areas, roads and abandoned land (MOA, 2004). Insufficient attention has been given to elucidating the factors that affect the soil erosion processes.

Evidence of concern about soil erosion in Palestine is provided by the Palestinian Authority government’s National Strategies of Agriculture and Environment), which have been formulated recently. Their aims are the promotion of sustainable land use, through the execution of conservation strategies intended to prevent soil erosion and to generate economic development for the population (MOA, 2000 and MEnA, 2000). However, in spite of the effort invested, this institution is based on textbook technical proposals and lacks a scientific basis. Lack of understanding of the causes and effects of erosion hampers the development of appropriate conservation strategies. Obviously, there is a need for a better quantitative understanding of erosion processes at the hillslope.

1.8 Conclusion

The data from different research indicate that the humankind is facing a huge problem of soil deterioration and degradation by the process of accelerated soil erosion. Soil erosion was recognized as a major problem of natural recourses depletion in the early 20th century. Increased population and rapid industrialization accelerated urbanization leading to rapid exploitation of natural resources beyond its renewal capacity. Soil erosion may be a slow process that continues relatively unnoticed, or it may occur at an alarming rate causing serious loss of topsoil. The loss of soil reflected in reduced crop production potential, lower surface water quality and damaged drainage networks. The rate and magnitude of soil erosion by water is controlled by the Rainfall Intensity and Runoff, Soil Erodibility, Slope Gradient and length, Vegetation and Conservation Measures.

A wide range of models exists for use in soil erosion prediction. Few of these models have component to consider the hillslope erosion.These models differ in terms of complexity, processes considered, and the data required for model calibration and validation to a new condition. In general there is no ‘best’ model for all applications. The most appropriate model will depend on the intended use, availability of the data, and the characteristics of the study area being considered. Other factors affecting the choice of a model for an application include data requirements, accuracy and validity. Within the literature, the preferences of researchers for certain model types over others largely reflect two main viewpoints: emphasis on the processes at work or emphasis on the output.

Soil erosion data on soil erosion in the Palestinian territories are limited, and long time soil erosion research lack. Those sparse measurements provide little information about the spatial distribution of soil loss rate across the nation. The most used Empirical erosion prediction model RUSLE, require a long research experimental data to be validated and adopted to the Palestinian territories. RUSLE predicts long-term average values of soil erosion (effects of sub processes are lumped on annual basis). A large number of parameters in this model will have to be determined through calibration in sparse data situations, raising difficulties with identifiability, model uniqueness and the physical interpretability of calibrated parameters. These problems will also be observed with complex conceptual models. A common modelling problem is that the data requirements of the models often exceed the data availability in the area being modelled.

Physically based models are being developed to explain the dynamic relationships of the erosion process (detachment, transport, deposition), and the models provide a great opportunity to improve the estimation of erosion. The most notable advantage of the Water Erosion Prediction Project (WEPP) model include capabilities for estimating spatial and temporal distributions of soil loss (net soil loss for an entire hillslope or for each point on a slope profile can be estimated on a daily, monthly, or average annual basis), and since the model is process-based it can be extrapolated to a broad range of conditions that may not be practical or economical to field test.

Another fascinating area that has emerged in the 1990s is the application of artificial neural networks (ANNs) to natural resources phenomena modelling. Because ANNs have the ability to learn from data and can result in significant savings in time required for model development. A trained neural network can be thought of as an "expert" in the category of information it has been given to analyse. Therefore neural networks, with their remarkable ability to derive meaning from complicated or imprecise data, can be used to extract patterns and detect trends that are too complex such as soil erosion.

Based on the soil erosion result data on the daily basis from tow years experiment under five different land uses in the Palestinian central land. The WEPP model will be used to predict the soil loss from these data as it has the ability to predict soil loss in the daily basis. In addition the ANN modeling will be used to develop a new erosion prediction tool for the study area, and compared with the WEPP model.

Chapter 2---

Study area and data collection

2 Study area and data collection

2.1 Introduction

The Palestinian Territories (PT) is located to the east of the Mediterranean Sea between 29° and 33° North latitude and between 35° and 39° longitude (PEnA, 1999). Located at the meeting point between Eurasia and Africa, specifically in the south-eastern corner of the Mediterranean sea, creates unique topography and ecosystems (Figure 2.1). Worth mentioning that PT refers to the West Bank and Gaza Strip. The PT has a total area of about 6,210 km^2 (5845 km^2 in the West Bank and 365km^2 in Gaza Strip) (Ministry of Agriculture, 2004). The West Bank is characterized by a great variation in topography and altitude, where variations range between 1020 meters above sea level and 375 meters below sea level (PEnA, 1999).

The West Bank is classified into four major ecosystem based on several factors including climate, topography and soil types. These systems are the Jordan Valley region, the Eastern Slopes region, the Semi Costal region and the Central Highlands region. The central highland region extends the length of the West Bank with the most populated and accessible area to the Palestinian people. This is the largest region in the West Bank with an approximate area of 3500 km^2 (PEnA, 1999). Its length is 120km including the area from Jenin in the north to Hebron in the South. It is mountainous with some areas exceeding an elevation of 1000m above sea level. It has a good average of annual rainfall ranging between 400mm in the Southern foothills and about 700mm in the mountainous areas (Dudeen, 2001).

The vast majority of the cultivated area in the highlands is rainfed. Since old history, the olive cultivated hills gave the west bank landscape its distinguished character. Of the total agricultural area, olives and grapes predominate, and with almonds and fruit trees occupying 60% (PEnA, 1999).

In this Chapter, the present conditions of the study area, including the soil, topography, vegetation, land use and climate are briefly described for a better understanding of the extent of the erosion problems. Methodology of data collection from the field experiments and survey carried out during the implementation of the Regional Initiative Project for Dry Land Management by the Palestinian Ministry of Environment in the period 2003/2004-2004/2005 and published information from various sources explained. To understand the issue of soil erosion in this ecosystem, five land use types investigated at small scale, which represent the major land use present in the study area. The land uses investigated include olive grove, vineyard terraced, vineyard non-terraced, forest land and natural grassland.

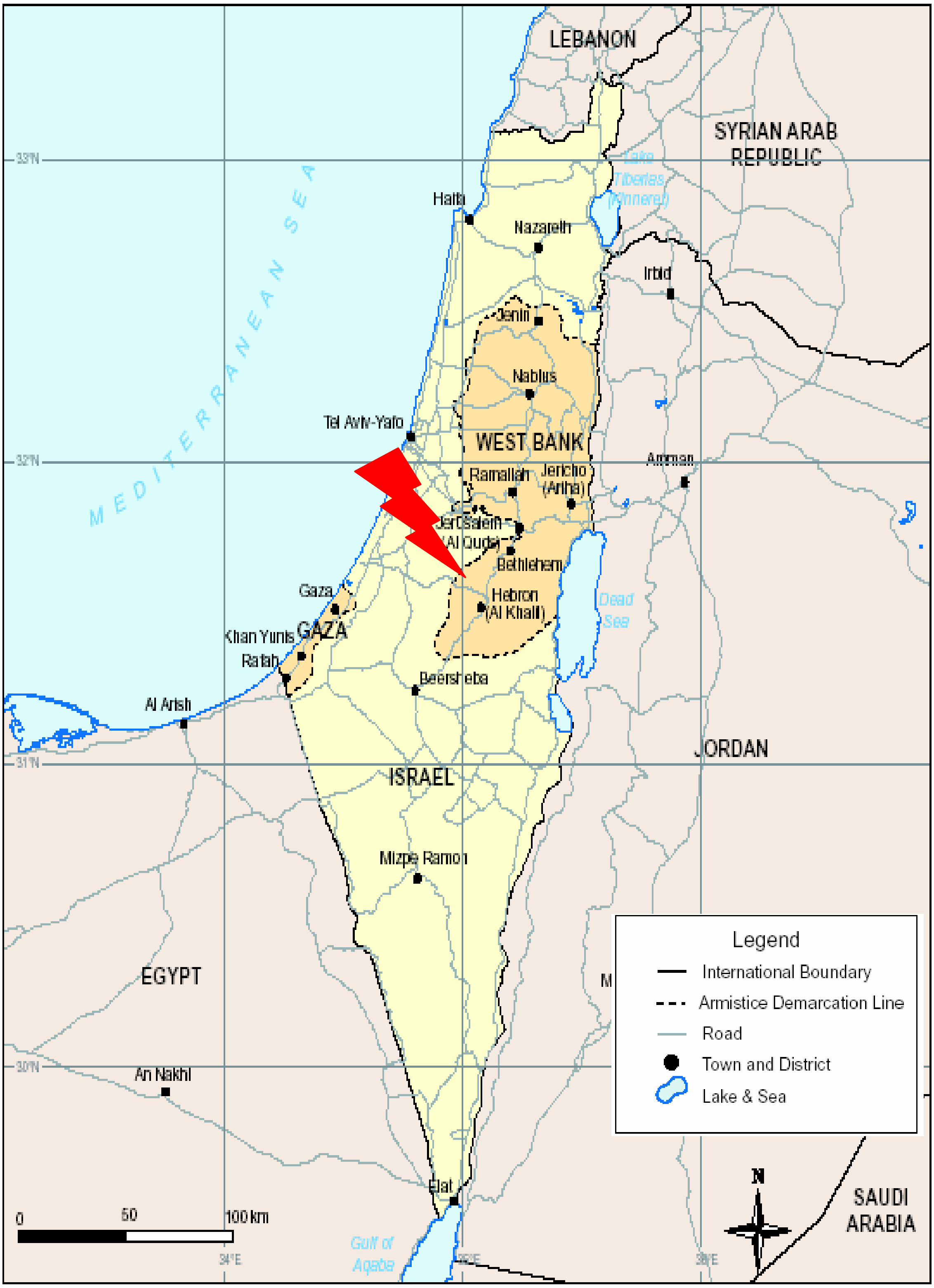


Figure 2.1 Geographical Projection of the study area (Source **UNEP, 2003**)

2.2 General description of the study area

2.2.1 Location

The study area is located in the Central Highland mountainous region of West Bank in the Palestinian territories about 13 km to the north west of Hebron city (Figure 2.1). Coordinated at latitude 31^{o} 38' and longitude 35^{o} 04', with elevation of 750 m.

2.2.2 Topography

The topography of the area is dominated by faults with a thrust of 500-800 m, which have divided the anticline ridge into a number of isolated blocks with a general direction perpendicular to the fold axis. The topography of the study area varies from undulating to mountainous. The lowest elevation of the Central high land mountains is 450 m and the highest is 1020 m above the sea level (LRC, 2002). Slope ranges from 2% to 40%, and the length of the slope from 20 m to 50 m. The footslope and summit surfaces of the study area, generally gently inclined (3-8%); hillcrests also are mainly gently inclined (3-8%); and sometimes moderately inclined (8-18%); hillslopes are moderately inclined (8-18%) and sometimes steep (18-32) while valley flats are always gently inclined (3-8%) (LRC, 2000).

Topography, especially slope and slope length, in general have a strong influence on runoff and hence the potential for erosion.

2.2.3 Geology

In general, Hebron Mountains has a shallow soil but the area of study which is located to the north west of Hebron has a good cultivation cover in the slopes and the valley bottoms (LRC, 2000). The most common geological formation in the study area consists from limestone, marl and dolomite dated to the Turonain age (Abed, 1999). The oldest formations were exposed a long the Hebron Anticline and the formation become younger westward and eastward (Rofe and Raffety 1963). The study area is part of the mountainous series that extends from the farthest south of Palestine to form the mountains of Neqab (Negev), Hebron, Jerusalem, Nablus and Galelee. The uplifting of the mountains coincided with the formation of the Jordan rift.

2.2.4 Vegetation and Land use

Indigenous plants include Aleppo Pine forest and Maquis, Evergreen Oak Forest, Carob-Lentisk Maquis, Garique and Batha in which Quercus calliprinos and Pistaca palaestina are shown to be the dominant species (PEnA, 1999). Unfortunately all these forests were destroyed and only scattered trees are found. This area is mainly cultivated with vine yards and olive groves. Stone terraces along the hillside of the central highland mountains area used to support different type of fruit trees such as olive, almond, and vine yard. Large areas are principally occupied by agriculture with significant areas of natural vegetation. Thorny shrubs such as *Sarcopoterium spinosum, Calycotome villosa* and *Caridothymus capitatus* are common shrubs of the natural grassland (MEnA, 2000). During the winter the grassland has a sporadic surface coverage, whereas during the summer time, most of these grassland disappeared due to lack of soil moisture as well as overgrazing. The total area occupied by forests is small in comparison with the other form of land use. Coniferous of *Pinus halepensis* is the only remaining kind of forest.

2.2.5 Soil

The soil in this area is generally classified by Reifenberg as terra rossa soils. The parent materials, from which this soil originally was initiated, are mainly dolomite and hard limestone. Terra rossa is a product of Mediterranean climate as a result of alternation of rain in winter with dry period in summer; this soil is characterized by low amounts of humus, relatively high clay content (20-50 %), soil reaction is generally neutral or moderately alkaline, with clay-to-clay loam soil texture (Yaalon, 1997; Zohary, 1947; Retrenbreg et al., 1947).

Terra Rosa's $CaCO_3$ content ranges between 15-40 percent, which makes it a fertile soil in general (MEnA, 2000).The natural soils have a low to moderate content of organic matter from 2% to 4% (Dan et al., 1976). Land with these soil types is used to cultivate field crops, mainly wheat and barley, vineyards, olive and fruit trees. The American great group classification that represents these soil associations are *Xerorthents* (MEnA, 2000). The USDA soil temperature regime is thermic, since the difference between the mean summer (June, July and August) and mean winter (December, January and February) soil temperature is higher than 5 ^{o}C (Dudeen,1999).

This type of soil is a characteristic of the hilltop areas with numerous rock outcrops that could reach to about 30% to 50%. Different soil slopes are permanent in such type of soil according to various topography and elevation. The soil depth varies according to the location; less than 50 cm in the hilly and sloppy areas, and more than 100 cm in areas of low inclination.

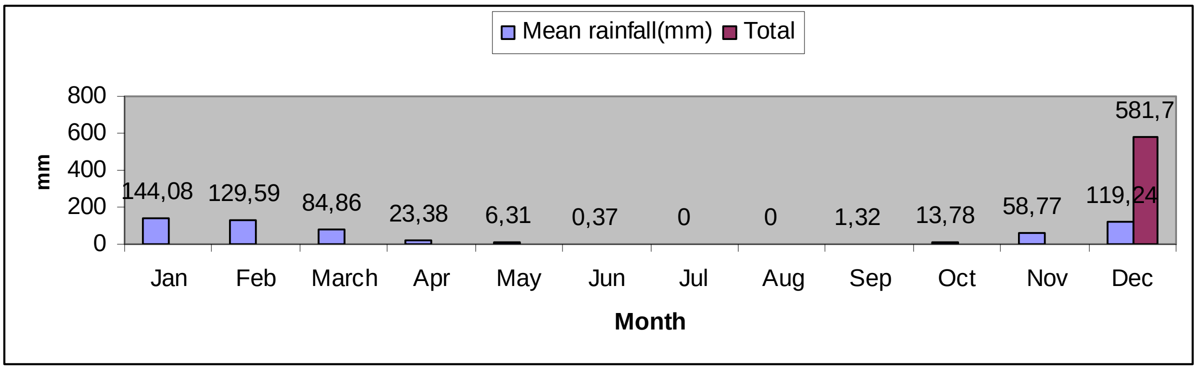
2.2.6 Runoff and Infiltration

All the drainage systems in the Western Aquifer Basin of the study area originated from the inland Hebron Mountains and are largely controlled by a few streams flowing westwards, some of which have cut deeply into the highlands with their numerous main streams lines (Awadallah and Owaiwi, 2005). Therefore all the water flowing to the study area that is located in the North Western Hebron District Basin watershed comes from the relatively high rainfall areas of the mountains regions to the east. The drainage systems are of the dendrite type, which means that the area is subject to a long time of erosion process, despite of many tectonic events affected affecting the area (Ayed and Wishahi, 1999). The percent of water infiltrated to the groundwater basins depends on many factors such as topography, soil types, rock formations, the rainfall and rainfall intensity. The infiltration rate in the study area is more than 26 mm\h (Ravikovitch, 1992).

2.2.7 Climate

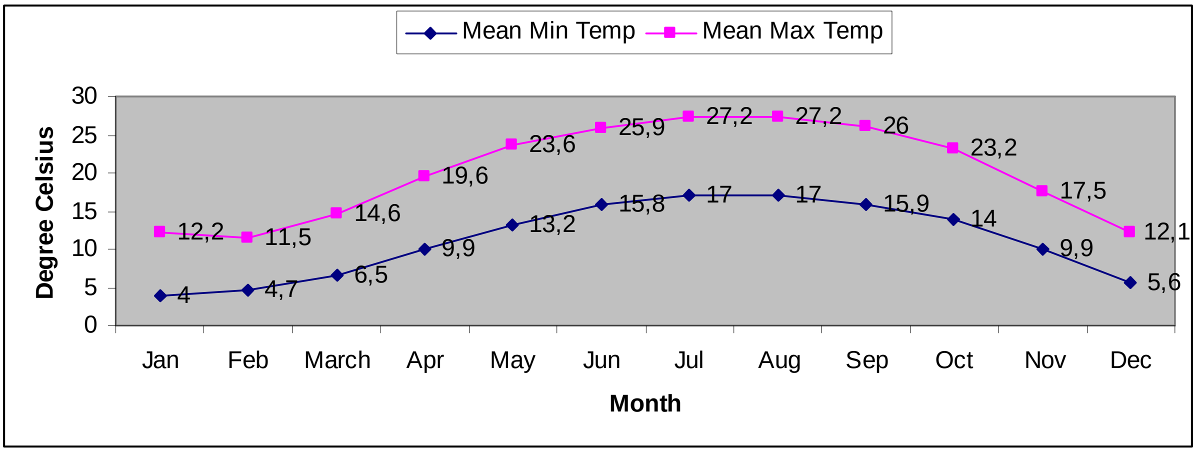
The climate is typical of the Eastern Mediterranean, with a short, cool, rainy winter and long, hot, dry summer. The Eastern Mediterranean climate is semi-arid, located in a narrow transition zone between humid and arid climates, and is associated with a well-defined precipitation pattern of winter rains, related to the cyclonic activity created or intensified within the Mediterranean basin (Gat, 1982). In this climate zone, rain only occurs during the winter and the summer is dry. Gat (996) has shown that the rain pattern is influenced by the origin of the storms and the evaporative effect of the Mediterranean Sea. Most of the rainstorms are associated with the Mediterranean fronts. Whereas few storm events originate over the Red Sea.

Although the rainstorms are restricted to the winter period, their seasonal distribution, amount of rainfall, intensity, span and intermittence vary considerably (Rozanski et al., 1993). The percentage of rainy days is very low and it ranges only between 15.6% and 24.7% in the winter season (Ministry of Transport, 2004). The mean annual rainfall is ~500 mm distributed unevenly between October and May with most rainfall (~70%) occurring between December and April, l0-20% from October to November, and l0-20% from April to May (Bar-Matthews et al., 1996). Long period average monthly rainfall data in mm for Hebron metrological station is given in (Figure 2.2).



Source: Ministry of Transport, 2004.
Figure *2.2 Average Monthly Rainfall in mm for Hebron Metrological station (1975-2002)*

The mean monthly temperatures during the summer months, from June to August, in the study area 21.7°C. The hottest days of the year occur in August. The mean monthly maximum temperature in the mountain area is 27.2°C and the mean monthly minimum temperature is 17°C. In the winter (December to February), the mean monthly temperatures is 8°C. January and February are the coldest months, with average maximum temperatures 10.3°C, and mean monthly minimum temperatures is 4°C (Figure 2.3). At the end of the winter, the temperature begins to rise again; however, warming the atmosphere in April and May is normally slower than the November cooling. Temperatures below the freezing point are registered nearly every winter in the mountains. The registered minimum temperature was -3°C in January (Kessler, Y. 1994).

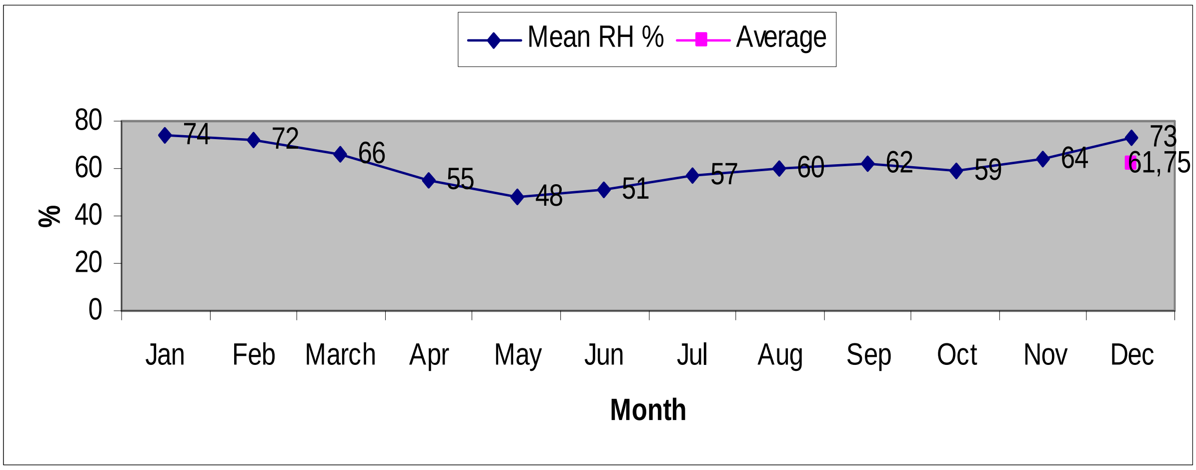


Source: Ministry of Transport, 2004.
Figure 2.3 Average Monthly Maximum and Minimum Temperature in Degree Celsius for Hebron Metrological station (1975-2002).

The direction and velocities of winds in the study area change according to the seasons of the year. The main wind direction is from west, southwest and northwest. Variation during winter is associated with the pattern of depressions passing from west to east over the

Mediterranean. During the summer, the prevailing winds come from north-west, at an average speed of 10 km/hour during the day, decreasing to 5 km/hour during the night and early morning hours. In the winter, the winds are most frequently from the south-west, with a wind velocity reaching 35 km/hour (MEnA, 2000). The Khamaseen, desert storm, may occur during the period from April to June. During the Khamaseen, the temperature increases, the humidity decreases and the atmosphere become hazy with dust of Arabian desert origin.

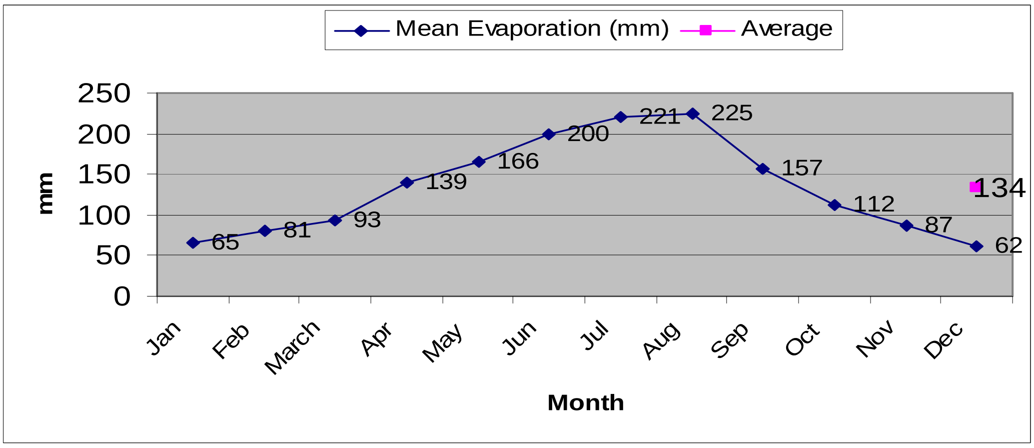
The mean range of annual relative humidity is 60-75% (Figure 2.4). The relative humidity reaches 40% in mid-day and increases gradually to reach 80-100% as an average at night (Kessler, Y. 1994).



Source: Ministry of Transport, 2004.

Figure 2.4 Average Monthly Relative Humidity for Hebron Metrological station (1975-2002)

Mean daily evaporation varies from 2 mm/day in December to 8.5 mm/day in August. Long period average evaporation data from Hebron metrological station (31^o 30' lat. N. - 35^o 6' Long. E., elevation 920 m) are shown in (Figure 2.5).



Source: Ministry of Transport, 2004.

Figure 2.5 Average Monthly Evaporation for Hebron Metrological station (1975-2002)

2.3 Field Study

The physical conditions of the study area including soil, topography and vegetation are important in erosion studies because they can indicate how the area is subject to erosion. The differences in these properties will have a different influence on runoff and erosion.

The field data collected during the two year field experiments and survey carried out during the implementation of the Regional Initiative Project for Dry Land Management by the Palestinian Ministry of Environment in the period 2003/2004-2004/2005, included rainfall, runoff, erosion, and vegetative cover in each plot. Some physical and hydraulic properties of the soil were also determined. The methods used for collecting the data are presented in the next paragraphs.

2.3.1 Field Experiments

Field experiments in the present study are intended at providing runoff and erosion statistics under various land use types. The data will help in assessing the effect of land use type, on soil properties, runoff and sediment yield. The data also aid in analysing the relationships between rainfall-runoff-erosion and for identifying appropriate runoff and erosion models suitable for the Central highland. Field experiments involved five different land use types representing the major land use types of the Central highland mountainous area. These include forest, grassland, olive grove, vineyard terraced and vineyard non-terraced. Five plots having an area ranging from 450 to 2337 m^2, and a slope from 8% to 22% were used (Table 2.1). A small earth bank 0.5 m wide and 0.5 m high was constructed along each plot boundaries to prevent runoff out of the plots. At the outlet of each plot, a sediment pond was provided to collect sediments followed by a collection tank to collect the runoff.

Table 2.1 Description of experimental plots.

PLOT NO.	LAND USE	PLOT DIMENSIONS	AVERAGE SLOPE %	SUPPORT PRACTICES
1	Forest Land	57m × 41m	22	Non-terraced with no tillage.
2	Natural grassland	52m × 36m	19	Non terraced with no tillage
3	Olive grove	37m × 28m	13	Non terraced with conventional tillage.
4	Vineyard	31m × 23 m	10	Terraced with conventional tillage.
5	Vineyard	18 × 25 m	8	Non terraced with conventional tillage.

2.3.2 Topography

A slope is the rise or fall of the land surface. Going up from the foot of a hill toward the top, this is called a rising slope and going downhill, this is a falling slope. The slope of a field is expressed as a ratio. It is the vertical distance, or difference in height, between two points in a field, divided by the horizontal distance between these two points. The formula is:

$$Slope = \frac{heightdifference(meters)}{horizontaldis\tan ce(meters)} \tag{2.1}$$

The slope can also be expressed in percent; the formula used is then:

$$Slope\% = \frac{heightdifference(meters)}{horizontaldis\tan ce(meters)} \times 100 \tag{2. 2}$$

The data relating to topography of the area were obtained from a study by LRC (2000). Confirmation of the data at the study areas was carried out together with the soil survey. This confirmation is necessary, especially for the land under forest and orchard cover, where land slope can not be estimated accurately from a map without on site assessment.

The land slopes and slope length were measured at each site. A grid system was used to determine the land topography of each land use type. One gridline were drawn in the longitudinal direction of each land use under study. The slope was measured using an Abney level, and slope length using a measuring tape. The slope length for each gridline was determined as the length travelled by runoff along the gridline. Depending upon the topography, there were one or more slopes and length of slope measurements for each site. The average values of slope and slope length for the test site were determined using Equations 2.1 and 2.2:

$$\bar{S} = \frac{\sum_{i=1}^{n} S_i}{n} \tag{2. 3}$$

$$\bar{L}_s = \frac{\sum_{i=1}^{nt} L_{si}}{n} \tag{2. 4}$$

Where

S = average slope, %,

S_i = slope along i^{th} segment of gridline, %,

n = number of gridline segments,

L_s = average slope length, m, and

L_{si} = slope length along i^{th} segment of gridline, m.

2.3.3 Rainfall

Rainfall is often expressed in millimetres per day (mm/day) which represents the total depth of rainwater (mm), during 24 hours. It is the sum of all the rain showers which occurred during these 24 hours. Rainfall data were collected from two manual rain gauges set up near the experimental area to measure the rainfall during the field experiments. Rainfall data were noted everyday at 8 a.m. and after each rainfall event. Rainfall data were also obtained from a nearby automatic Israeli metrological station, located 2 km north of the study area. Soil moisture from this metrological station were recorded in the daily basis where also obtained. The data recorded at depth of 25 cm in the data logger.

The rainfall intensity is the depth of water (in mm) received during a shower divided by the duration of the shower (in hours). It is expressed in millimetres of water depth per hour (mm/hour). The rainfall intensity was calculated using the following equation:

$$Ra\inf all\int ensity(mm/h) = \frac{totalamountofrainwater(mm)}{durationofrainwater(h)} \quad \textbf{2. 5}$$

2.3.4 Vegetative cover and land use

Vegetative cover affects both runoff and erosion in plots, and therefore a proper description of vegetative cover is important. Surveys on vegetation under the investigated land use at the present study were carried out together with soil and topographic surveys on the same sites Observations on vegetation were obtained by recording the land cover during the rainy season in monthly basis. However, there is currently no standard method available for accurately measuring the vegetative cover. In this study, data on the conditions of vegetative cover in the plots were obtained using the quadrant sampling method. The measuring was taken at the various stages of plant growth. The estimation of the vegetative cover under the forest and the orchard trees was relatively subjective. Three sample areas, each 100 m^2 (10 m x 10 m), were used for the measurement of vegetative cover in the plot.

2.3.5 Soil physical and hydraulic properties

Information on Soil and soil fertility present in the study area was obtained from the Study of Hebron Governorate Land and population (LRC, 2002) and from the soil data base prepared by the LRC. Information on soil physical and hydraulic properties of the plots was obtained from soil samples and field measurements. A total of ten samples from the surface soil were taken randomly in each plot for the description of the surface soil. Soil properties measured include texture, bulk density, and aggregate stability, soil moisture contents at saturation and field capacity, total porosity, effective porosity and infiltration characteristics.

Texture

Soil texture is an important parameter that affects soil structure, pore size distribution, aggregate stability and ease of soil particle detachment and transportation, and therefore it has significant influence on the erodibility of soil. For example, clay soil is difficult to be detached but due to its low infiltration rate, the runoff on this soil is high, and therefore the soil is prone to erosion hazard for rainfall events with high intensities. Silt soil is easily detached and transported, and the possibility of runoff is also high due to a relatively low infiltration rate. Sandy soils have a high infiltration rate, but due to lack of structure and weak aggregate stability the soil is easily detached. However, in sandy soil the detached materials is relatively

difficult to transport (due to heavier particle) by low overland flow rate compared to silt and clay materials. Among those three soils, silt soil is probably the easiest to be eroded. Soil texture was determined in the laboratory using the sieve analysis and pipette methods (Tan, 1994).

Bulk density

The bulk density (γ) indirectly provides a measure of total porosity (ρ_t), infiltration characteristics and the water holding capacity of the soil, and thus may relate to the runoff and erosion. The samples were taken using bulk density rings, and were oven dried for 48 hr and the γ was determined using the following equation:

$$\gamma = \frac{W_d}{V_r} \qquad \textbf{2.6}$$

Where γ = bulk density, kg m^3

W_d = weight of dry soil in the ring, kg, and

V_r = volume of soil ring, m^3

The value of V_r was computed using the following equation:

$$V_r = \pi r^2 d \qquad \textbf{2.7}$$

Where r = the radius of the ring,

d = the depth of soil ring.

Total porosity and effective porosity

The volumetric water content of the soil at saturation level is equal to the total porosity (ρ_t) of the soil. The difference between ρ_t and the value of soil moisture at field capacity (θ_f) is defined as the effective porosity (ρ_e) (Ahuja ***et*** *al.*, 1984). The values of soil moisture at saturation (θ_s) and field capacity (θ_f) are used for describing the effective porosity. The effective porosity (ρ_e) is related to the infiltration rate of soil (Boyer-Bower, 1993). The values of θ_s, and θ_f were determined in the laboratory.

Aggregate stability

Aggregate stability determines the stability of soil structure and is important in maintaining the infiltration rate and hydraulic conductivity. For soils with a weak structural stability, the soil structure changes considerably after saturation and affects the porosity, which in-turn affect the infiltration rate and hydraulic conductivity. Soils with low structural stability tend to have a high potential for runoff and consequently are more prone to erosion.

Soil samples for the determination of aggregate stability were the same as those used for determination of soil texture. Aggregate stability was measured following the method of Castro (1991). Soil samples were sieved to pass through a 4 mm diameter opening and were than air dried for 7 days. Samples were then put into a series of sieves which retained soil aggregates with sizes 4 to 2 mm, 2 to 1 mm, 1 to 0.5 mm, 0.5 to 0.25 mm and < 0.25 mm. The soil in the sieves was wetted for 15 min and then shook for 10 min. The soil remained on each sieve was then oven dried at 105°C for 48 hr and weighed. The aggregate stability of soil retained in each sieve was computed using the following equation:

$$A_{si} = \frac{W_{si}}{W_s} \times 100 \qquad \textbf{2.8}$$

Where A_{si} = aggregate stability of soil retained in the i^{th} sieve (%),

W_s = total oven dry weight of soil sample used for the test,

W_{si} = oven dry weight of soil remained in the i^{th} sieve after the test.

Infiltration characteristics

The infiltration rate of a soil is the velocity at which water can seep into it. It is commonly measured by the depth (in mm) of the water layer that the soil can absorb in an hour. The infiltration rate of a soil depends on factors that are constant, such as the soil texture. It also depends on factors that vary, such as the soil moisture content. During a rain shower, the soil pores will fill with water. If all soil pores are filled with water the soil is said to be saturated. After the drainage has stopped, the large soil pores are filled with both air and water while the smaller pores are still full of water. At this stage, the soil is said to be at field capacity.

Infiltration characteristics of the soil are important for the study of runoff and erosion. The ρ_e**,** is the most dominant factor to influence the movement of water in soil (Ahuja, ***et*** al., 1984). The main soil water transmission parameters include the saturated or field-saturated hydraulic conductivity, and the matric flux potential or Sorptivity (Elrick and Reynolds, 1992). Infiltration characteristics of the surface soil were measured in the field using a disc permeameter. Infiltration was described by three parameters, sorptivity (S_r), steady-state or long-term infiltration rate (I_s) and saturated hydraulic conductivity (K_s).

The parameter S_r is the quick absorption of water by soil at the beginning of infiltration. S_r is a measure of the ability of an unsaturated porous medium to absorb or store water as a result of capillarity. The parameter K_s is related to ease with which the water can move in the soil profile. The saturated hydraulic conductivity characterizes the saturated component of soil water flow, while the matric flux potential or Sorptivity characterizes the unsaturated component of flow. Rainfall at rates greater than the infiltration capacity will result in surface runoff. The steady infiltration rate represents the minimum capacity as the soil can absorb additional amounts of water in and on the soil. The steady infiltration rate is a function of the pore configuration of the soil.

2.3.6 Runoff

The runoff data for each plot were obtained after each rain event. The rain event separated from another rain event by more than six hours (Soil and Water Conservation Society, 1994).

The water collected in the runoff collection tanks were measured after allowing the sediment to settle down by emptying the tanks. Then the run off in each tank was mixed thoroughly and samples were taken to determine the weight of the soil loss in the runoff water collection tanks.

2.3.7 Soil loss

Soil loss data for the plots were obtained from the sediments deposited in (i) sediment pond, and (ii) from the runoff water collected at the runoff collection tank. After that Sediment yield, on dry weight basis, from a plot for a given rainfall event was determined using the following equation:

$$Y_s = \frac{S_p + S_{rwt}}{A_{pt}} \qquad \textbf{2.9}$$

Where Y_s = sediment yield of plot for a given rainfall event, kg ha^{-1},

S_p = sediment deposited in the sediment pond, kg,

S_{rw} = sediment present in the runoff water collection tank, kg, and

A_{pt} = area of plot, ha.

The values of $S_p, and S_{rwt}$ for each rainfall event were obtained as follows.

Sediments deposited in the sediment pond (S_p)

Sediments deposited in the sediment pond were weighed under moist condition. To obtain the dry weight of the sediment yield, five samples (about 200 g each) of the moist sediment were taken. The samples where then oven dried at 105'C for 48 hours to get the moisture content. The moisture content (θ) of the moist sediment in a sample was computed using the following equation:

$$\theta = \frac{W_m - W_d}{W_d} \times 100\% \qquad \textbf{2.10}$$

Where θ = the moisture content of the sediment sample, %

W_m = the moist weight of the sediment sample, kg, and

W_d = the dry weight of the sediment sample, kg.

The average moisture contents were computed from those five moisture content. The dry weight of the sediment in the pond was computed using the following equation:

$$S_p = \frac{\left(100 - \bar{\theta}\right) \times S_{pm}}{100} \qquad \textbf{2.11}$$

Where S_p = dry weight of the sediment in the pond, kg,

$\bar{\theta}$ = average moisture content of the sediment samples, %, and

S_{pm} = weight of the moist sediment in the pond, kg.

Amount of sediments contained in runoff water (S_{rw})

The sediment concentration of the runoff water was obtained by knowing the average weight of dry sediment per unit volume of the runoff water. From the runoff collected in a runoff collection tank, five samples, each 100 ml, were taken. These samples were then oven dried to obtain dry weight of the sediment *(W_d)*.The sediment concentration of the runoff water was computed using the following equation:

$$C_s = \frac{W_{d1} + W_{d2} + W_{d3} + W_{d4} + W_{d5}}{5} \times 10 \qquad \textbf{2.12}$$

Where C_s is the sediment concentration in the runoff water, mg/L, and $W_{d1}, W_{d2}, W_{d3}, W_{d4} and W_{d5}$ is the dry weight of sediment for samples 1, 2, 3, 4 and 5 respectively, mg. then S_{rw} computed as follow:

$$S_{rw} = C_s \times runoff \qquad \textbf{2.13}$$

2.4 Conclusion

The Palestinian territories located to the east part of the Mediterranean have a short, cool, rainy winter and long, hot dry summer. The central high land mountains ecosystem represent the most and large cultivated area with different land use prevailing in the Palestinian territories.

Understanding the different factors that effect soil erosion problem in the Palestinian Central highland mountainous area, it is a prerequisite for modelling and predicting the soil loss under this condition. Therefore this understanding must be based on experimental data, to model the cause and effect of relationship of soil loss factors. In order to achieve that, soil loss; runoff and soil erosion factors were collected from a field study carried out for two years under five major land uses existing in the central highland. The data collected are the runoff, soil loss, vegetation cover, rainfall and rainfall intensity, topography including the slope and slope length, and the soil physical and hydraulic properties.

In the next chapter and based in the collected data, rainfall data will be analyzed, the runoff and erosion data from each plot will be studied to examine the effect of land use on runoff and erosion, and to study the relation between the rainfall-runoff-erosion relationship. The effect of land use types on soil physical and hydraulics properties of the soil will also be examined in the next chapter, in addition to the relation between hydraulic and physical properties of the soil.

Chapter 3---

Rainfall erosivity and soil erodibility in the study area

3 Rainfall erosivity and soil erodibility in the study area

3.1 Introduction

Soil erosion is highly influenced by rainfall detachment force and soil resistance and erodibility. In this chapter the rainfall erosivity and soil erodibility under the different land use during the study period are studied and discussed to develop a better understanding of rainfall energy and soil resistance parameters. Study related to rainfall analysis and soil erodibility is almost absence in the Palestinian territories, and has not been studied previously due to the lack of needed data. These parameters are very important in soil erosion prediction and modelling.

3.2 Rainfall characteristics (Depth and Erosivity)

Rainfall erosivity is a very important factor in the soil erosion research. Rainfall data and characteristics such as duration, frequency and intensity affect the soil erosion process (Whiteman, 2000; Schwab, et al., 1993). The raindrops energy helps detach soil particles, and by generating runoff the rain contributes to the transport of these particles (Morgan, 1995). Rainfall can be characterised in many ways, varying from total precipitation in a year, season or other period, to daily rainfall or totals per rainfall event (Hoogmoed, 1999). This section is carried out to determine the erosive potential of the rainfall (for each rainfall event, maximum thirty minute intensity I_{30}), utilizing the daily and event based rainfall data collected during 2003-2004 and 2004-2005 rainy seasons. Total amount, duration, rainfall event intensity, maximum thirty minute intensity I_{30}, and kinetic energy analyzed.

3.2.1 Rainfall depth and duration

A total of 41 and 32 rainfall events were monitored during 2003-2004 and 2004-2005 rainy season respectively. The events were monitored during the rainy season, which is normally from October to April. Table 3.1 shows the rainfall depth during the two rainy seasons. Rainfall depth varies from 0.5 mm to11.7 mm with its average value per rainfall event 4.12 mm, and from .06 mm to 9 mm with its average value per rainfall events 4 mm for 2003-2004 and 2004-2005 rainy season respectively, under the rainfall event class $\leq$ 4h. Similarly the rainfall events depth under > 4h duration class varies from 1.3 mm to 44 mm with its average value 20.1 mm, and from 10 mm to 72.2 mm with average value 29.3 mm for 2003-2004 and 2004-2005 respectively.

Rainfall duration varies from 0.25h to 4h with average 1.72h, and 0.25h to 3.16h with average 1.65h for 2003-2004 and 2004-2005 respectively under duration ≤ 4. Also the duration varies from 4.25h to 16h with average 7.35h, and from 4.55h to 18.25h with average 9.8h, for 2003-2004 and 2004-2005 respectively under duration class > 4.

The analysis of the rainfall duration and depth revealed that the total rainfall events with average duration above 4 hours for both seasons contribute more than 80% of the total rainfall; despite they represent only 43.5% of the total rainfall events.

Rainfall distribution patters in the study area for 2003-2004, 2004-2005, and 1975-2002 (long term data from the Hebron metrological station) are given in Fig 3.1. The onset of the rainy season was late, and the number of the rainfall event was less in 2004-2005 compared to one in 2003-2004. However the cumulative rainfall during the 2004-2005 was higher than those in 2003-2004. The total rainfall depth in 2003-2004 was 393.48 mm and that in 2004-2005 was 558.5 mm.

The long term average values (1975-2002) of rainfall depth from the Hebron metrological station was 581.33 mm. the total rainfall depth for 2003-2005 and 2004-2005 are only about 67% and 96% respectively of the corresponding values for the long term data. This mean the potential erosivity of the rainfall under 2004-2005 rainy season will be almost as those occur under average conditions. While the erosivity under average conditions is expected to be much greater than those occurred during 2003-2004.

Table 3.1. Analysis of rainfall events number, duration and depth

	≤ 4 H	> 4 H	TOTAL
Rainy season 2003-2004			
No. of events	27	14	41
% of total	65.9	34.1	
Min. event duration h	0.25	4.25	
Max. event duration h	4	16	
Avg. event duration h	1.72	7.35	
mm in class	111.48	282	393.48
% of total	28	72	
Min. event depth mm	0.5	1.3	
Max. event depth mm	11.7	44	
Avg. event depth mm	2.12	20.1	

	≤ 4 h	> 4 h	Total
Rainy season 2004-2005			
No. of events	15	17	32
% of total	47	53	
Min. event duration h	0.25	4.55	
Max. event duration h	3.16	18.25	
Avg. event duration h	1.65	9.8	
mm in class	59.5	499	558.5
% of total	10.7	89.3	
Min. event depth mm	0.6	10	
Max. event depth mm	9	72.2	
Avg. event depth mm	4	29	

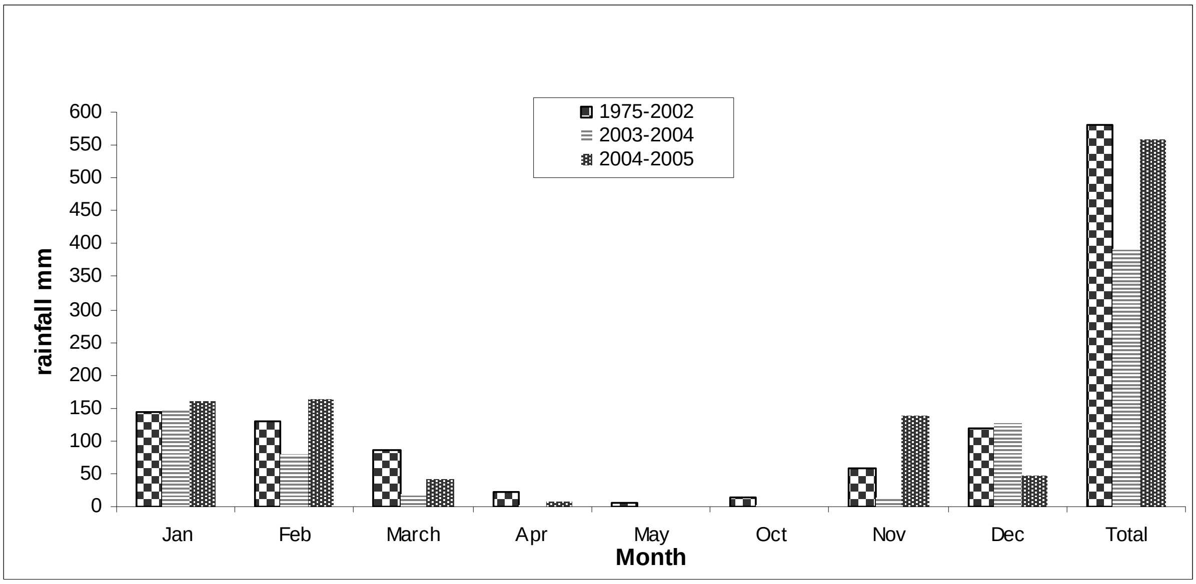


Figure 3.1. Rainfall distribution during the study (2003-2004, and 2004-2005) and that based on long term data (1975-2002).

3.2.2 Rainfall size and intensity

The rain events were divided into 4 size classes: very small (<1mm), small (1-10 mm), medium (10-20) and large (>20 mm) (Hoogmoed and Stroosnijder, 1984). From the frequency analysis of rainfall size classes (Table3.2), it can be seen that approximately 60% of the events were < 10 mm. Though small events, they represented 18% of total rainfall. While only 40% were bigger than 10 mm, this percentage was responsible for 82% of the total rainfall. However, events > 20 mm were moderately common, representing 22% of the total events but up to 58.5 % of total rainfall.

Table3.2. *Frequency analysis of rainfall size classes for 2003-2004 and 2004-2005 seasons.*

RAINY SEASON 2003-2004					
	< 1 mm	1-10 mm	10-20 mm	>20 mm	Total mm
No. of events	4	23	7	7	41
% of total	9.7	56.1	17.1	17.1	
mm in class	2.6	98.48	104.4	188	393.48
% of total	0.7	25	26.5	47.8	
Rainy season 2004-2005					
	< 1 mm	1-10 mm	10-20 mm	>20 mm	Total mm
No. of events	1	15	7	9	32
% of total	3.1	46.9	21.9	28.1	
mm in class	0.6	68.9	120.8	368.2	558.5
% of total	0.1	12.5	21.6	65.9	
Rainy season 2003-2004 and 2004-2005					
	< 1 mm	**1-10 mm**	**10-20 mm**	**>20 mm**	**Total mm**
No. of events	5	38	14	16	73
% of total	6.8	52	19.2	22	
mm in class	3.2	167.38	225.2	556.2	951.98
% of total	0.3	17.6	23.6	58.5	

According to the NWS (1995) there are three categories of rainfall intensity: light (up to 2.5 mm h^{-1}), moderate (2.6 to 7.5 mm h^{-1}) and heavy (more than 7.5 mm h^{-1}). Our analysis of the average intensity of all rainfall events during 2003-2004 and 2004-2005 rainy seasons (Table 3.3) revealed that 41% of the events were < 2.5 mm h^{-1}, approximately 59% of events were between moderate and 0% of events were heavy. The light events represented 23.5% of total rainfall and the moderate events represented 76.5% of the total rainfall.

Table 3.3. Frequency analysis of rainfall events intensity classes for 2003-2004 and 2004-2005 rainy seasons.

Rainy Season 2003-2004				
	< 2.5 mm h^{-1}	2.5-7.5 mm h^{-1}	> 7.5 mm h^{-1}	Total
No. of events	17	24	0	41
% of total	41.5	58.5	0	
mm in class	94.88	298.6	0	393.48
% of total	24.1	75.9	0	
Rainy season 2004-2005				
	< 2.5 mm h^{-1}	2.5-7.5 mm h^{-1}	> 7.5 mm h^{-1}	Total
No. of events	13	19	0	32
% of total	40.6	59.4	0	
mm in class	128.7	429.8	0	558.5
% of total	23	77	0	
Rainy seasons 2003-2004 and 2004-2005				
	< 2.5 mm h^{-1}	2.5-7.5 mm h^{-1}	> 7.5 mm h^{-1}	Total
No. of events	30	43	0	73
% of total	41	59	0	
mm in class	223.58	728.4	0	951.98
% of total	23.5	76.5	0	

So far, the analysis has been based on the average intensities of the rain event. Yet within a rain event there are short periods when the intensity can be very high, and therefore very erosive. The I_{30} term was calculated from the maximum rainfall depth measured in a 30-min period for each rainfall event (Table 3.4). Storm durations <30 min were occasionally detected for temporal resolutions $\Delta t \leq 15$ min. In this case, I_{30} was twice the amount of the rain (Wischmeier and Smith, 1978). The I_{30} intensity revealed that 20.5% of the events were < 2.5 mm h^{-1}, approximately 54.8% of events were between moderate and 24.7% of events were heavy. The light events represented 3.4% of total rainfall; the moderate events represented 37.8% of the total rainfall, and the heavy events represented 58.8% of the total rainfall depth. The intensity analysis was done to find out the kinetic energy of rainfalls.

Table 3.4. Frequency analysis of maximum thirty minute (I30) intensity classes for each rainfall even for 2003-2004 and 2004-2005 rainy seasons.

Rainy Season 2003-2004				
	< 2.5 mm h^{-1}	2.5-7.5 mm h^{-1}	> 7.5 mm h^{-1}	Total
No. of events	8	25	8	41
% of total	19.5	61	19.5	
mm in class	15.1	171.88	206.5	393.48
% of total	3.8	43.7	52.5	
Rainy season 2004-2005				
	< 2.5 mm h^{-1}	2.5-7.5 mm h^{-1}	> 7.5 mm h^{-1}	Total
No. of events	7	15	10	32
% of total	21.9	46.9	31.2	
mm in class	17.2	188.3	353	558.5
% of total	3.1	33.7	63.2	
Rainy seasons 2003-2004 and 2004-2005				
	< 2.5 mm h^{-1}	2.5-7.5 mm h^{-1}	> 7.5 mm h^{-1}	Total
No. of events	15	40	18	73
% of total	20.5	54.8	24.7	
mm in class	32.3	360.18	559.5	951.98
% of total	3.4	37.8	58.8	

3.2.3 Rainfall erosivity

The rainfall erosivity is a numerical descriptor of the ability of rainfall to erode soil (Wischmeier, 1959). The most suitable expression of the erosivity of rainfall is an index based on the kinetic energy (E) of the rain (Morgan, 1995). In runoff and soil erosion research it is crucial to determine the kinetic energy of rainfall, since this energy is what drives these processes. Many empirical relationships have been developed in different areas of the world for calculating E from the measured intensities. A comprehensive examination of these relationships has been recently presented by Salles et al. (2002).

The original, discontinuous unit energy equation (Wischmeier and Smith, 1978) was applied to calculate E:

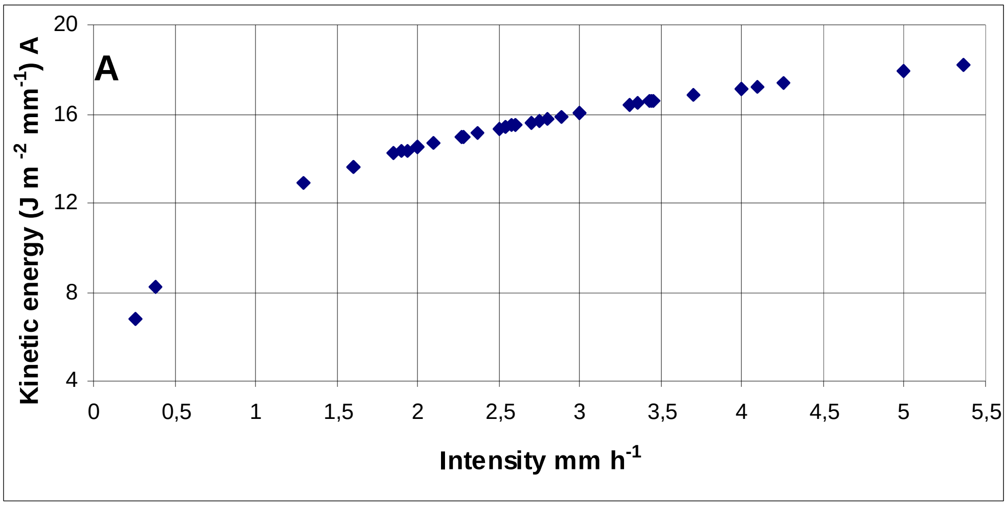
$KE = 11.87 + 8.73 \log I$

Where I is the rainfall intensity (mm h^{-1}) and KE is the kinetic energy (J m^{-2} mm^{-1}).

We determined this parameter from data of the two years rainy season both for each rainfall event intensity, and for maximum 30 minute intensity (I_{30}) for each rainfall event for both rainy seasons.

The Kinetic Energy results for the whole events are shown in Figure 3.2.a and b for the 2003-2004 and 2004-2005 rainy seasons. At least 65% and 55% of the rain events had kinetic energy values below 16 J m^{-2} mm^{-1} ; most of the remaining rain event for both seasons did not surpass values of 19 J m^{-2} mm^{-1}.Whereas the kinetic energy for the maximum thirty minute intensity for each event of the tow seasons as shown in Figure 3.3.a and b, that 75% of the values are above 16 J m^{-2} mm^{-1} , and value didn't surpass the 23 19 J m^{-2} mm^{-1}.

In general the kinetic energy values were low. This confirms that most of the rainfall events in the study area are light, but some are heavy enough to cause real damage to the soil surface.



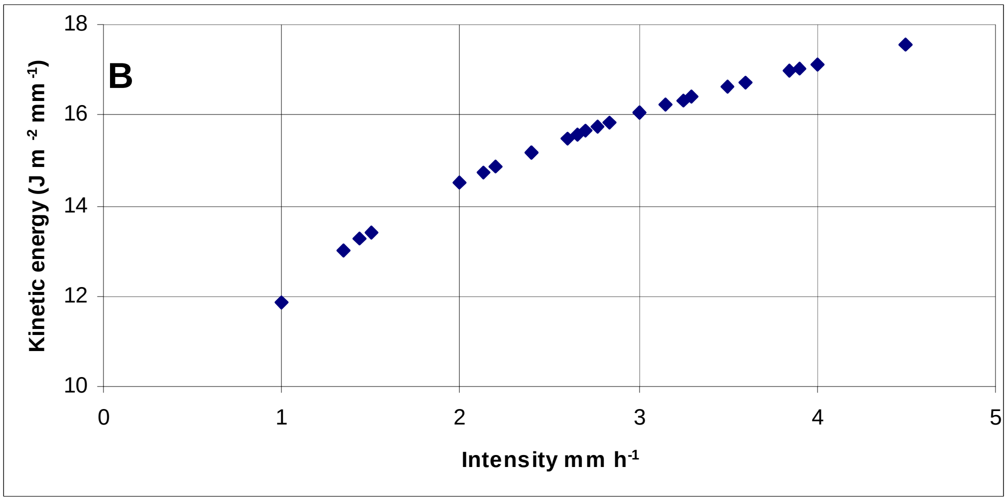


Figure 3.2.a and b. Kinetic energy *of rainfall events, figure A for 2003-2004 and figure B for 2004-2005 rainy seasons.*

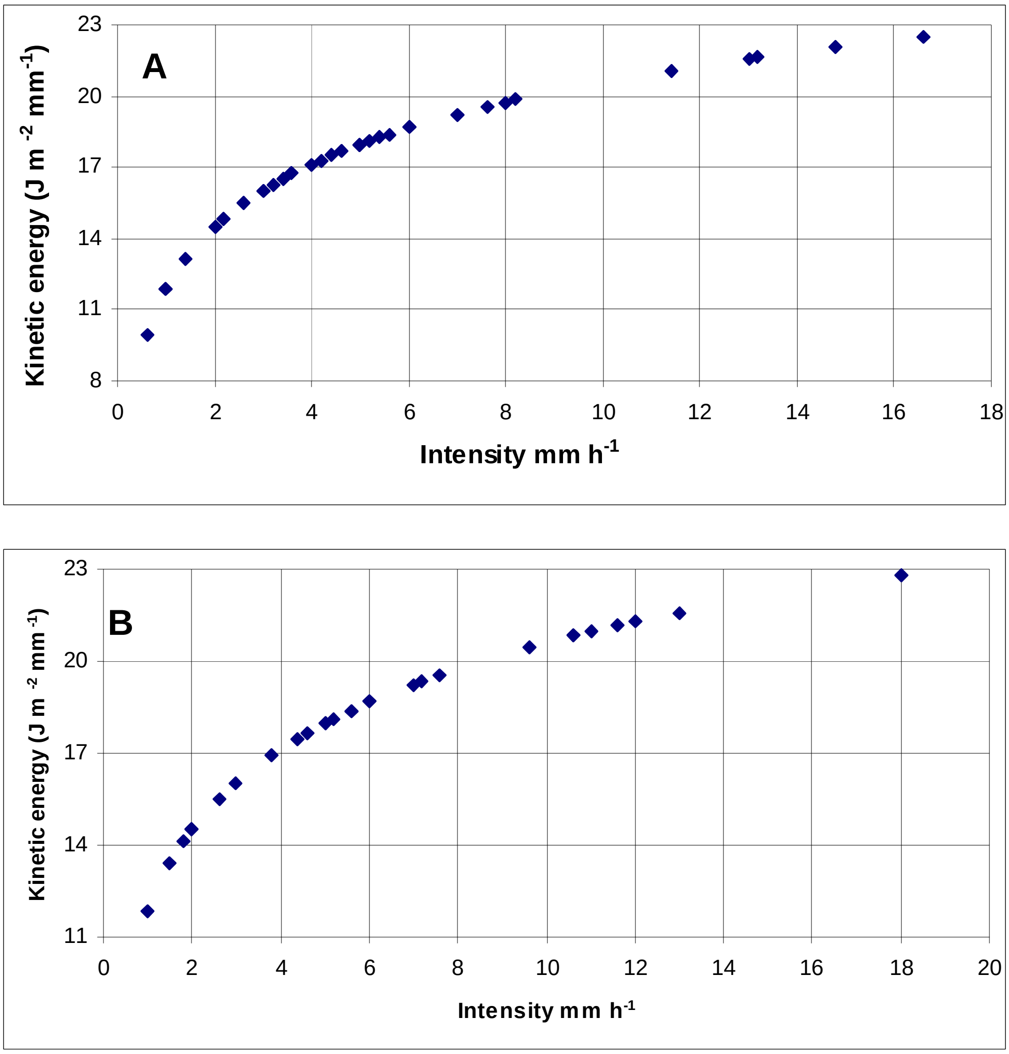


Figure 3.3.a and b. Kinetic energy *of maximum thirty minute intensity* I_{30} *, of each rainfall events, figure A for 2003-2004 and figure B for 2004-2005 rainy seasons.*

3.3 Soil erodibility

There is little information about erodibility in the study area, even though this one of the most important factors affecting soil erosion. A soil's inherent susceptibility to erosion by water is quantitatively expressed by its erodibility (El-Swaify and Dangler, 1977). With the development of the soil erosion prediction technology, identification of the soil erodibility parameters became a central issue in erosion studies (Bryan et al., 1989).

The soil erosion resistance values in models are often acquired through calibration because it is very difficult to estimate the actual value since soil erosion resistance does not represent an actual measurable soil property. However, while interest in the best practice and management systems, calibration becomes undesirable because it does not allow the prediction of soil erosion rates for areas where calibration data is not available and more importantly, where calibration does not lead to an increase in knowledge. Therefore it becomes crucial to link a soil's erosion resistance to one or some easy-measurable soil properties. This resistance depends on soil properties like texture, structural stability, organic matter content, type of clay and chemical properties (Berzegar et. Al., 1998, Moore and Singer, 1990). Kunwar et al. (2003) pointed out the importance of aggregate stability as an important property related to soil erodibility and water acceptance.

To accurately predict erosion, all the prediction models require the user to specify soil erodibility parameters. For example in Computer simulation models like the Water Erosion Prediction Project – WEPP (Nearing et al., 1989) – developed by the United States Department of Agriculture (USDA), two major components of water erosion have been identified: rill erosion and interrill erosion. The erodibility parameters reflect the resistance of the soil mass to the detachment and transport mechanisms operating during a water erosion event.

Erodibility has generally been deduced from rainfall simulations experiments on soil samples (Barthes and Roose, 2002) since this evaluation in the field is often expensive or time-consuming. These are research tools designed to apply water in a form similar to a natural rain. The drawbacks of rainfall simulator research are the cost and time required to construct a suitable simulator and the logistics (equipment and personnel) entailed (Meyer, 1994).

Extensive research has been done in the United States to define water erosion processes and to provide data for developing and testing erosion prediction technologies (Elliot and Laflen, 1993). These studies have determined equations which predict values for interrill erodibility (K_i), rill erodibility (K_r) and rill critical shear (τ_c). K_r and τ_c measure soil erosion due to the erosive forces of water flowing in small channels or rills. K_i represents the soil erodibility due to raindrop impact and sheet flow.

Therefore soil physical and chemical properties determined from soil samples taken at each land use were used to derive soil erodibility parameters utilizing the predictive equations of the WEPP technology.

At each of the 10 points in each land use type where soil sample were taken for analysis, K_i was estimated using the formula of Flanagan and Nearing (1995) used in the WEPP model:

$Ki = 2728000 + 19210000 \text{ vfs}$,

where vfs = very fine sand fraction in %.

The derived interrill erodibility (K_i) values ranged from 42to 71 10^5 kg s m^{-4} under all the land use considered in the study (Figure 3.4). The maximum K_i value (71 10^5 kg s m^{-4}) was under the Vineyard non terraced land use. The minimum measured Ki value (42 10^5 kg s m^{-4}) was observed under the Forest land use. The K_i range given for agricultural soils in the USA is between 20 10^5 kg s m^{-4} and 110 10^5 kg s m^{-4} (Flanagan and Nearing, 1995), this indicates that soils in this area of study are moderately resistant to erosion by raindrops.

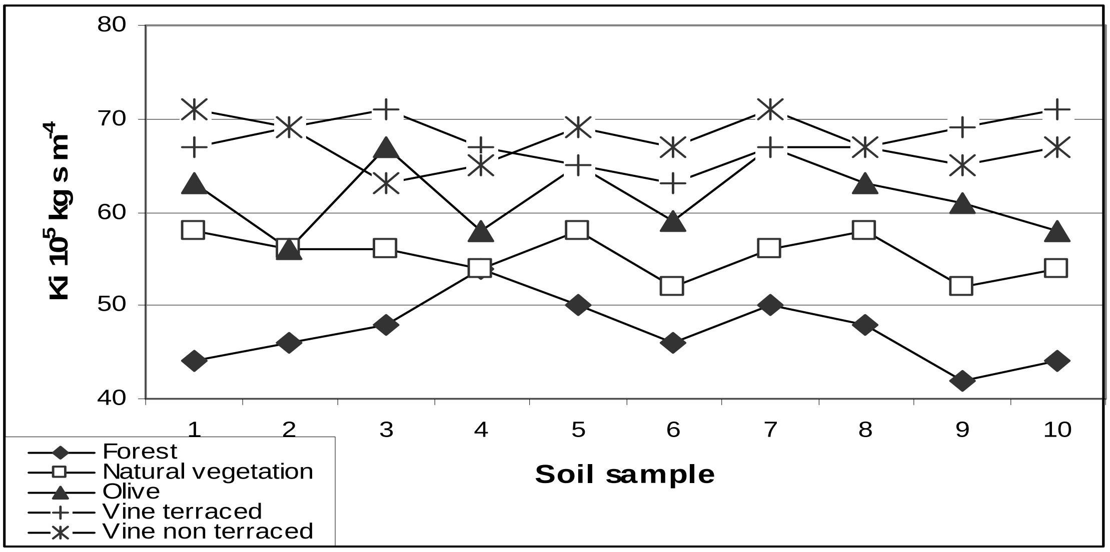


Figure 3.4. The derived interrill erodibility (K_i) under the studied land use types.

Also at each of the 10 points in each land use where soil sample were obtained, rill erodibility (Kr) and critical shear stress (τ_c) were also estimated with the formulas of Flanagan and Nearing (1995) used in the WEPP model:

$Kr = 0.00197 + 0.030\ vfs + 0.03863\ e^{-184orgmat}$ and (4)

$\tau_c = 2.65 + 6.5\ clay - 5.8\ vfs$

Where, vfs = %very fine sand fraction and orgmat = %organic matter fraction and clay = %clay fraction.

The derived rill erodibility (K_r) values ranged from 4 - 10 10^{-3} s m^{-1}; for most of the soils under the studied land use (Figure 3.5). The minimum K_r value was under the Forestry land use as K_i, whereas the maximum K_r value was Vineyard non terraced land use also. The K_r standard for agricultural soils in the USA is likely to range between 2 10^{-3} and 45 10^{-3} s m^{-1} (Flanagan and Nearing, 1995).These derived values were within the range standard for agricultural soils in the USA, but with a great difference between the two higher values. These results indicate that soils in the study area are also moderately likely to be resistant to detachment and transport by water.

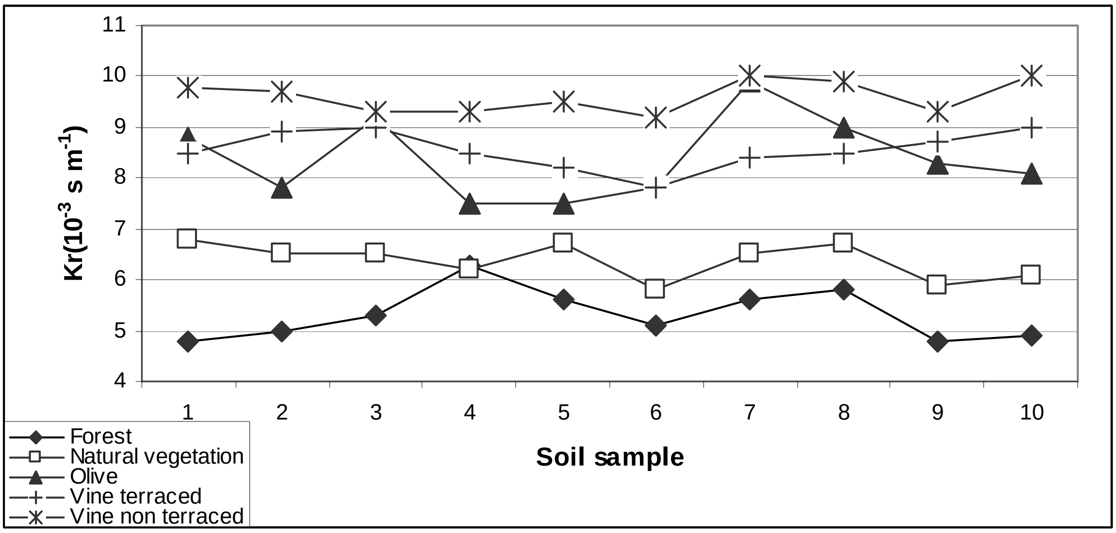


Figure 3.5. The derived rill erodibility (K_r) values under the studied land use types.

The derived τ_c values ranged from 3.96 to 5.83 Pa (Figure 3.6). The minimum value was under the olive trees land use, whereas the maximum value was under the forest land use. The standard of the agricultural soils in the USA range between 2.1 to 4.9 Pa (Flanagan and Nearing, 1995). The very high values under forest land use indicate that the soil under this land use type is more resistant to detachment and transport by flow in rills than the other land use type. These values agree with lower values of K_r and K_i under the Forestry land use.

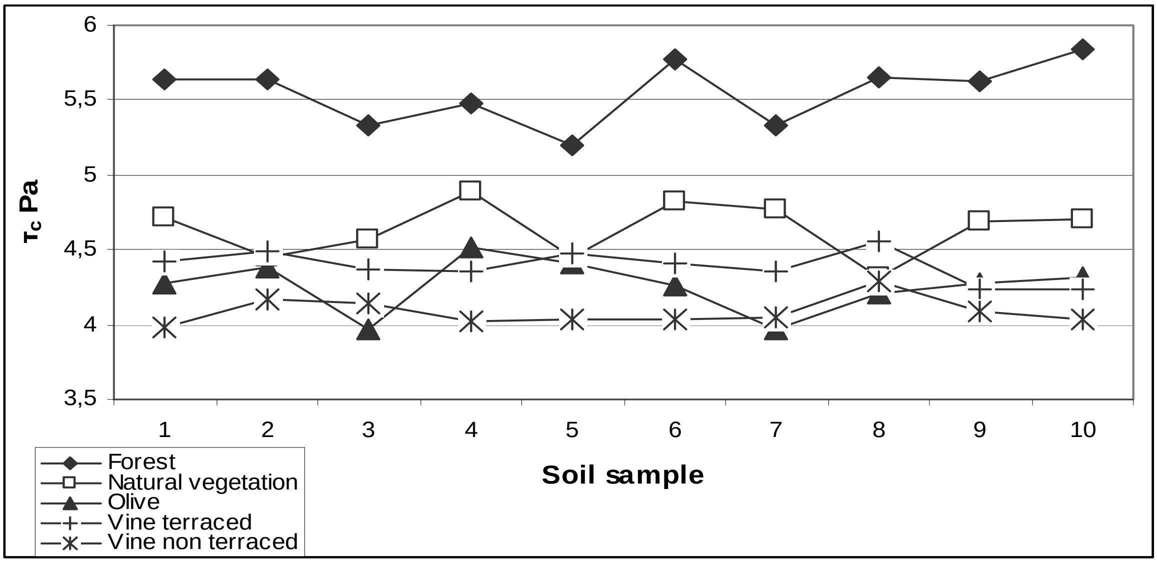


Figure 3.6. The derived critical shear stress values under the studied land use types.

3.4 Conclusion

The study of the rainfall characteristics revealed in general that, the rainfall intensity was very low, with only a few rainfall events with considerable intensity and kinetic energy, which may cause a real damage to the soil surface.

Derived soil erodibility parameters under the different land use on the study area, showed that the soil erodibility is low in comparison with the standard soil erodibility expected for the US soil. the most erodibile soil were under the Vine yard non terraced land use, while the most resistance soil were the soil under the forest land use. Unfortunitly there are no rill and interrill erodibility data available that would allow for direct comparison of the studied soil with other soil in the region.

Having the main data required for soil erosion modelling. The next chapter will present and summarize these parameters and prepare it for modelling. The effect of the different land use will be examined on these parameters. So the runoff and erosion data from each plot will be studied to examine the effect of land use on runoff and erosion, and to study the relation between the rainfall-runoff-erosion relationships.

Chapter 4---

Analysis of soil Erosion

4 Analysis of soil Erosion

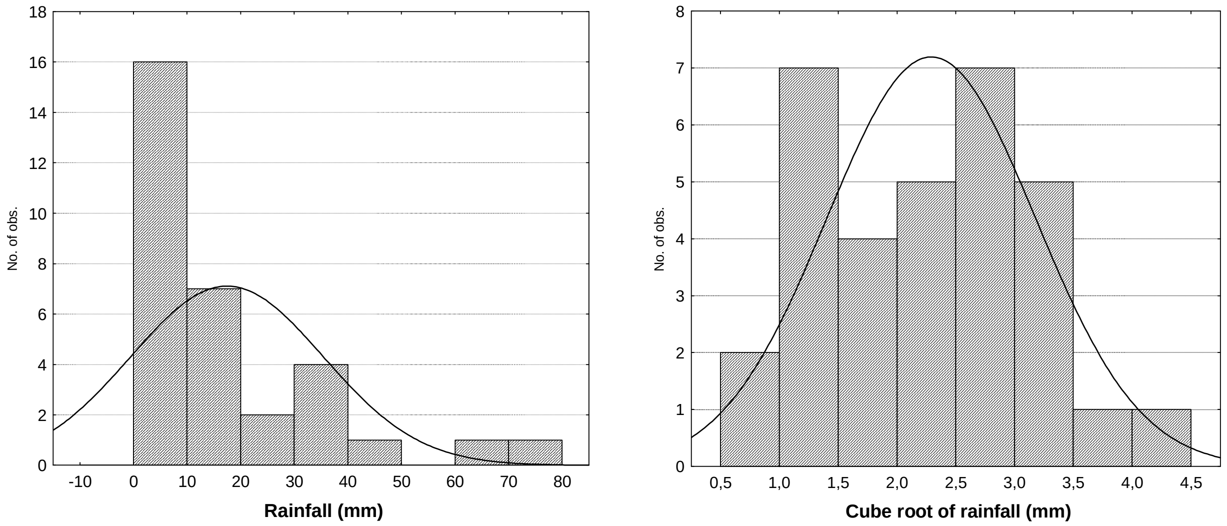
4.1 Introduction

Soil is the one of the most important natural resource that is not renewable in a historical time scale. Erosion is a complex phenomenon resulting from numerous interacting factors: soil, topography, land cover and climate (Wischmeier and Smith, 1978). Runoff is the main agent of soil erosion by water (Hudson, 1995). Soil erosion by water is considered the main land degradation and desertification process leading to progressive inability of vegetation and soils to regenerate (Mainguet, 1994), is significantly influenced by land use and management. Runoff response and erosion is highly variable under different land use and management practises. Different management practices under the different land use types have a significant effect on soil physical and hydraulic properties. The erosion, to lesser degree, is also influenced by the soil surface characteristics (Agassi, 1995). An interpretation of vegetative cover, soil physical and hydraulic properties, and erosion and runoff data under the different land use types obtained from the study, based on rainfall events are discussed and elaborated in this chapter.

4.2 Data presentation:

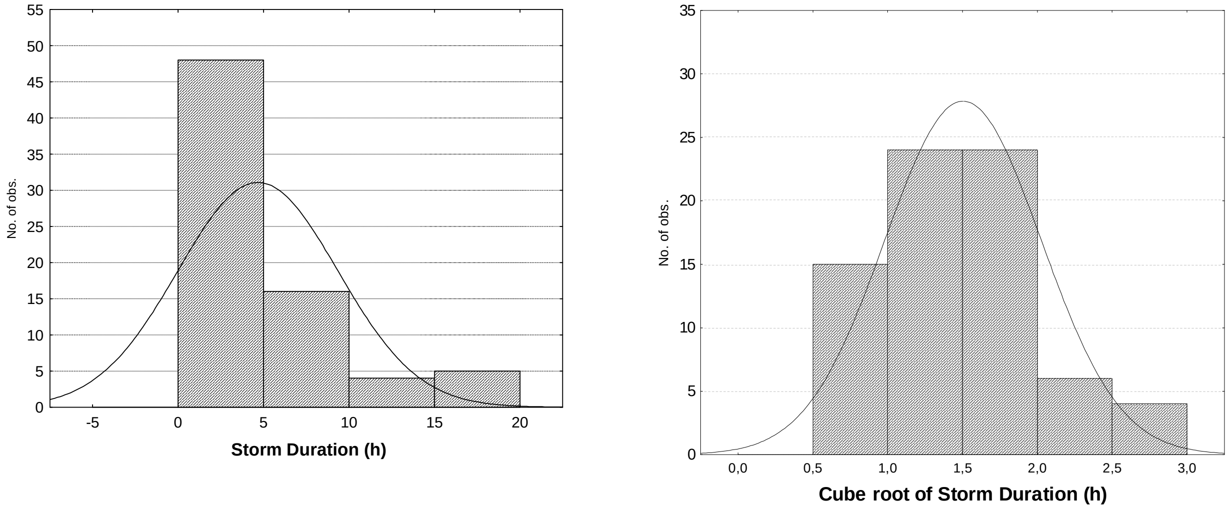
A series of univariate analysis were taken to explore the data for each variable alone. Non-normal distribution of the data, particularly in form of large skewness, can result in serious errors in analysis and incorrect conclusions. Data that come from a normal or Gaussian distribution should yield standardized skewness and standardized kurtosis values between –2 and +2 (George et al, 2005). As for the analysis of variance the difference between the smallest standard deviation and the largest must not be more than a 3 to 1, since the analysis of variance assumes that the standard deviations at all levels are equal.

Therefore, normality test for each variable has been performed; hence, the results of this test will be the base for the statistical analysis test applied. Results from normality test for all the variables gave evidences that some of the variables have non-normal distribution with mostly a positive skewness. Transformation using the cube root is reasonably fit well for all intended variables. Data transformations have been performed using cube root ($\sqrt[3]{x}$) of the variables values in order to minimize the skewness and produce a normally distributed data. Figure 4.1 shows the data transformation for two indicators as an example of the procedure followed for all indicators.



Data on rainfall depth before transformation

Data on rainfall depth after transformation



Data on storm duration before transformation

Data on storm duration after transformation

Figure 4.1. Normality test and data transformation for events rainfall depth and duration parameters.

4.3 Vegetative under different land use types:

Vegetative and land surface cover and condition consider one of main factors that influenced the characteristics of water runoff and soil erosion. Soil losses and sediment yield from cropped area have been estimated several times greater than the native forest and natural vegetation land use type (Rey, 2003). Percentage values of vegetative cover in five different land use types, forest (LU1), natural vegetation (LU2), Olive groove (LU3), vine yard terraced (LU4) and vine yard non-terraced (LU5) are given in Table 4.1. The vegetative cover and plant residues during the rainy season in the monthly basis in LU1 is estimated to have a constant value of 85% and with LU3 approximately 60%. The forest were growing under semi-natural conditions, preventing the formation of surface sealing and minimizing the velocity of the runoff water. The vegetative cover under LU2 range from 35% to 85%, while the vegetation under LU4 and LU5 decline from 50% at the beginning of rainfall season to the 0% around the middle of the rainy season to the end of the rainfall period in both years of the study.

LU4 and LU5 soils cultivated with vines remain almost bare during fall, winter and early spring due to the removal of annual vegetation by plowing or application of pesticides and fall of the vegetation cover. Therefore the minimum vegetation covers were observed under these two land use. The vegetative cover for LU4 and LU5 are similar during both years. So the vegetative covet under these land use types are not significantly different. This indicates the terraces support practices dose not have a significant effect on vine vegetative cover.

Table 4.1. Percentage values of vegetative cover under the five land use types.

YEAR/ LAND USE TYPES	VEGETATIVE COVER %								
	Month of the year							Mean	Stdev
	10	11	12	1	2	3	4		
2003/ 2004									
LU1	85	85	85	85	85	85	85	85	
LU2	30	35	40	55	65	80	85	54.2	
LU3	60	60	60	60	65	65	65	62.2	
LU4	50	40	20	0	0	0	0	15.7	21.5
LU5	50	40	20	0	0	0	0	15.7	21.5
2004/ 225									
LU1	85	85	85	85	85	85	85	85	
LU2	30	32	35	65	75	85	85	58.1	
LU3	60	60	60	60	65	65	65	62.1	
LU4	50	40	20	0	0	0	0	15.7	21.5
LU5	50	40	20	0	0	0	0	15.7	21.5

4.4 Soil properties under different land use type:

Soil properties qualify as important parameters in determining the soil erodibility and water movement, infiltration and runoff (cerda, 1998c). This section analyse the effects of land uses on the soil hydrologic and physical properties. One-way analysis of variance (ANOVA) was used to compare the effects of the five land-use types on the soil properties. Since the P-value of the F-test is less than 0.05, there is a statistically significant difference between the means of soil properties under the five land use at the 95% confidence level. To determine which means are significantly different from which others, Multiple Range LSD procedure was conducted at $p < 0.05$ level. Data analyses were carried out using Statistic software (version 7.0).

Table 4.2 show the effect of land use types on the soil aggregate stability. Distribution of soil aggregates differed significantly between all the land use types. The soils under LU3, LU4, LU5 had significantly higher mass of aggregates in the smaller diameter classes (<0.50 mm) than the LU1 and LU2 soils. In the (>0.5 mm) class, however, the LU1 and LU2 soils demonstrated greater number of aggregates than LU3, LU4 and LU5 soils. Given that small aggregate size (<1.2 mm) was found to be a practical indicator of soil degradation (Whalen and Chang, 2002). Therefore Land use type LU1 and LU2 tend to increase the stability of the soil aggregate, as it is evident from the percentage of their larger sized soil aggregate. The difference in aggregate size may be an important factor in controlling the surface runoff and soil loss, as the smaller aggregate may detached easily with rainfall. The presence of the macro aggregates is usually and positively associated with OM concentration (Duiker et al., 2003).

The effect of land use types, whether significant statistically, on soil physical properties are given Table 4.3. The soil texture of the land use types is clay, and the % of sand, silt and clay vary between the land use types. The average % of sand ranges from 25 to 38.3 %, silt from 20.7 to 29 %, and clay from 41 to 54.1%. LU1 show the lower value of sand and the highest value of clay percentage followed by LU4, which may explain the resistance of this land use types to runoff and soil erosion, since the clay tend have a stable aggregate.

Table 4.2. Analysis of variance of the surface soil aggregate stability under the different land use types.

LAND USE TYPES	% AGGREGATES BASED ON SIEVE OPENING (MM)				
	<0.25	0.25-0.5	0.5-1	1-2	2-4
LU1	$13,5^{a}$	$14,6^{a}$	29^{a}	$21,5^{a}$	$21,4^{a}$
LU2	$15,85^{b}$	$16,7^{b}$	27.5^{bc}	20^{b}	$19,95^{b}$
LU3	$18,4^{c}$	$18,6^{c}$	$26,2^{d}$	18^{c}	$18,8^{c}$
LU4	$18,4^{c}$	$19,7^{d}$	28^{b}	$17,5^{d}$	$16,4^{d}$
LU5	20^{d}	19^{e}	$27,2^{c}$	17^{e}	$16,8^{d}$
F-Ratio *P-Value*	459,25 0,0000	506,49 0,0000	34,04 0,0000	570,48 0,0000	70,58 0,0000

* Means followed by the same letter in the same column are not significantly different.

The average value of γ of the soil ranges from 1203 to 1412 kg m^{-3} under the different land use. The value γ are significantly different under all the land use types. The lower value of γ is found under LU1 and the highest value under LU5. Soils under cultivation land use types (LU3, LU4, and LU5) had higher bulk density than the soils under forests and Natural vegetation. The loss of soil organic matter under the cultivated fields probably caused a higher bulk density in the cultivated soils. In addition, under the cultivation, a decline in soil aggregation resulted in the increased bulk density.

The average value of total porosity range from 53 to 43 % under the five land use types. While the average value of the effective porosity varies from 21 to 23.85 % under the five land use types. The highest values of total porosity and effective porosity were under LU1 and LU2. Depending upon the increases in bulk density and disruption of pores by cultivation, total porosity decreased accordingly. There was a significant difference in total porosity between the cultivated soils (LU3, LU4, and LU5) and the forest and natural vegetation soils. The large value of total porosity under LU1 and LU2 can be related to aggregate stability of the soil. Soil aggregation usually implies the presence of large and linked macropores and largely controls movement of water, particularly near the soil surface, where crust formation and compaction can seal the surface (Morin et al., 1989; Cerda, 1996).

Table 4.3. Analysis of variance of the surface soil physical properties under the different land use types.

LAND USE TYPES	SOIL PHYSICAL PROPERTIES						
	sand %	silt %	clay %	γ (kg m^{-3})	ρ_t %	ρ_e %	OM %
LU1	25^{a}	20.9^{a}	54.1^{a}	1203^{a}	53^{a}	23,85^{a}	3,2^{a}
LU2	34.4^{b}	21.9^{a}	43.7^{b}	1272^{b}	48.7^{b}	23,25^{ab}	4.07^{b}
LU3	38.3^{c}	20.7^{a}	41^{c}	1336^{c}	47.15^{c}	22,9b^{c}	1,94^{c}
LU4	28.2^{d}	26^{b}	45.8^{b}	1376^{d}	44.6^{d}	22,7^{c}	2.74^{d}
LU5	30^{d}	29^{c}	41^{c}	1412^{e}	43^{e}	21,0^{d}	1,82^{c}
F-Ratio *P-Value*	40,79 0,0000	43,61 0,0000	73,74 0,0000	504,51 0,0000	142,63 0,0000	10,97 0,0000	172,30 0,0000

* Means followed by the same letter in the same column are not significantly different.

The highest value of organic matter was observed under the LU2 followed by LU1, LU4, LU3 then LU5. The higher organic matter content under LU1 and LU2 is mainly to the higher vegetation cover. Vegetation increases soil organic matter, soil porosity, and reduces bulk density and soil erodibility (Cerda, 1996).

Relative to organic matter of the LU1 and LU2 soils, SOM of the LU3, LU4 and LU5 soils decreased by 40, 15, 43% and 51, 31, 55% respectively. In addition the LU3, LU4 and LU5 comparative LU1 and LU2 increase the bulk density by 11, 6% and 15, 9% and 17, 11% respectively. Similar findings were reported by Hajabbasi et al. (1997) that subsequent tillage practices resulted in nearly a 20% increase in bulk density and a 50% decrease in organic matter for a soil depth of 0–30 cm in the central Zagrous mountain in Iran.

The relatively higher and significant organic matter content under LU1 and LU2 contribute to more stable soil aggregate as compared to LU3, LU4 and LU5. Therefore the difference between the aggregate stability under the different land use could be attributed to the difference in soil organic matter. The soil organic matters affect in the improvement of aggregate stability, through its cementing action between primary soils particles (Idowu 2003). Table 4.4 show the effect of land use type, whether significant statistically, on soil hydraulic properties.

Table 4.4. Analysis of variance of the surface soil hydraulic properties under the different land use types

LAND USE TYPES	SOIL HYDRAULIC PROPERTIES					
	θ_f %	θ_s %	S_r **mms**$^{-1/2}$	K_s mm/h	I_i mm/h	I_s mm/h
LU1	29,15^{a}	53^{a}	31^{a}	23^{a}	38,05^{a}	4,91^{a}
LU2	25,75^{b}	48,7^{b}	29^{b}	20^{b}	33,35^{b}	3,87^{b}
LU3	24,25^{c}	47,15^{c}	25,85^{c}	19^{c}	27,7^{c}	3,49^{c}
LU4	21,9^{d}	44,6^{d}	26,05^{c}	15^{d}	27,75^{c}	3,56^{c}
LU5	22^{d}	43^{e}	23.8^{d}	11^{e}	26,8^{d}	3,5^{c}
F-Ratio *P-Value*	192,31 0,0000	142,63 0,0000	313,55 0,0000	233,77 0,0000	840,53 0,0000	370,49 0,0000

* Means followed by the same letter in the same column are not significantly different.

The average values of θ_f ranges from 21.9 to 29.15 %, and θ_s from 43 to 53 % (Table 4.4). The highest values are observed under LU1 and the lowest values are under LU5 and LU4. Land-use types significantly differed in saturated hydraulic conductivity and Infiltration characteristics. Hydraulic conductivities were statistically different between all land use types. The infiltration parameters of the cultivated soil land use types (LU3, LU4, LU5) were significantly different from those of the forest and natural vegetation soils. While the forest and natural vegetation land use types had the highest hydraulic conductivity and infiltration, and the cultivated lands had the lowest values. The decrease in hydraulic conductivity and infiltration characteristic of the soil under the cultivated land use (LU3, LU4, LU5), relative to the LU1 and LU2 may be attributed to the decreases in bulk density and the mechanical disruption of pore arrangements by the tillage. *The finding of* the analysis of soil properties under the different land use is in line with previous study conducted under similar condition in the Mediterranean ecosystem and soil type of clayey type in Turkey *(Celik, 2005).*

The higher S_r values of under LU1and LU2 are probably related to the lower value of antecedent moisture content of soil under these land use, due the more water uptake by the plant. It is well known that the Sorptivity is strongly influenced by the antecedent moisture content of the soil (Boyer-Bower, 1993). The higher values of I_i and I_s are under LU1 and LU2 and the lowest value are under LU5 and LU4.

The cultivation practices under the cropland are known to deteriorate soil properties, especially reduce OM and change the distribution and stability of soil aggregates (Singh and Singh, 1996). Therefore the soils become more vulnerable to erosion since macro aggregates are disrupted (Six et al., 2000).

In conclusion, the results showed that the cultivation land degraded the soil physical properties, leaving soils more susceptible to the erosion. This suggests that land disturbances by the cultivation practices should be minimized to avoid the further depletion of the soil properties.

4.5 Effect of land use on runoff

Summary of the runoff data under the five land use type during the two years are given in Table 4.5. The data show the ability of land use surface to generate runoff varies with land use types. The runoff data under the five land use types were normally distributed. From the 41 rainfall events monitored during the 2003-2004 rainy seasons, 36% of the events generated runoff under LU1 and LU4 and 39%, 49%, 56% under LU2, LU3 and LU5 respectively. From 32 rainfall events monitored in 2004-2005 rainy season, 53% generated runoff under LU1, LU2 and LU4, and 59% and 65% under LU3 and LU5 respectively. The average, maximum and total values of the runoff for all land use types in the year 2004-2005 are considerably higher than those respective land use types in the year 2003-2004 rainy season. This was mainly due to the lower rainfall depth occurred in the rainy season of 2003-2004 in respect to that of 2004-2005.

Table 4.5. Summary of the runoff under the five land use during the two years.

YEAR/ LAND USE TYPES	LU1	LU2	LU3	LU4	LU5
2003/ 2004					
No. of events	41	41	41	41	41
No. of events generated runoff	15	16	20	15	23
% of the events generated runoff	36	39	49	36	56
Min.runoff (mm)	0	0	0	0	0
Max. runoff (mm)	1.3	4	3.5	2.1	6.2
Avrg. Runoff (mm)	0.28	0.58	0.8	0.5	1.3
Total runoff (mm)	11.4	24	32.7	20.4	53.4
2004/ 225					
No. of events	32	32	32	32	32
No. of events generated runoff	17	17	19	17	21
% of the events generated runoff	53	53	59	53	65
Min.runoff (mm)	0	0	0	0	0
Max. runoff (mm)	3	4.1	4.9	3.5	7.5
Avrg. Runoff (mm)	0.72	1.3	1.55	1.1	2.4
Total runoff (mm)	23.2	41.9	49.8	35.3	67.8

The analysis of variance of the runoff data for assessing statistical significance of the effect of different land use type for the year 2003-2004 are given in Table 4.6 and figure 4.1 .

Table 4.6. Analysis of variance of runoff under the different land use type for the year 2003-2004.

Contrast	*Sig.*	*Difference*	+/- Limits
LU1 - LU2		-0,307317	0,482829
LU1 - LU3	*	-0,519512	0,482829
LU1 - LU4		-0,219512	0,482829
LU1 - LU5	*	-1,02439	0,482829
LU2 - LU3		-0,212195	0,482829
LU2 - LU4		0,0878049	0,482829
LU2 - LU5	*	-0,717073	0,482829
LU3 - LU4		0,3	0,482829
LU3 - LU5	*	-0,504878	0,482829
LU4 - LU5	*	-0,804878	0,482829

Method: 95% LSD

*denotes a statistically significant difference.

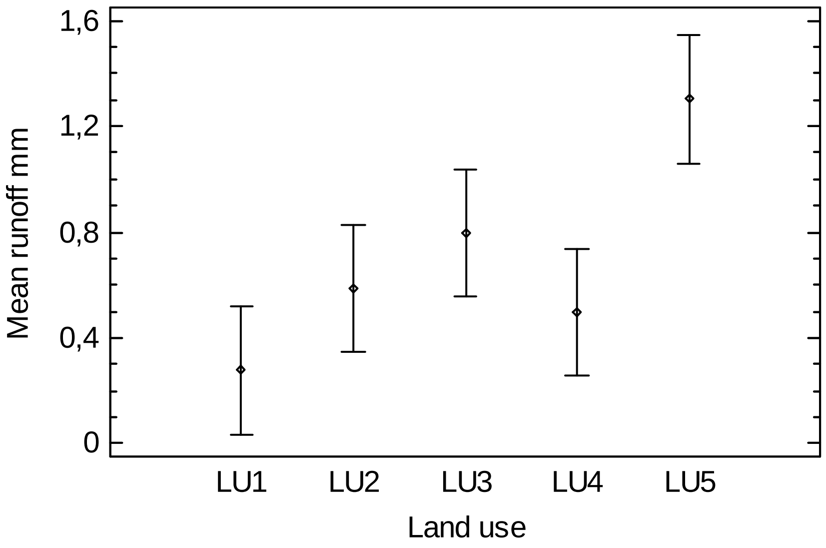


Figure 4.2. Analysis of variance of runoff under the different land use type for the year 2003-2004 (Means and 95% LSD intervals).

The average value of runoff per rainfall event is 0.28 mm for LU1, 0.58 mm for LU2, 0.8 mm for LU3, 0.5 mm for LU4 and 1.3 mm for LU5. The value of LU1, LU2, LU3 and LU4 are significantly different than the value under the LU5 at P-Values 0.05. Also the value of LU1 is significantly different from the value of LU3 at P-Values 0.05 but the value of LU3 is not significantly different from those for LU2 and LU4.

The analysis of means plot Figure 4.3 displays each sample mean together with a vertical line drawn to the grand mean of all the observations. Decision limits are included above and below the grand mean. Any sample means that fall outside the limits may be declared to be significantly different than the grand mean. The average value of runoff for LU1 is significantly lower than the over all mean runoff of this year for all land use types. While the average value of LU5 is significantly higher than the over all mean. The average values of LU2, LU3 and LU4 are within the grand average of runoff for this year.

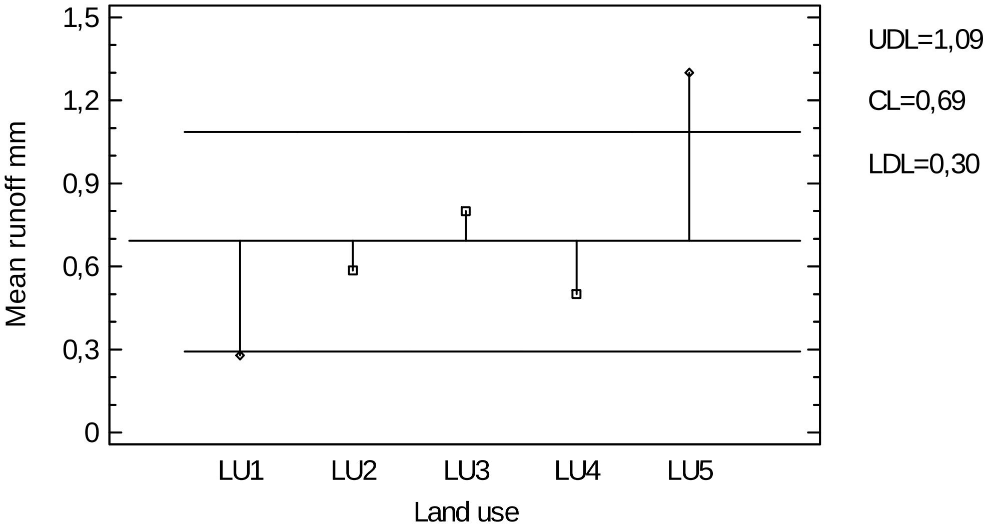


Figure 4.3. Analysis of means plot of runoff under the different land use type for the year 2003-2004.

The analysis of variance of the runoff data for assessing statistical significance of the effect of different land use type for the year 2004-2005 are given in Figure 4.4 . The average of runoff per rainfall event is 0.72 mm forLU1, 1.3 mm for LU2, 1.55 mm for LU3, 1.1 mm for LU4 and 2.4 mm for LU5. The analysis of variance indicate a similar trend as that of the year 2003-2004. So the value of LU1, LU2, LU3 and LU4 are significantly different than the value under the LU5 at P-Values 0.05. Also the value of LU1 is significantly different from the value of LU3 at P-Values 0.05 but the value of LU3 is not significantly different from those for LU2 and LU4.

The analysis of means plot Figure 4.5 for the year 2004-2005 also similar to that of the year 2003-2004, where the average value of runoff for LU1 is significantly lower than the over all mean runoff . As well as the average value of LU5 is significantly higher than the over all mean. The average values of LU2, LU3 and LU4 are within the grand average of runoff for this year

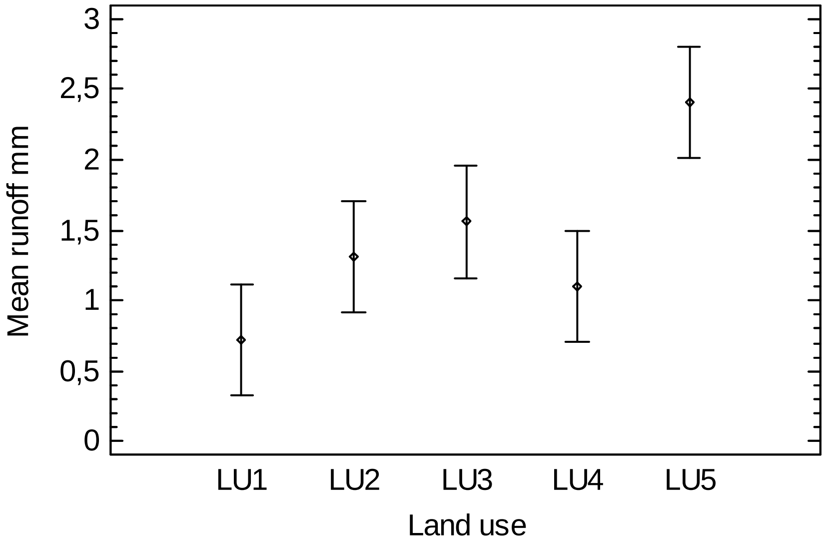


Figure 4.4. Analysis of variance of runoff under the different land use type for the year 2004-2005 (Means and 95% LSD intervals).

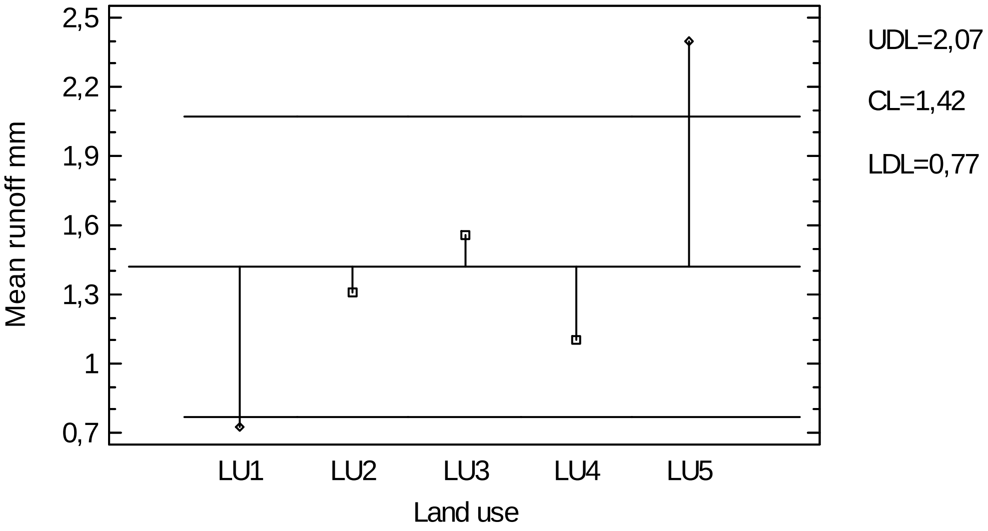


Figure 4.5. Analysis of means plot of runoff under the different land use type for the year 2004-2005.

The analysis of variance of runoff data for assessing significance of the effect of different years for each land use types are shown in Table 4.7. Since the ratio of variance interval does not contain the value 1, and the P-value is less than 0.05, for runoff values under LU1, LU2, LU3 and LU4 for the two rainy seasons, there is a statistically significant difference between the standard deviations of these land use types at the 95% confidence level. While the runoff values with LU5 are significantly different.

Table 4.7. Analysis of variance of different years in runoff under land use types.

Year	Runoff (mm)				
	LU1	LU2	LU3	LU4	LU5
2003-2004 2004-2005	0,28 0,72	0,58 1,30	0,79 1,55	0,49 1,10	1,30 2,4
Ratio of Variances	**(0,131691; 0,50731)**	**(0,215714; 0,830987)**	**(0,238709; 0,91957)**	**(0,173434; 0,668113)**	(0,281647; 1,08498)
F test value	0,26	0,42	0,47	0,34	0,56
P-value	**0,00009**	**0,012**	**0,027**	**0,0017**	0,085

The results indicate that the runoff value is the highest for LU5 followed by LU3, LU2, LU4 and LU1. The runoff value for LU5 is more than 3.5 and 2.2 of the values of LU1, and LU4 respectively.LU2 and LU4 tend to have a similar value of runoff. While the LU3 has a value in the middle of those for LU1 and LU5. The lower value of runoff under LU1 is properly due the higher value of the soil hydraulic conductivity, infiltration characteristics, and lower value of the bulk density of the soil under this land use as has been shown in the analysis of soil properties. In addition to the higher vegetation cover will intercept and lower the velocity and power of the rain drops. As well as the lower antecedent moisture content of soil under these land use, due the more water uptake by the plant, which lead to increase in the infiltration capabilities of the soil and lower the runoff under this land use type.

Terraced plot under LU4 were more effective in reducing runoff than vegetation cover under LU2 and LU3. The difference in runoff under LU4 and LU5 is mainly to the support practices represented by the terraces protection structure. So runoff under different land use type is attributed to the vegetation cover of each land use, soil hydraulic and infiltration properties, bulk density, and also to the support practices as terracing.

4.6 Effect of land use on erosion

Summary of the erosion data under the five land use type during the two years are given in Table 4.8. The data show the ability of land use surface to generate erosion varies with land use types. From the 41 rainfall events monitored during the 2003-2004 rainy seasons, 36% of the events generated erosion under LU1 and LU4 and 39%, 46%, 51% under LU2, LU3 and LU5 respectively. From 32 rainfall events monitored in 2004-2005 rainy season, 50 %

generated erosion for LU1, 53% under LU2 and LU4, and 59% under LU3 and LU5 respectively. The average value of erosion per rainfall event is 1.28 kg/ha for LU1, 6.9 kg/ha for LU2, 11.51 kg/ha for LU3, 2.96 kg/ha for LU4 and 21.19 kg/ha for LU5 for the year 2003-2004. Whereas the average value of erosion per rainfall event for the year 2004-2005 is 4.2 kg/ha for LU1, 15.96 kg/ha for LU2, 24.1 kg/ha for LU3, 6.65 kg/ha for LU4 and 50.6 kg/ha for LU5

The average, maximum and total values of erosion for all land use types in the year 2004-2005 are considerably higher than those respective to land use types in the year 2003-2004 rainy season. This was mainly due to the lower rainfall depth and runoff occurred in the rainy season of 2003-2004 in respect to that of 2004-2005. The erosion data under the five land use types were non-normally distributed; therefore transformation has been performed using the Cube root of the erosion value to provide a symmetrical distribution data. As well to decrees the difference of the standard deviations to be within the range of 1-3, as pre requirement for the analysis of variance and standard deviation comparison.

Table 4 .8. Summary of the erosion under the five land use during the two years.

Year/ Land Use Types	LU1	LU2	LU3	LU4	LU5
2003/ 2004					
No. of rain fall events	41	41	41	41	41
No. of events generated soil loss	15	16	19	15	21
% of events generated soil loss	36	39	46	36	51
Min. soil loss (kg/ha)	0	0	0	0	0
Max. soil loss (kg/ha)	7	58	82	17	125
Avrg. soil loss (kg/ha)	1,28	6,90	11,51	2,96	21,19
Total soil loss (kg/ha)	52.5	283	472	121.6	869
2004/ 225					
No. of rain fall events	32	32	32	32	32
No. of events generated soil loss	16	17	19	17	19
% of events generated soil loss	50	53	59	53	59
Min. soil loss (kg/ha)	0	0	0	0	0
Max. soil loss (kg/ha)	31	120	110	45	197
Avrg. soil loss (kg/ha)	4,20	15,96	24,09	6,65	50,62
Total soil loss (kg/ha)	134.6	511	771	213	1620

The analysis of variance for assessing the effect of land use types on erosion for the year 2003-2004 (Figure 4.6) shows that the LU1, LU2 and LU3 are significantly different from the LU5 at P-Values 0.05. Also the LU1 is significantly different than LU3, and the LU2, LU3 and LU4 are not significantly different from each other. Further more LU3 is not significantly different than LU5 at P-Values 0.05.

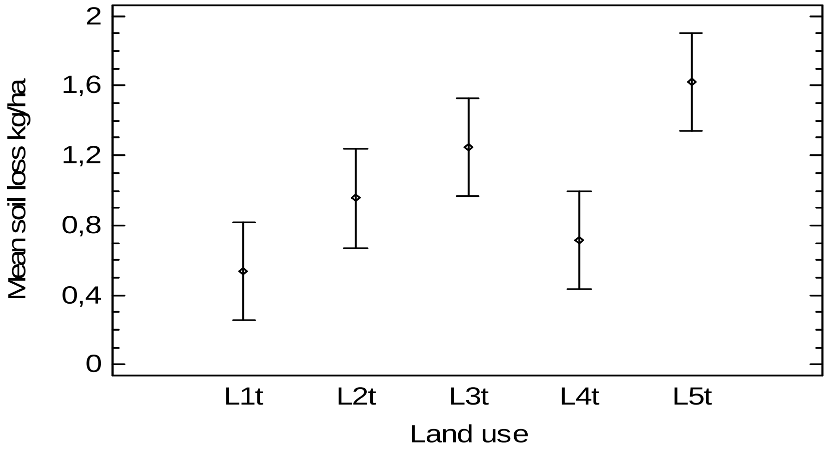


Figure 4.6. Analysis of variance of erosion under the different land use type for the year 2003-2004 (Means and 95% LSD intervals)

.

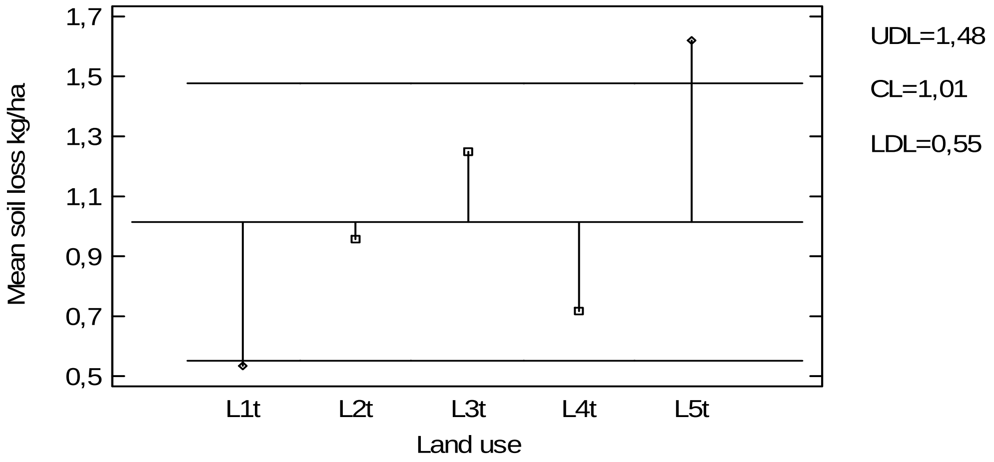


Figure 4.7. Analysis of means plot of erosion under the different land use type for the year 2003-2004.

The analysis of means plot (Figure 4.7) show The average value of erosion for LU1 is significantly lower than the over all mean erosion of this year for all land use types. While the average value of LU5 is significantly higher than the over all mean. The average values of LU2, LU3 and LU4 are within the grand average of the grand mean of r this year.

The analysis of variance of the erosion data for assessing statistical significance of the effect of different land use type for the year 2004-2005 are given in Figure 4.8. The analysis of variance indicates a similar trend as that of the year 2003-2004. So the value of LU1, LU2 and LU3 are significantly different from the LU5 at P-Values 0.05. Also the LU1 is significantly different than LU3, and the LU2, LU3 and LU4 are not significantly different from each other. Further more LU3 is not significantly different than LU5 at P-Values 0.05. In the same way the analysis of means plot (Figure 4.9) for is also similar to that of 2003-2004, where The average value of erosion for LU1 is significantly lower than the over all mean erosion of this year for all land use types. While the average value of LU5 is significantly higher than the over all mean. The average values of LU2, LU3 and LU4 are within the grand average of the grand mean of r this year.

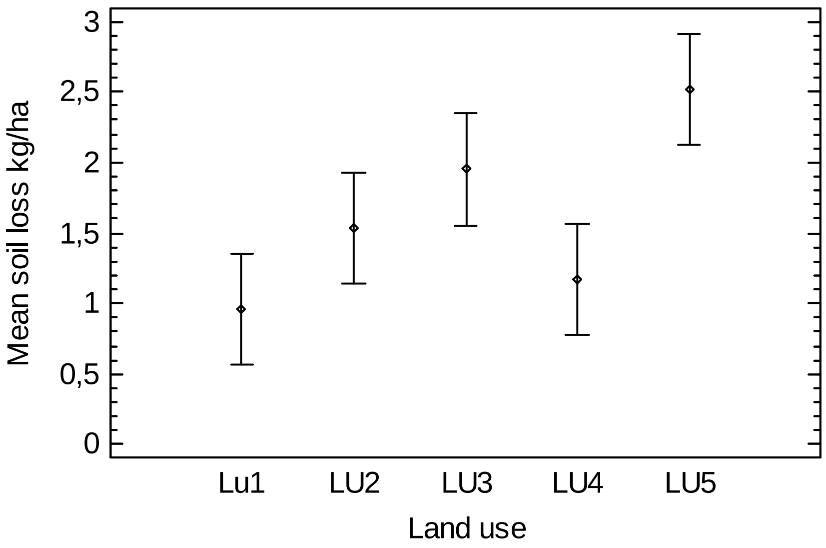


Figure 4.8. Analysis of variance of erosion under the different land use type for the year 2004-2005 (Means and 95% LSD intervals)

.

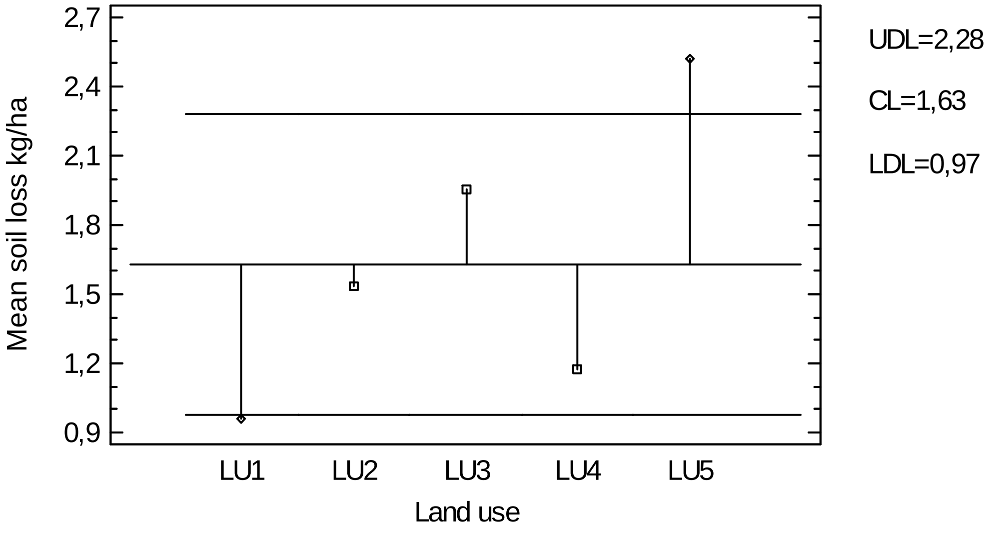


Figure 4.9. Analysis of means plot of erosion under the different land use type for the year 2004-2005.

The analysis of variance of erosion data for assessing significance of the effect of different years under each land use types are shown in Table 4.9. Since the ratio of variance interval contain the value 1, and the P-value is greater than 0.05, for erosion values under LU2, LU3, LU4 and LU5 for the two rainy seasons, there is a statistically significant difference between the standard deviations of the land use types at the 95% confidence level. While the erosion values with LU1 are significantly different.

Table 4.9. Analysis of variance of different years in erosion under each land use types.

Year	Erosion (kg/ha)				
	LU1	LU2	LU3	LU4	LU5
2003-2004 2004-2005	0,53 0,95	0,95 1,53	1,24 1,95	0,71 1,17	1,61 2,51
Ratio of Variances	**(0,177832; 0,625322)**	(0,326057; 1,25606)	(0,361233; 1,39157)	(0,34348; 1,32318)	(0,316437; 1,219)
F test value P-value	0,33 **0,0007**	0,64 0,19	0,71 0,32	0,68 0,25	0,63 0,16

The results indicate that the erosion value is the highest for LU5 followed by LU3, LU2, LU4 and LU1. The runoff value for LU5 is more than 13.5 and 7.5 of the values of LU1, and LU4 respectively. The low eroded materials under the forest LU1 is attributed to the stable aggregate, highest value of hydraulic and infiltration characteristics of the soil and to the dense vegetation cover. Many studies have confirmed that in a wide range of environments both runoff and sediment loss decrease exponentially as the percentage of vegetation cover increases (Francis and Thomes, 1990). While the difference between LU4 and LU5 is mainly due the terraces structures that prevent the soil movement away from the field which is present in LU4. Which indicate that the terracing practice played a very important role in protecting the soil from soil loss. The variation in runoff and sediment yields is attributed to the vegetation cover and land use management changes (Newson, 1985; Bryan and Campbell, 1986). Abu Hammad et al., 2005, showed the significant positive reduction of soil erosion under the terracing structure under the wheat field in the Palestinian territories. The terracing structure under LU4 generates less erosion than natural vegetation under LU2 without any support practices. This mainly due to the lower vegetation cover at the beginning of the rainy season under the natural vegetation. The low soil loss under LU2 compared to LU3 may be attributed to the high organic matter under LU2 and more stable aggregate as has been shown in the soil properties analysis, where the organic matter play as a cementing agent on soil aggregate stability, and reduce the slacking of aggregate from the kinetic energy of the rain drop.

The difference of run off and soil erosion under the different land use type is probably due to the difference in soil physical and hydraulic properties, % of land cover and absence or presence of the support practices like terracing structures. The result clearly show that under the absence or low vegetation cover as in vines yards and olive orchard, that the terracing structure could be very highly significant in reducing the runoff and consequently the soil erosion and improve the soil organic materials from being deteriorate and lost .

Most rainfall and runoff events occurred in the period from late October to early march in this region of the world. Whereas the soils cultivated with vine are almost bare, or the vegetation cover is not sufficient to protect the soil from raindrop impact. Therefore greater rates of runoff and sediment loss is expected in central hills cultivated with perennial crops that require frequent removal of annual vegetation (weed control) such as vines and olives, etc. creating favourable conditions for overland flow and soil erosion. Hence the land under cropping needs additional soil conservation measures to reduce runoff and erosion. The soil should be covered by the vegetation by not removing the weeds and adding mulch during the rainy period and implementing the terracing structures. Also increasing the porosity of the soil and improving the soil structure, this could be achieved by increasing the organic matter content of the soil, which improve the resistibility of the soil to erosion and increase water retention of the soil (Rose et. Al., 1997)

4.7 Interaction between runoff -erosion and potential cause factors

4.7.1 Correlation matrix

Correlation matrix analysis was undertaken to explore the direction, strength and significance of relationship between runoff, soil erosion and the potential variables that expected to contribute to the runoff and soil erosion phenomena. The most commonly-used measure of correlation is Pearson's r. Pearson's r assumes that the data follow bivariate normal distribution (Helsel and Hirsch, 1992. pp. 218). The correlation is high if it is can be approximated by a straight line (sloped upward or downward). This line called the regression line or least squares line. Initially, 24 variables were selected for the bivariate correlation analysis. The cube root of the entire variable has been used, since some of the variables are not normally distributed. Table 4.10 shows the correlation between the runoff, soil erosion and the possible influential indicators.

Runoff is show positive linear correlation with event rainfall depth, event duration, maximum I30 intensity, maximum I30 KE and soil erosion. The correlation between the runoff and the events rainfall intensity is relatively low, due to the fact the study area is characterized by low intensity of rainstorm in general as has been shown the analysis of rainfall in chapter III. Therefore the correlation between runoff generation and rainfall depth and storm duration were higher than the runoff correlation with rainfall intensity. This indicates the runoff is generally related to the total amount and duration of the storm. The runoff also shows a fairly negative correlation with slope, slope length, vegetation cover and support practices, where these main factors of soil erosion generation, as has been shown in the Literature review, chapter I. The negative correlation of runoff with these factors, demonstrate that the decrease in vegetative cover and support practices and increase in slope and slope length will increase the amount of runoff.

The soil erosion shows a strong and significant positive correlation with runoff, rainfall event depth, rainfall event duration. It also show a positive correlation with maximum I30 intensity, maximum I30 KE. Also the erosion demonstrates a fair negative correlation with slope, slope length, vegetation, and support practices. The correlation between erosion and runoff is better than others parameters, which mean that the erosion is more dependent on the amount of runoff generated.

Table 4.10. Correlation Matrix of runoff and soil erosion and selected influential cause parameters.

No.	parameter	Runoff	Soil Erosion
1	Event depth	**0.87**	**0.84**
2	Event duration	**0.82**	**0.79**
3	Intensity	0.36	0.34
4	Max.I30 intensity	**0.76**	**0.74**
5	Event KE	0.35	0.32
6	I30KE	**0.71**	**0.69**
7	θ_0	0.22	0.20
8	Runoff	1	**0.96**
9	Soil erosion	**0.96**	1
10	Slope	-0.32	-0.37
11	Slope length	-0.34	-0.39
12	Vegetation%	-0.38	-0.40
13	Aggr% <0.5	0.14	0.25
14	Clay	-0.16	-0.3
15	γ	0.15	0.21
16	θ_s	-0.15	-0.20
17	OM	-0.18	-0.21
18	K_s	-0.16	-0.23
19	I_{in}	-0.15	-0.21
20	I_s	-0.14	-0.21
21	Support practices	**-0.40**	**-0.45**
22	Kr	0.15	0.24
23	Ki	0.13	0.18
24	Shear Stress	-0.19	-0.24

Cube root used for all variables listed above (significant correlation at $p<0.05$)

4.7.2 Rainfall-runoff relationships

The relationships between rainfall and runoff are expressed by the runoff coefficient. Runoff coefficient defined as a percentage of precipitation measured as surface runoff. Exploring the relationships between rainfall and runoff (R_0/R_f), considered very important in selecting the best management practices. The cube root of the variables has been used for analysis of variance. Table 4.11 show the summary statistics of runoff to rainfall ration for both rainy seasons. The highest maximum values were observed under LU5, and the lowest were observed under LU1 for both years.

Table 4.11. Runoff to rainfall ratio (R_0/R_f) % under the five land use during the two years.

Year/ Land Use Types	LU1	LU2	LU3	LU4	LU5
2003/ 2004					
Min. (R_0/R_f)	0	0	0	0	0
Max. (R_0/R_f)	7,7	13,2	23	12,8	33,3
Avrg. (R_0/R_f)	1,48	3,03	4,6	2,75	7,68
2004/ 225					
Min. (R_0/R_f)	0	0	0	0	0
Max. (R_0/R_f)	10	29	26	22	40
Avrg. (R_0/R_f)	2,73	5,36	6,51	4,45	10,27

The analysis of means plot (Figure 4.10) for 2003-2004 show that the average value of (R_0/R_f) for LU1 is significantly different to that of the LU3 and LU5 and non significant than those for the LU2 and LU4. The average of value of (R_0/R_f) for LU5 is significantly higher than the over all mean. The analysis of mean plot (Figure 4.11) for 2004-2005 of the average values of (R_0/R_f), demonstrate a similar trend as that of the year203-204.

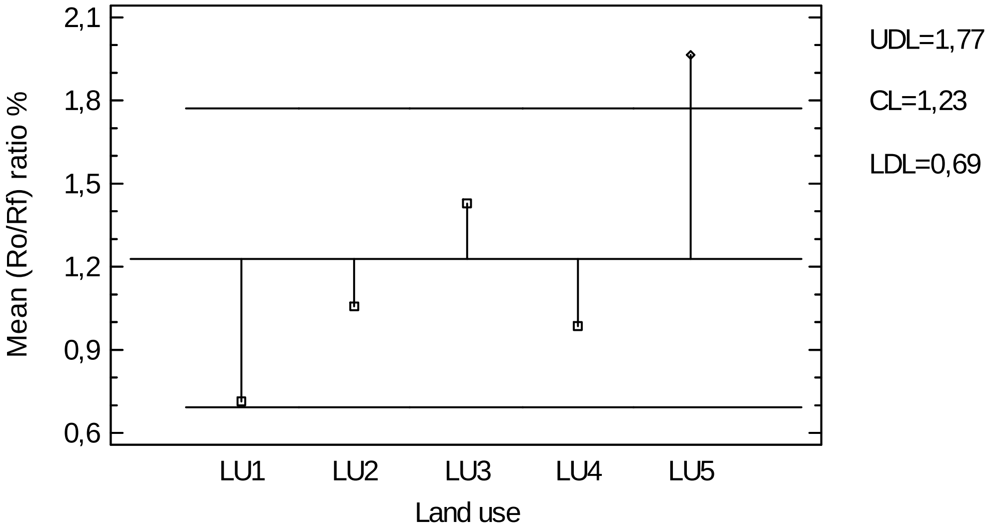


Figure 4.10. Analysis of means plot of (R_0/R_f) % under the different land use type for the year 2003-2004.

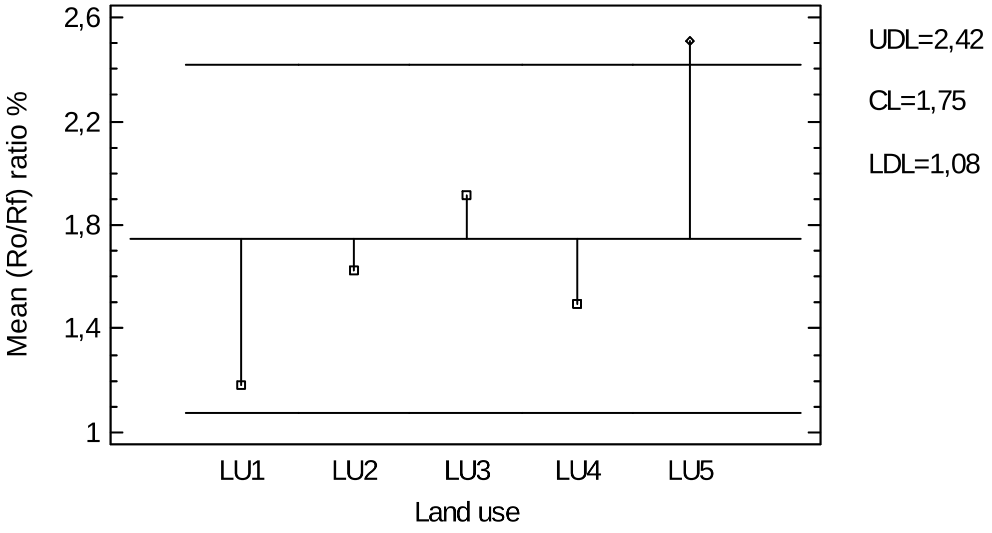


Figure 4.11. Analysis of means plot of (R_0/R_f) under the different land use type for the year 2004-2005.

The analysis of variance for assessing the difference between (R_0/R_f) values for each land use under the two years is given in Table 4.12. The result indicates that the ratio is significantly different between the two years for all the land use types. The reason of the difference between the two years is the total rainfall depth, which was higher for the year2004-2005.

Table 4.12. The analyses of variance of (R0/Rf) ratio for each land us of the two years.

Year	(R_0/R_f) ratio %				
	LU1	LU2	LU3	LU4	LU5
2003-2004	0,714818^{a}	1,05583 ^{a}	1,43001 ^{a}	0,984294 ^{a}	1,96564 ^{a}
2004-2005	1,18633^{b}	1,62253 ^{b}	1,91553 ^{b}	1,4961 ^{b}	2,51158 ^{b}
F test valu	0,729229	0,694784	0,911924	0,796847	0,956582
P-value	0,344577	0,276524	0,775366	0,494493	0,884932

* Means followed by the same letter in the same column are not significantly different.

4.7.3 Regression analysis

Based on the strong correlation between runoff and rainfall depth, and soil erosion and runoff, simple regression for these two sets applied. This test performed to extract the threshold value of rainfall depth that will result in no runoff, and the threshold value of runoff that will result in no soil erosion under the different land use types and to examine the strength of those relationships.

Linear regression model has been found suitable for fitting the relation between rainfall, runoff and erosion data. The model for simple linear regression is:

$$Y = a + bX + e$$

Where Y is the predicted value of the dependent variable, X is the independent variable, a is the intercept, b is the coefficient estimated by the regression equation or the slope of the regression line and it can be interpreted as the rate of changes of the dependent variables due to change of the independent variable and e is the random error. The performance of the model fit is evaluated by computing the coefficient of determination (R^2) and standard error of estimate (σ). The greater the value of R^2 and the smaller the value of σ, the better the relation between the variables involved. The cube root of the variables has been utilized in performing the test.

4.7.3.1 Linear regression between runoff and rainfall depth

The regression model between the rainfall depth and the runoff under the different land use types for the year 2003-2004 are given in Table 4.13. The fit were good with R^2 0.75 for LU1, 0.77 for LU2, 0.79 for LU3, 0.74 for LU4 and 0.83 for LU5.

Table 4.13. Regression fits for the rainfall depth (x_1) vs. runoff (y) for the year 2003-2004.

Land use types	Regression equations	R^2	σ
LU1	$y = -1{,}1108 + 0{,}546148\ x_1$	0.75	0,22
LU2	$y = -1{,}4174 + 0{,}70431\ x_1$	0.77	0,26
LU3	$y = -1{,}2679 + 0{,}761421\ x_1$	0.79	0,27
LU4	$y = -1{,}3532 + 0{,}662574\ x_1$	0.74	0,27
LU5	$y = -1{,}3463 + 0{,}884581\ x_1$	0.83	0,28

The regression equation is expected to provide a reasonable prediction of the runoff .The value of threshold rainfall depth that will result in no runoff is generally depend on the characteristic of each land use. Based in the regression equation the threshold value of rainfall depth calculated as (–a/b).The threshold value of rainfall depth for which the runoff is zero is 8.4 mm for LU1, 8.1 mm for LU2, 4.6 mm for LU3, 8.5 mm for LU4 and 3.5 for LU5.The threshold values of rainfall depth for zero runoff based on the regression fit for all land use types tend to be different. This indicates that the values of runoff are much affected by the type of land use.

As it has been shown that the runoff potential in the area is mostly dependent on the rainfall depth. So to understand how the rainfall depth affects the runoff, the runoff potential of rainfall depth, ψ, is calculated from the regression equation. It is defined as an increment in rainfall depth of a storm necessary to generate additional unit of runoff (1 mm) for a given land use type. The value of ψ calculated as the reciprocal of the slope of the regression line (b). The values ψ is 6.2 mm for LU1, 2.9 mm for LU2, 2.3 mm for LU3, 3.5 mm for LU4 and 1.5 mm for LU5. The value of ψ for LU1 is about 4 times greater than that under LU5 and 2.7 than that under LU3. This mean to produce an additional 1 mm of runoff under LU1, the increment in rainfall depth should be 4 times of that under LU5 and 2.7 times of that under LU3.

The regression model between the rainfall depth and the runoff under the different land use types for the year 2004-2005 are given in Table 4.14. The fit were good with R^2 0.81 for LU1, 0.76 for LU2, 0.80 for LU3, 0.78 for LU4 and 0.83 for LU5. The values of R^2 indicates that the regression fits between rainfall depth and runoff data for various land use types were almost similar compared with those of the year 2003-2004.

Table 4.14. Regression fits for the rainfall depth (x_1) vs. runoff (y) for the year 2004-2005.

Land use types	Regression equations	R^2	σ
LU1	$y = -1{,}173 + 0{,}571405\ x_1$	0.81	0,25
LU2	$y = -1{,}35197 + 0{,}677813\ x_1$	0.76	0,33
LU3	$y = -1{,}18185 + 0{,}704016\ x_1$	0.80	0,30
LU4	$y = -1{,}31178 + 0{,}645178\ x_1$	0.78	0,30
LU5	$y = -1{,}18265 + 0{,}788869\ x_1$	0.83	0,32

The threshold value of rainfall depth for which the runoff is zero is 8.6 mm for LU1, 8 mm for LU2, 4.7 mm for LU3, 8.3 mm for LU4 and 3.3 for LU5. The values ψ is 5.3 mm for LU1, 3.2 mm for LU2, 2.8 mm for LU3, 3.7 mm for LU4 and 2 mm for LU5. The threshold value of rainfall depth and the ψ for the different land use type during the year 2004-2005 are similar to those of year 2003-2004.

4.7.3.2 Linear regression between erosion and runoff

Regression fit between erosion and runoff data for the year 2003-2004 are shown in Table 4.15. The values of R^2 0.95 for LU1, 0.97 for LU2, 0.95 for LU3, 0.97 for LU4 and 0.94 for LU5. The fits generally are highly significance, which indicate that the erosion is highly dependent on the amount of runoff generated by the given event.

The threshold runoff value for no erosion based on regression fit is 0.17 mm for LU1, 0.28 mm for LU2, 0.1 mm for LU3, 0.5 mm for LU4 and 0.16 mm for LU5. The values are somewhat low, and show that for all land use types erosion will start shortly after the runoff produced. The erosion potential of runoff, ε, is defined as an incremental runoff necessary to generate unit amount of additional erosion (1kg or1tonne) for a given land use type. It is calculated as the reciprocal of slope of the regression line (b). The values of ε is (0.23 mm/kg or 235 mm/tonne) for LU1, (0.9 mm/kg or 90 mm/tonne) for LU2, (0.075 mm/kg or 74 mm/tonne) for LU3, (0.18 mm/kg or 183 mm/tonne) for LU4 and (0.06 mm/kg or 63 mm/tonne) for LU5. The difference in ε values for different land use type is mainly due to the difference of soil properties and the management's practices under each land use types.

Table4.15. Regression fits for the runoff (x_1) vs. erosion (y), for the year 2003-2004.

Land use types	Regression equations	R^2	Σ
LU1	$y = -0,910+ 1,62x_1$	0.95	0,15
LU2	$y = -1,471 + 2,23 x_1$	0.97	0,21
LU3	$y = -1,12+ 2,38x_1$	0.95	0,33
LU4	$y =- 1,432+ 1,76 x_1$	0.97	0,17
LU5	$y = -1,38 + 2,51x_1$	0.94	0,41

The regression fits between erosion and runoff for the year 2004-2005 are given in Table 16. The values of R^2 0.92 for LU1, 0.94 for LU2, 0.95 for LU3, 0.93 for LU4 and 0.93 for LU5. The values were almost the similar to those in the year 2003-2004, which also support that the erosion is highly dependent on the amount of runoff generated. Based in the regression fits the threshold value of runoff for zero erosion is 0.55 mm for LU1, 0.7 mm for LU2, 0.4 mm for LU3, 0.9 mm for LU4 and 0.3 mm for LU5. The value under the different land use type is very low, which indicate that the soil eroded as the runoff generated.

The erosion potential value of runoff, ε, is (0.2 mm/kg or 196 mm/tonne) for LU1, (0.1 mm/kg or 90 mm/tonne) for LU2, (0.06 mm/kg or 68 mm/tonne) for LU3, (0.18 mm/kg or 183 mm/tonne) for LU4 and (0.04 mm/kg or 46 mm/tonne) for LU5.

Table4.16. Regression fits for the runoff (x_1) vs. erosion (y), for the year 2004-2005.

Land use types	Regression equations	R^2	σ
LU1	$y = -1,41037 + 1,72\ x_1$	0.92	0,28
LU2	$y = -1,9834 + 2,23\ x_1$	0.94	0,36
LU3	$y = 1,81 + 2,44\ x_1$	0.95	0,35
LU4	$y = -1,7213 + 1,76\ x_1$	0.93	0,30
LU5	$y = -1,89 + 2,79\ x_1$	0.93	0,59

The result show that for a given amount of incremental runoff, the additional erosion under LU5 will be about 4 times more than that under LU1, and nearly 3.5 times more than under LU5. This indicate that the vegetation cover and support practises is highly effective in preventing the soil from being eroded. The sight difference in the values ε between the two years could be to the difference of total rainfall depth between the two years.

4.8 Conclusion

The presence of annual vegetation and plant residues on the soil surface and the terracing structures is responsible for the reduction of soil loss to very low *values*; and therefore further degradation of the land is restricted. The results confirm the existence of a strong positive relation between rainfall depth and runoff and sediment loss for particular different kinds of land use, and between runoff and soil loss with the presence or absence of the support practices as terraces in the region.

The lowest rates of runoff and sediment loss were found under Forest grown under semi-natural conditions, i.e. with undestroy vegetation of annual plants, under this land use, annual vegetation and plant residues have a high soil surface cover, occasionally up to 85% of the ground, so preventing surface sealing and minimizing the velocity of the runoff water. The greatest rates of runoff and soil erosion were observed under vine yard none terraced, which possess conditions most favourable for water runoff and sediment loss.

The decrease in vegetation cover and increase in mechanical activities under the cultivated land use resulted in significant decrease in the soil organic matter, aggregate stability, and the hydraulic conductivity and total porosity and effective porosity of the soil.

Despite the existing variation of the collected data, attributed to different soil surface properties, slope grade and length, there is a tendency of increasing runoff and sediment loss with decreasing vegetation cover and insufficient preventive, where the soil surface remains bare and thus very susceptible to raindrop impact, runoff and soil erosion. The application of suitable management practices (terraces, vegetation cover and others) is essential to minimize the erosivity of the rainfall and reduce runoff and erosion.

In conclusion when the cultivated land utilized without the use of proper practices of securing organic matter and soil stability, they are easily threatened and exposed to runoff and soil erosion. Therefore the measure should be implemented to sustain the land and prevent them from degradation.

Soil erosion modelling represents a very important part of the soil erosion research, and in selecting the best management practices for the soil resources. The next chapter will test some of the modelling techniques and procedures for predicting the soil erosion and runoff on the rainfall event basis in the study area. Moreover to select the best procedure fit the study environment, for predicting the soil erosion under the similar condition in the study region.

Chapter 5---

Soil erosion modeling

5 Soil erosion modeling

5.1 Introduction

Soil erosion by water represent a key threat to long term efficiency of the soil. Controlling water erosion to preserve soil quality and to maintain land productivity is therefore a great challenge and one of the most pressing environmental issues. To help combat this threat, land use managers, and soil conservation specialist, need a quantitative perceptive of the problem and how it interacts with different land use and management to either decreased or increased. Soil erosion can be reduced by proper land management and adapting best management practices. The evaluations of different land use and management scenarios need accurate soil loss estimation. Field measurements of erosion and sedimentation using classical techniques is difficult, time-consuming and expensive (Bujan et al., 2000). Among the available tools to assess soil erosion, prediction models have become important because adequate and reliable models can be used to evaluate a variety of management scenarios without costly and lengthy field tests. The modelling of erosion processes has progressed rapidly and a variety of models have been developed to predict runoff, and soil loss (Zhang et al., 1996).

The Water Erosion Prediction Project (WEPP, Nearing et al., 1989), very well validated erosion prediction model and one of the most utilized tools for simulating runoff and soil water erosion (Merrit et al., 2003). WEPP is a process-based continuous simulation model and is gaining popularity worldwide for the use of state-of-the art technology. The Artificial Neural Network (ANN) is an emerging modelling technique that may be very well suited for soil erosion prediction in the study area. The ANN technique is now being applied successfully to a wide range of application in environmental and planning fields.

It is essential to evaluate soil erosion prediction models before their application. In this chapter we evaluated the suitability and efficiency of the WEPP and ANN modelling techniques in simulating runoff, and water erosion under the different land use in the central highland mountains in the Palestinian territories. First approximation of ability of the WEPP and ANN models for simulating soil loss and runoff in the study region is presented. Predicted soil loss and runoff values were compared with the measured soil loss and runoff values. Models were evaluated on the basis of individual rainfall events.

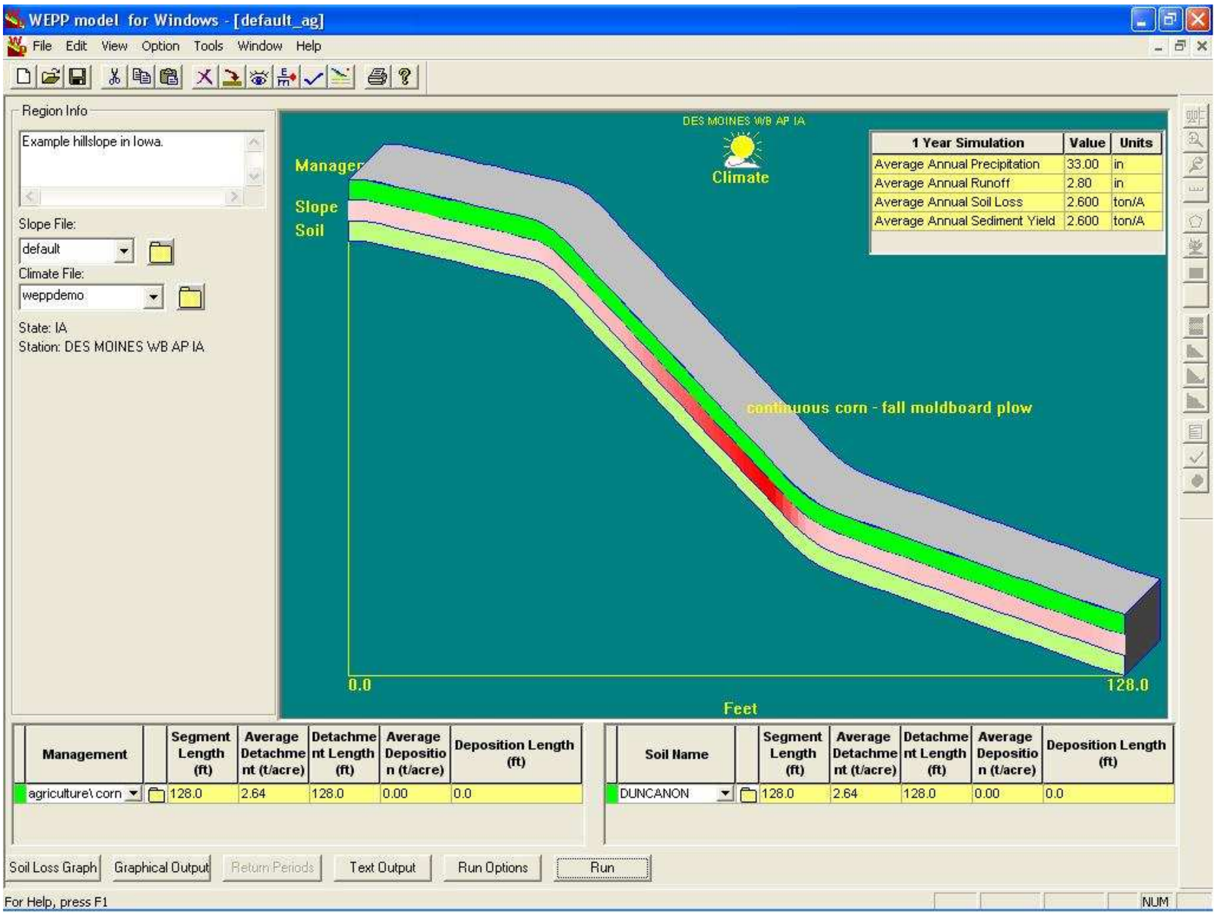
5.2 Validation of the hillslope WEPP model

5.2.1 Model description and mechanism:

WEPP software consists of an erosion prediction model, a climate generator program (CLIGEN) written in the FORTRAN programming language, and a Windows interface written in the Visual C++ programming language (Flanagan and Frankenberger 2002). The main Windows interface screen shows a graphical illustration of a hillslope profile, with various areas providing access to input databases and output display (Figure 5.1). The profile shape is drawn based upon the model slope inputs, which can be accessed through the middle layer on the graphic. Soil information can be accessed through the bottom layer on the graphic, and the cropping/management information through the top profile layer. Climate inputs can be selected or generated through the icon at the top centre of the screen. The horizontal profile length dimensions are provided at the bottom of the screen in either English or metric units.

The major inputs entered into WEPP are specified in four data files: climate, slope, soil, and plant management. The climate file requires daily values for precipitation, maximum and minimum temperature and solar radiation. The slope file provides the topographic input to the model, including the length and gradient of the hillslope. The soil file contains information on the physical characteristics of the surface soil and soil layers. The surface soil parameters required are the effective hydraulic conductivity, interrill erodibility (sheet erosion mostly caused by raindrop impact), rill erodibility (small eroded channels), critical shear stress (rill detachment threshold factor), and albedo (fraction of solar radiation reflected back to the atmosphere). For each soil layer, the inputs required are cation exchange capacity (CEC) and the percentages of sand, clay, organic matter, and rock fragments. The management file contains information needed to define management and plant growth factors, such as tillage, biomass energy ratio, and decomposition rate and, with more than 50 parameters, is the most complex input file.

For each day that has a precipitation event, WEPP determines whether the event is rain or snow and calculates the infiltration and runoff. If there is runoff, WEPP routes the runoff over the surface and calculates erosion and deposition rates for the event, and the average sediment yield that is delivered from the surface. Soil loss, sediment deposition, and sediment yield (off-site delivery) are calculated for each runoff event and added to a series of sum totals.



Region Info

Example hillslope in Iowa.

Slope File: default

Climate File: weppdemo

State: IA

Station: DES MOINES WB AP IA

1 Year Simulation	Value	Units
Average Annual Precipitation	33.00	in
Average Annual Runoff	2.80	in
Average Annual Soil Loss	2.600	ton/A
Average Annual Sediment Yield	2.600	ton/A

Management	Segment Length (ft)	Average Detachment (t/acre)	Detachment Length (ft)	Average Deposition (t/acre)	Deposition Length (ft)
agriculture\ corn	128.0	2.64	128.0	0.00	0.0

Soil Name	Segment Length (ft)	Average Detachment (t/acre)	Detachment Length (ft)	Average Deposition (t/acre)	Deposition Length (ft)
DUNCANON	128.0	2.64	128.0	0.00	0.0

Figure 5.1 WEPP Windows Interface.

5.2.2 Input data for the model

WEPP developed to overcome spatial and temporal limitation of many previous models like USLE and EPIC. It is essential to evaluate soil erosion prediction models before their application. In this section the WEPP is used for simulating soil loss and testing the capability of the models in predicting soil losses form single storm rainfall events under the five different land use types in the Palestinian Central Highland mountainous area. The land use types considered are forest (LU1), natural vegetation (LU2), Olive groove (LU3), vine yard terraced (LU4) and vine yard non-terraced (LU5).

Data collected from the study area used to construct the climate files for single event simulations of WEPP. Amount and duration of rainfall, maximum and minimum temperature, solar radiation, wind velocity and dew temperature are required on a daily basis. Two years of actual data were applied in the simulations. Soil input file and slope file were also prepared using graphical user interface included in the model. Model parameters such as organic matter content, percentage clay, percentage silt, percentage sand, and percentage rock fragment were obtained from the soil analysis data and also from the soil data base prepared by the Land

Research Centre (LRC, 2002, unpublished).The baseline effective hydraulic conductivity, interrill erodibility parameter, rill erodibility parameter, and critical flow hydraulic shear stress values for WEPP were estimated as described in the WEPP user manual (Anonymous, 1995).Management input files were built for the different land use types from the management data and information obtained from the study area. Due to the lack of some information about the land use data required to prepare the management file, a suitable management data from the WEPP database and user manuals (Anonymous, 1995) that matched the adopted land use condition were used.

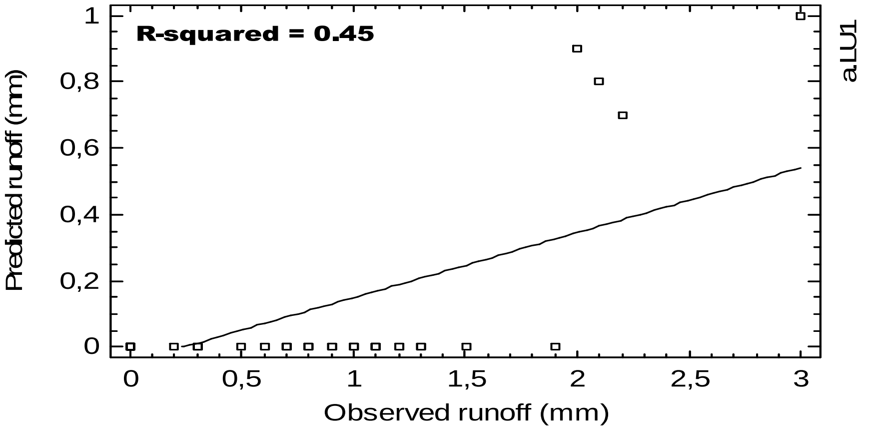
5.2.3 Evaluation criteria

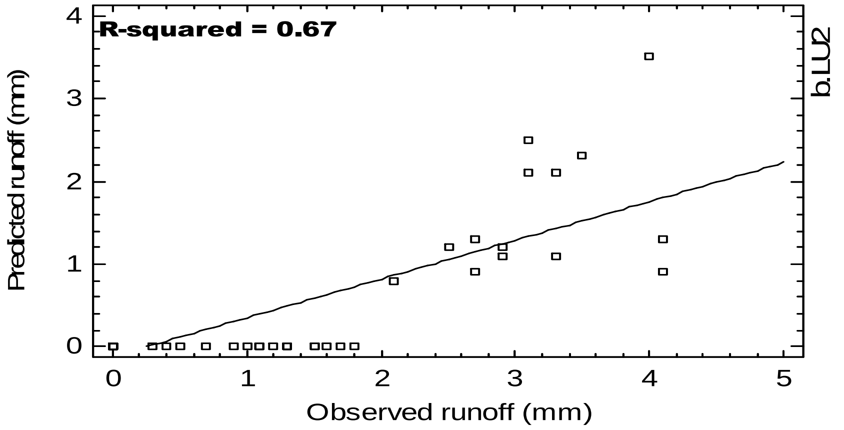
After the input files had been prepared, runoff and soil loss were simulated for all rainfall events in 2003-2005 for the different land use types. The models were evaluated by fitting regression equations between the predicted values and the observed values. The goodness of fit of the equations to the data is evaluated from the values of coefficient of determination and the standard error of estimate. The greater the values of R^2, the better will be the fit of the data to the equations, and the closer the simulated values to observed values. Also the slope of the regression equations (b) closes to unity means unbiased the prediction. When the slope values <1, they indicate under prediction, and when the slope is>1, they indicate over prediction. Quantitatvely to test the model performance and efficiency, and to find whether there are statistically significant differences between the observed and predicted values. The analysis of variance was performed by comparing the Standard Deviations of the observed and predicted values under each land use types. Of particular interest of this test is the confidence interval for the ratio of the variances. If the ratio of variances does not contain the value 1, there is a statistically significant difference between the standard deviations of the two samples at the 95% confidence level.

5.2.4 WEPP results

Runoff

The plot of the observed and predicted soil loss values computed using the WEPP model for all land use types are shown in Figure 5.2. The WEPP Hillslope model simulated fewer runoff events than measured for all land use types during 2003–2005. In particular, runoff values were underestimated by the WEPP model as shown by the slope values of the regression equations (Table 5.1) and small runoff events (<2 mm) were mostly missed. This type of model response was also observed by Soto and Dı`az-Fierros (1998) were runoff events (<1 mm) were simulated with no runoff, and by Grønsten and Lundekvam were small runoff events (<5 mm) were mostly missed (2006). The WEPP model simulated less surface runoff than measured for all land use types, (Table 5.2). Association between measured and simulated runoff was best under LU5, with 50% of measured surface runoff (R^2 = 0.67). Simulated surface runoff for the other four land use types, LU1, LU2, LU3 and LU4 was 10, 34, 38 and 30% respectively, of measured values. Testing the statistically difference between the observed and predicted values shows that there is a significance difference between observed and predicted values for all land use types as indicated by the ratio of variances (Table 5.1). Since the ratio of variances dose not contain the value of 1, this signify that the predicted values are not within the range of observed values.





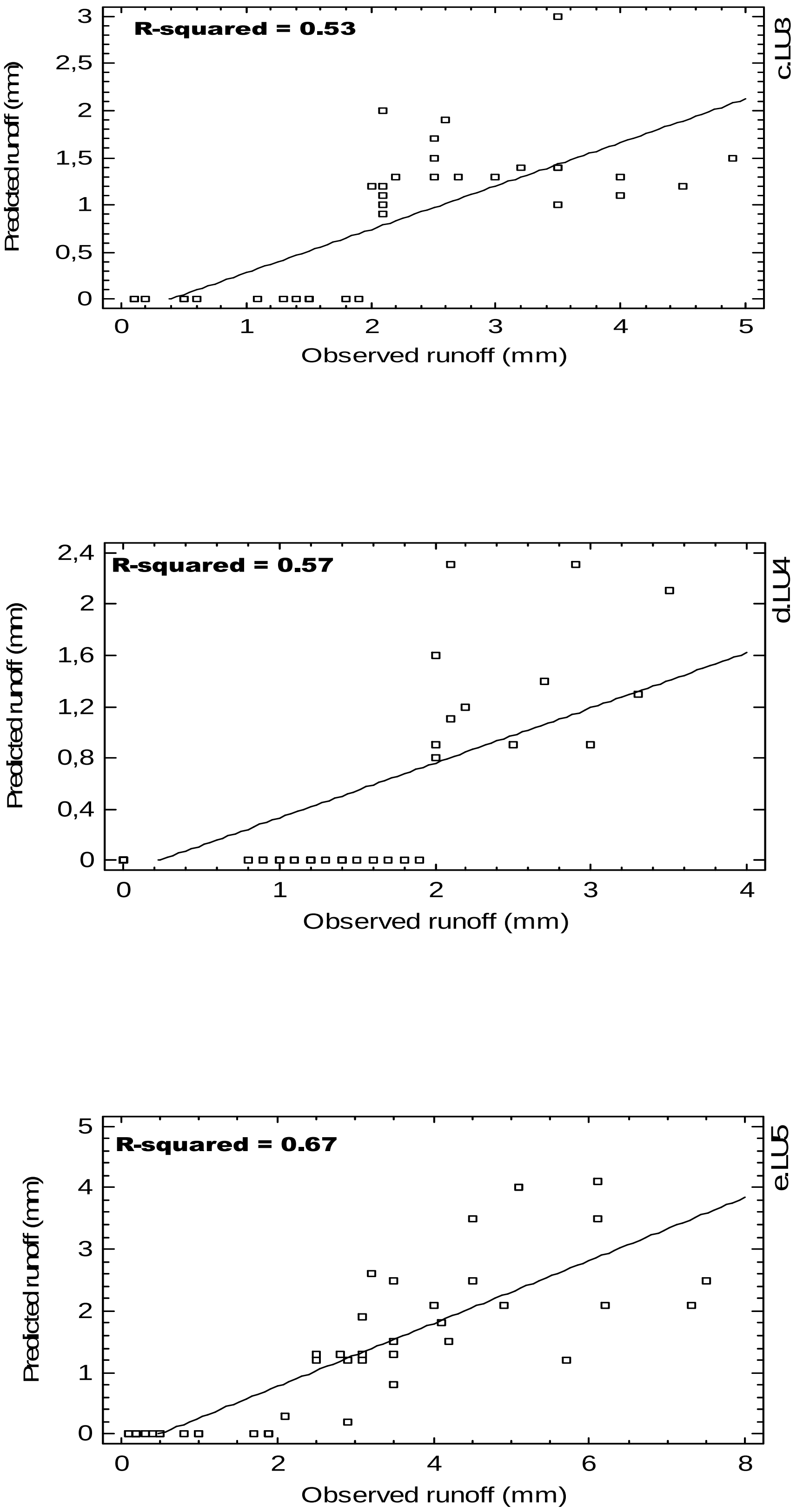


Figure 5.2. Observed vs.WEPP Predicted runoff under the five land use types

Table 5.1 Summary statistics of the WEPP model validation for runoff according to the land use types.

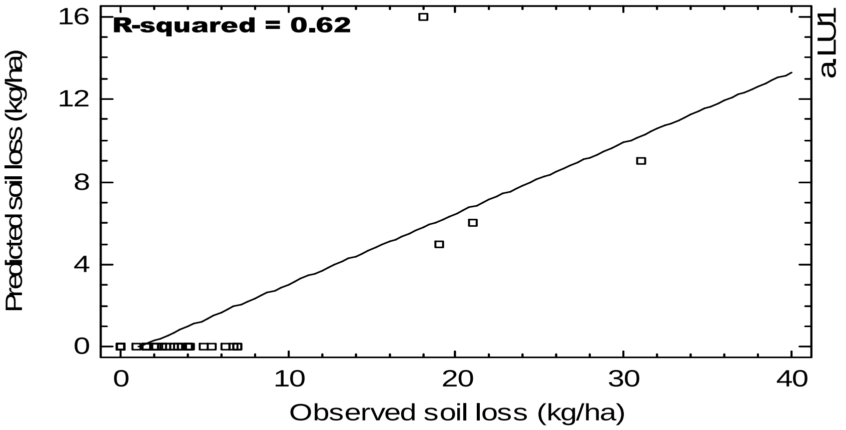
Statistics	LU1	LU2	LU3	LU4	LU5
R2	0.45	0.67	0.53	0.57	0.67
σ	0,146666	0,409234	0,54	0,374029	0,737677
b	0,195736	0,468384	0,459995	0,42877	0,511398
Ratio of variances	[7,38851; 18,7505]	[1,93524; 4,91121]	[1,32119; 4,80471]	[1,94334; 4,93177]	[1,41328; 4,7468]

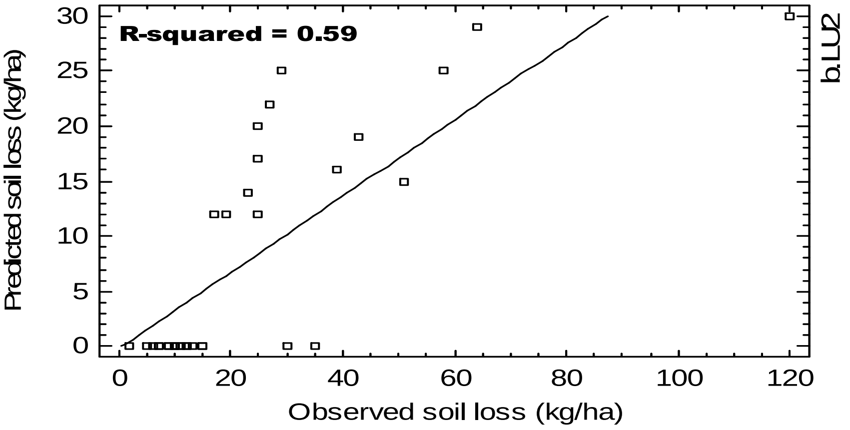
Table 5.2 Measured ($_M$) and simulated ($_S$) total runoff (R_O) and soil loss (SL) for the period 2003-2005

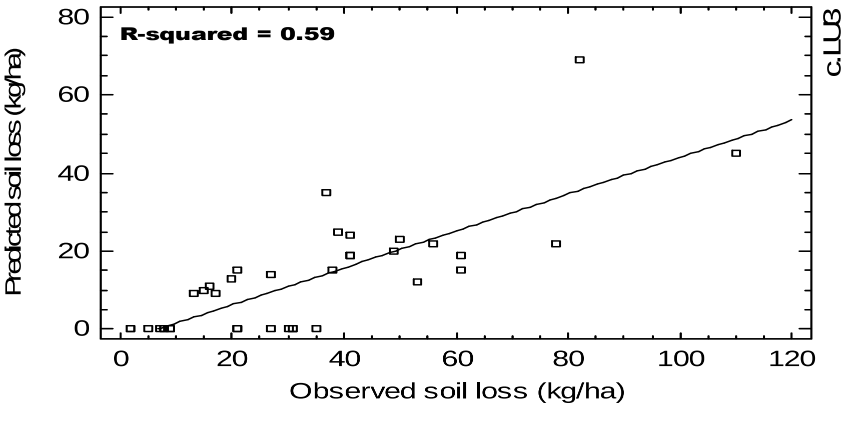
Land use types	R_{OM}(mm)	R_{OS}(mm)	R_{OS}/ R_{OM}(mm)	SL_M(kg/ha)	SL_S(kg/ha)	SL_S/ SL_M(kg/ha)
LU1	34.6	3.4	0.10	187.1	36	0.20
LU2	65.9	22.3	0.34	794	268	0.34
LU3	82.5	31	0.38	1283	465	0.37
LU4	55.7	16.8	0.30	334.6	83	0.25
LU5	130.2	65.6	0.50	2489	1143	0.46

Soil loss

The WEPP Hillslope model underpredicted runoff, and consequently, soil loss for the five land use types. Soil loss was underestimated as shown by the slope values of the regression equations (Table 5.3) and, in some cases, the model completely failed to predict soil loss, predicting values equal to 0 (Figure 5.2). This type of model response was also observed by Bowen et al. (1998), Bhuyan et al. (2002), Chikratar (2004) and Romero León (2005). The WEPP model simulated less soil loss than measured for all land use types, (Table 5.2). Association between measured and simulated soil loss was best under LU5, with 46% of measured total soil loss ($R^2 = 0.75$). Simulated soil loss for the other four land use types, LU1, LU2, LU3 and LU4 was 20, 34, 37 and 25% respectively, of measured values. Testing the statistically difference between the observed and predicted values shows that there is a significance difference between observed and predicted values fro all land use types as indicated by the ratio of variances (Table 5.3). Since the ratio of variances dose not contain the value of 1, this signify that the predicted values ate not within the range of observed values.


R-squared = 0.62
a.LU1
Predicted soil loss (kg/ha)
Observed soil loss (kg/ha)
0
4
8
12
16
0
10
20
30
40


R-squared = 0.59
b.LU2
Predicted soil loss (kg/ha)
Observed soil loss (kg/ha)
0
5
10
15
20
25
30
0
20
40
60
80
100
120


R-squared = 0.59
c.LU3
Predicted soil loss (kg/ha)
Observed soil loss (kg/ha)
0
20
40
60
80
0
20
40
60
80
100
120

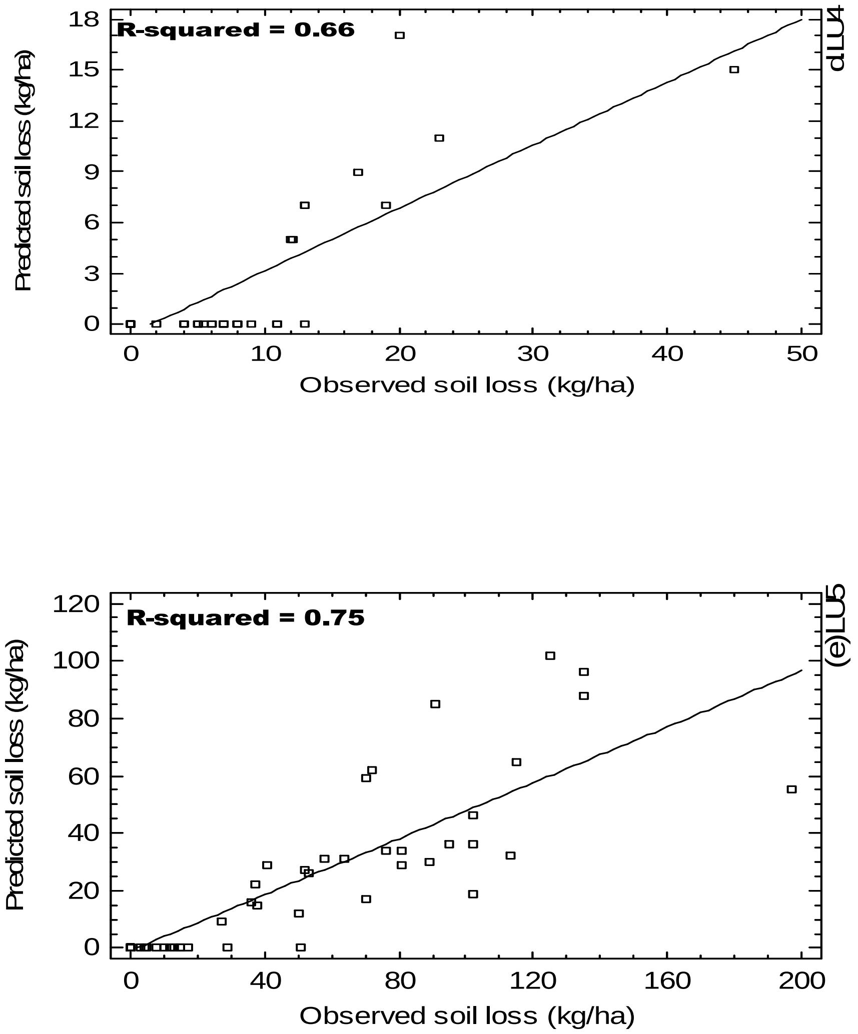


Figure 5.3 observed vs. WEPP predicted soil loss under the five land use types.

Table 5.3 Summary statistics of the WEPP model validation for soil loss according to the land use types.

Statistics	LU1	LU2	LU3	LU4	LU5
R2	0.62	0.59	0.59	0.66	0.75
σ	1,41584	6,71316	9,55895	1,95342	12,7812
b	0,341972	0,345612	0,472434	0,371057	0,487796
Ratio of Variances	[3,3586; 8,52341]	[2,46406; 10,1017]	[1,37927; 5,10637]	[3,05035; 7,74113]	[1,98794; 5,04496]

Due to variability and uncertainty of erosion data under field conditions, an error in model prediction up to 50% has been considered acceptable by some researchers (Kothyari *et al.*, 1993). At best, any predicted runoff or erosion value, by any model, will be within only plus or minus 50 percent of the true value (Elliot et al. 2000). The failure in predicting the soil loss and runoff under the studied condition could be to the reason that of the model are mostly dependent on the high rainfall intensity. According to Risse et al. (1994), some studies have indicated that events comprising long periods of low intensity rainfall could lead to redistribution of the wetting profile (due to the nature of the modified Green–Ampt equation) present in the WEPP model, and therefore, could be contributing to underestimation of runoff for larger events. As it has been shown in the previous chapters, that high intensity rainfall is almost absence in the study area and in this part of the world. Therefore surface runoff and erosion were mostly due to low-intensity rainfall with long duration and high rainfall depth.

In general, the WEPP Hillslope model simulated fewer runoff events than measured on under the five land use types. Hence, the WEPP Hillslope model did not give satisfactory estimates of surface runoff and soil loss in the study area.

5.3 Validation of the artificial neural network (ANN)

5.3.1 ANN description and mechanism

An artificial neural network (ANN) is a biologically inspired computational system that relies on the collective behaviour of a large number of processing elements (called neurons), which are interconnected in some information-passing settings (Hassan, 2001). The basic idea of an ANN is that the network learns from the input data and the associated output data, which is commonly known as the generalization ability of the ANN. Multilayer Perceptrons is perhaps the most popular network architecture in use today. To develop and train a NN involve, choosing a training set that contains input–output pairs; defining a suitable network (number of layers and number of neurons in each layer); training the network to relate the inputs to the corresponding outputs by estimating the NN weights; and testing the identified NN. Typically the data available for NN calibration is split in three parts, one for training, one for testing and one for validation.

As shown in Fig. 5.4, three-layered feed forward neural networks with one hidden layer, which have been used in this research for the prediction of water runoff and soil loss, provide a general framework for representing nonlinear functional mapping between a set of input and output variables. The explicit expression for an output value of network model is given by:

$$\boxed{\hat{y}_k = f_o\left(\sum_{j=1}^{M} w_{kj} \bullet f_h\left(\sum_{i=1}^{N} w_{ji}x_i + w_{jo}\right) + w_{ko}\right)}$$

where w_{ji} is a weight in the hidden layer connecting the *i*th neuron in the input layer and the *j*th neuron in the hidden layer, w_{jo} is the bias for the *j*th hidden neuron, f_h is the activation function of the hidden neuron, w_{kj} is a weight in the output layer connecting the *j*th neuron in the hidden layer and the *k*th neuron in the output layer, w_{ko} is the bias for the *k*th output neuron, and f_o is the activation function for the output neuron. The weights are different in the hidden and output layer, and their values can be changed during the process of network training.

Because there are no physical rules between inputs and outputs in designing ANNs, the relationship of the available input variables and output variables is generated by the training process. In this study, the process of training ANNs is accomplished by a backpropagation algorithm, as shown in Fig. 5.4. The weights are adjusted so as to make the actual response ($\hat{y}_k$) of the network closer to the desired response (y_k). The objective of the backpropagation training process is to adjust the weights of the network to minimize the sum of square errors of the network as seen in the next equation, which approximates the model outputs to the target values with a selected error goal.

$$\boxed{E(n) = \frac{1}{2}\sum_{k=1}^{k}\left[y_k(n) - \hat{y}_k(n)\right]^2}$$

where $y_k(n)$ is the desired target responses and $\hat{y}_k$ is the actual response of the network for the *k*th neuron at the *n*th iteration. The cyclic process of feed forward and error back propagation are repeated until the verification error is minimal (Liu et al., 2003).

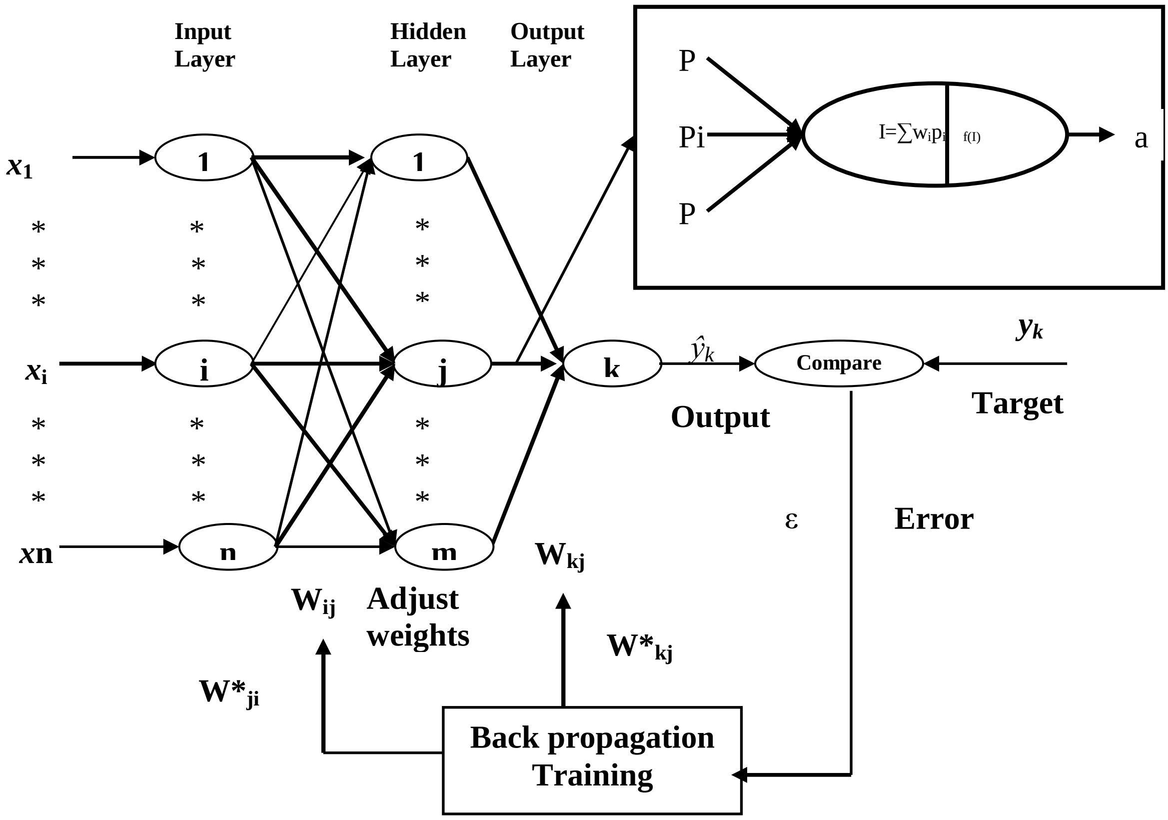


Fig (5.4): Typical three layered feed forward neural networks with a back propagation training algorithm

Each hidden node (j) receives signals from every input node (i) which carries scaled values ($\overline{X}_i$) of an input variable where various input variables have different measurement units and span different ranges. $\overline{X}_i$ is expressed as:

$$\overline{X}_i = \frac{X_i - X_{\min(i)}}{X_{\max(i)} - X_{\min(i)}}$$

Each signal comes via a connection that has a weight (W_{ij}). The net integral incoming signals to a receiving hidden node (Net_j) is the weighted sum of the entering signals, $\overline{X}_i$, and the corresponding weights, W_{ij} plus a constant reflecting the node threshold value (TH_j):

$$Net_j = \sum_{i=1}^{n} \overline{X}_i W_{ij} + TH_j$$

The net incoming signals of a hidden node (Net_j) is transformed to an output (O_j) from the hidden node by using a non-linear transfer function (*f*) of sigmoid type (Najjar and Zhang, 200), given by the following equation form:

$$O_j = f(Netj) = \frac{1}{1+e^{-Netj}}$$

This function then turns this number into a real output via some algorithm. This algorithm takes the input and turns it into a zero or one, a minus one or one, or some other number.
Qj passes as a signal to the output node (k). The net entering signals of an output node (Net_k)

$$Net_k = \sum_{i=1}^{n} O_j W_{jk} + TH_k$$

The net incoming signals of an output node (Netk) are transformed using the sigmoid type function (figure 5.5) to a standardized or scaled output ($\overline{O}_k$) that is:

$$\overline{O}_k = f(Net_k) = \frac{1}{1+e^{-Netk}}$$

Then, $\overline{O}_k$ is de-scaled to produce the target output:

$$O_k = \overline{O}_k (O_{max(k)} - O_{min(k)}) + O_{min(k)}$$

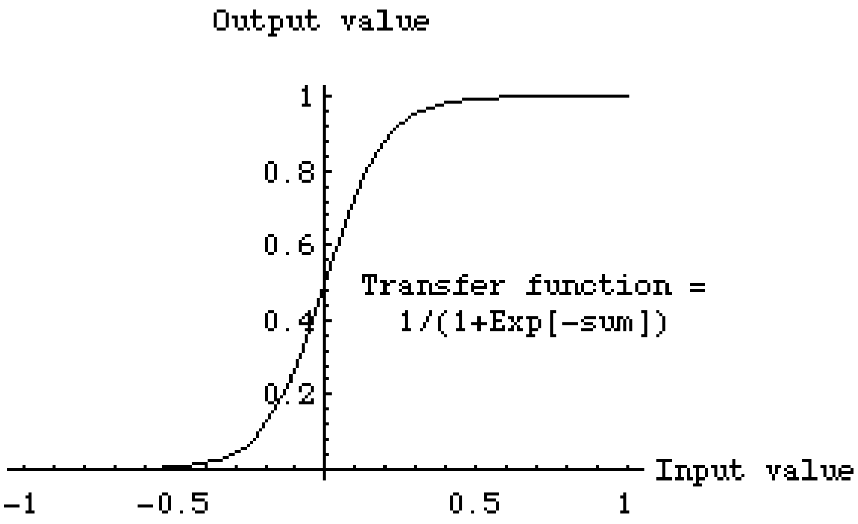


Figure 5.5 Sigmoid transfer functions

The neurons in a layer share the same input and output connections, but do not interconnect among themselves. Each layer performs specific functions. All the nodes within a layer act synchronously, meaning at any point of time they will be at the same stage of processing.

5.3.2 ANN program

The analysis accomplished by using the TR-SEQ1 artificial neural network programme, developed by Professor Yacoub Najjar from Kansas State University-USA (Najjar, 1999). The program capable of performing simultaneous sequential training and testing. It is a comprehensive, powerful and less time consuming package and characterized by intelligent problem solver that can guide step by step through the procedure of creating a verity of different networks and choosing the network with the best performance (Eila, 2005).The program use Multilayer Preceptrons (MLPs) network architecture with back propagation feed forward algorithm for training the network. The data is specified in two files, the SPEC.dat file which is used for data description and specification and configuration of the network. The second file is the STP.dat, and it is used to enter the intended data and utilized for the executing the training and testing phases of the network development.

Running the program include three phases training, testing and validation. Training is carried out on part of the data with aim to determine the connection parameters and the optimal number of hidden nodes of the network using the optimization technique. Testing phase is performed with the optimal number of the hidden nodes and connection weights determined in the testing phase on the second part of the data to check the network determined at the training phase. The validation phase is carried out for building the model using a cross verification technique to generalize and validate the network performance against the third set of data, which has not been used in the training and testing processes at all. In our work the is divided into parts as follow, 50% for training, 25% for testing and 25% for validation.

The program produces the following files: Result.dat which contains both observed and predicted values of the desired output for training and testing phases. The trisht.out file include history information and it provide the statistical measurement (R2, ASE and MARE), of the performance of the network for training and testing. The trent1.net file contains the connection weights between the neurons.

5.3.3 Evaluation criteria

Building the ANN model requires a clear definition of the criteria by which the performance of the model will be judged, as they can have a significant impact on the model architecture and weight optimization techniques selected (Maier and Dandy, 2000). Coefficient of determination (R-square), Average Squared Error (ASE) and the Mean Absolute Relative Error (MARE) on both training and testing data sets to used to select the most promising optimal networks. The optimal ANN model’s structure that resulted in minimum error and maximum efficiency during both training and testing was selected for validation. The values of both ASE and MERE close to zero indicate a better performing model. The values of R^2 range from 0 to 1, with higher values close to 1 indicating better model performance. Graphical representation also used for plotting, the predicted and actual outputs values for training, testing and validation sets for the selected most promising networks. To check the significance of the selected models, the analysis of variance testing the standard deviation of the observed versus predicted values performed. Of particular interest of this test is the confidence interval for the ratio of the variances. If the ratio of variances does not contain the value 1, there is a statistically significant difference between the standard deviations of the two samples at the 95% confidence level.

5.3.4 Network development

In this section we developed two types of networks. Type one is Global networks and it considered the whole data set from the five land use types, and type two is Individuals and it considered each land use types individually. Under type one three networks were developed: NET1 consider predicting both runoff and erosion, NET2 predict runoff only and NET3 predict erosion only. Input file for NET1 consisted of 365 rainfall events values and of 10 input parameters including: rainfall event depth, event duration, maximum 30 minute intensity, incident soil moisture, slope, slope length, support practices, maximum 30 minute intensity kinetic energy, vegetation cover and maximum daily temperature. Input file for NET2 were developed with the first 9 parameters which has been already considered for NET1 and excluding the maximum daily temperature. The input parameters for NET3 were the same 10 parameters used for developing the NET1, except that the maximum daily temperature was replaced by the average daily wind speed.

Input file for each individual land use type designed for simulation both the runoff and soil loss, consisted of a small number of data set (73 rainfall events). The number of input parameter used for developing the network for each land use type was only 6 for NETLU1 and NETLU3, as we did not take in to consideration slope steepness, slope length, and vegetation cover, which is mainly constant for these two land use. In the other hand the number of input parameters for developing the network for NETLU2, NETLU4 and NETLU5 were 7, as we considered the vegetation cover, since it is changeable with the period of the rainy season under these land use. All the rainfall events were considered either they are yielding runoff and soil loss or not in training the network, in to train the network with an ideal situation.

The main soil erosion factor which has been mentioned through out the literature has been the basis for developing the soil loss and runoff networks. Input parameters were carefully studied and effect of additional parameters that are considered very important by WEEP model were investigated (Table5 .4). The maximum daily temperature has shown a positive contribution to the performance of NET1. The average daily wind speed also contributed positively to the performance of NET3. Introduction of the other variables did not result in the improvement of the networks estimation, and in fact some of the parameters were negatively contributing to the network results.

Table 5.4 Effect of some of the parameters considered by WEPP in ANN networks

COMINATION	NET1	NET2	NET3
NETs with the 9 Parameters	81	87	88
Clay%	78	87	88
Bulk density	81	86	87
Total Porosity	78	87	88
OM%	78	85	88
H. conductivity	78	84	88
Max. Temperature	87	83	87
Min. Temperature	82	85	84
Avg. Wind speed	82	85	90
Kr	78	84	88
Ki	80	87	87

Sensitivity analysis was carried out to determine the effect some of the additional parameters, in addition to the classical soil loss factors that are normally considered on the performance of the NETs. Kinetic energy of the maximum 30 minute intensity was the most influential parameter that contributes to the performance of all the networks. As an example of the analysis, Table.5.5 show the result of analysis for NET1, that the maximum 30 minute Kinetic energy is the most influential parameters followed by incident soil moisture, Maximum 30 minute intensity, maximum daily temperature and rainfall event duration.

Table 5.5 Significance of the selected parameters on the NET1 performance

Input	R^2 testing	ASE testing
NET1	87	0.004482
NET1 – **Max I30KE**	72	0.000024
NET1 – Incident moisture	75	0.008659
NET1 – Max.I30	76	0.006653
NET1 - Temperature	81	0.006300
NET1 –Event duration	81	0.007289

As mentioned by (Florentina M. et., 1999), the number of neurons in the hidden layers cannot be achieved from a universal formula but in this research for running the MLP network we used the formula recommended by Najjar, 1999 to estimate the initial number of neurons, to prevent over-fitting. Najjar suggested that the initial appropriate number of neurons in a hidden layer can be calculated by (T – O)/(I+O+1), where T is the number of training set, O is the number of output variables and I is the number of input variables. It was noticed that the number of neurons in the hidden layer is influencing the quality of the result and the performance of the networks. Hence in order to select the network with the best performance, each network were trained and simulated with different number of neuron and net work architecture.

5.3.5 Artificial neural network results

5.3.5.1 Global networks

In order to develop the network with the best performance, network were trained and simulated with different number of neuron and net work architecture. Table 5.6 show results obtained for various architecture for the NET1. It is indicated that the model with 8 neuron in the hidden layer and 500 iteration give the best result among the trained models with minimum average squared error (0.004482) and high coefficient of determination (R^2=0.87) for the testing phase.

Table 5.6 NET1 testing phase with different architecture and neuron in the hidden layer.

Model	Architecture	Iteration	Nbr.Initial neurons	Nbr.Optimal neurons	ASE Testing	R^2 Testing
1	10-1-2	500	1	8	**0.004482**	**0.87**
2	10-2-2	1000	2	6	0.00562	0.85
3	10-3-2	1900	3	4	0.007988	0.77
4	10-4-2	9900	4	6	0.004889	0.86
5	10-5-2	10000	5	7	0.006731	0.79
6	10-6-2	9900	6	10	0.005605	0.83
7	10-7-2	1000	7	7	0.005899	0.83
8	10-8-2	400	8	8	0.00875	0.77
9	10-9-2	400	9	9	0.007481	0.76
10	10-10-2	100	10	10	0.007710	0.78

Table 5.7 present the architecture of the optimal models of the three global networks. The network with a 5 neuron in the hidden layer and 1100 iteration was found to be the best network of NET2. The optimal network for NET3 is obtained with 10 neuron in the hidden layer and 800 iteration.

Table 5.7 Global networks optimal model architecture

Net	Architecture	Iteration	Nbr.Initial hidden nodes	Nbr. Optimal Hidden nodes	ASE training	ASE testing
NET1	10-1-2	500	1	8	0.000765	0.004482
NET2	9-1-1	1100	1	5	0.001290	0.005825
NET3	10-10-1	800	10	10	0.000370	0.003144

Table 5.8 shows the performance and the efficiency of NET1 and NET2 in predicting the runoff. It shown that there is no significance difference between NET1 and NET2 in predicting runoff at the training and testing phases. While the NET2 performed some how better than NET2 at the validation phase.

Table 5.8 Summary statistics of the global NET1 and NET2 of observed versus predicted runoff.

	NET1			NET2		
Statistics	Training	Testing	Validation	Training	Testing	Validation
R2	0.96	0.89	0.80	0.96	0.87	0.86
Slope(b)	1,00336	0,815207	0,815207	0,976707	1,06147	0,85769
Ratio of variances	[0,781541; 1,39999]	[0,491545; 1,12913]	[0,770646; 1,77026]	[0,738611; 1,32097]	[0,851708; 1,95647]	[0,566678; 1,30172]

The runoff were very well predicted by both NET1 and NET2 as indicating by the slope of the regression fit equation between the observed values and predicated values for all phases of the network development (Table 5.8). Graphical representation of the observed versus predicted runoff values for both NET1 and NET2 is shown in figure 5.6 and figure 5.7. Testing the statistically significance difference between the observed and predicted values, shows that the predicted values are highly matching to the observed values and there is no significance difference between the observed and predicted runoff values as indicating by the ratio of variances for all phases (Table 5.8). Given that the ratio variances contain the value of 1; this confirms that the predicted values are not significantly different from the observed values.

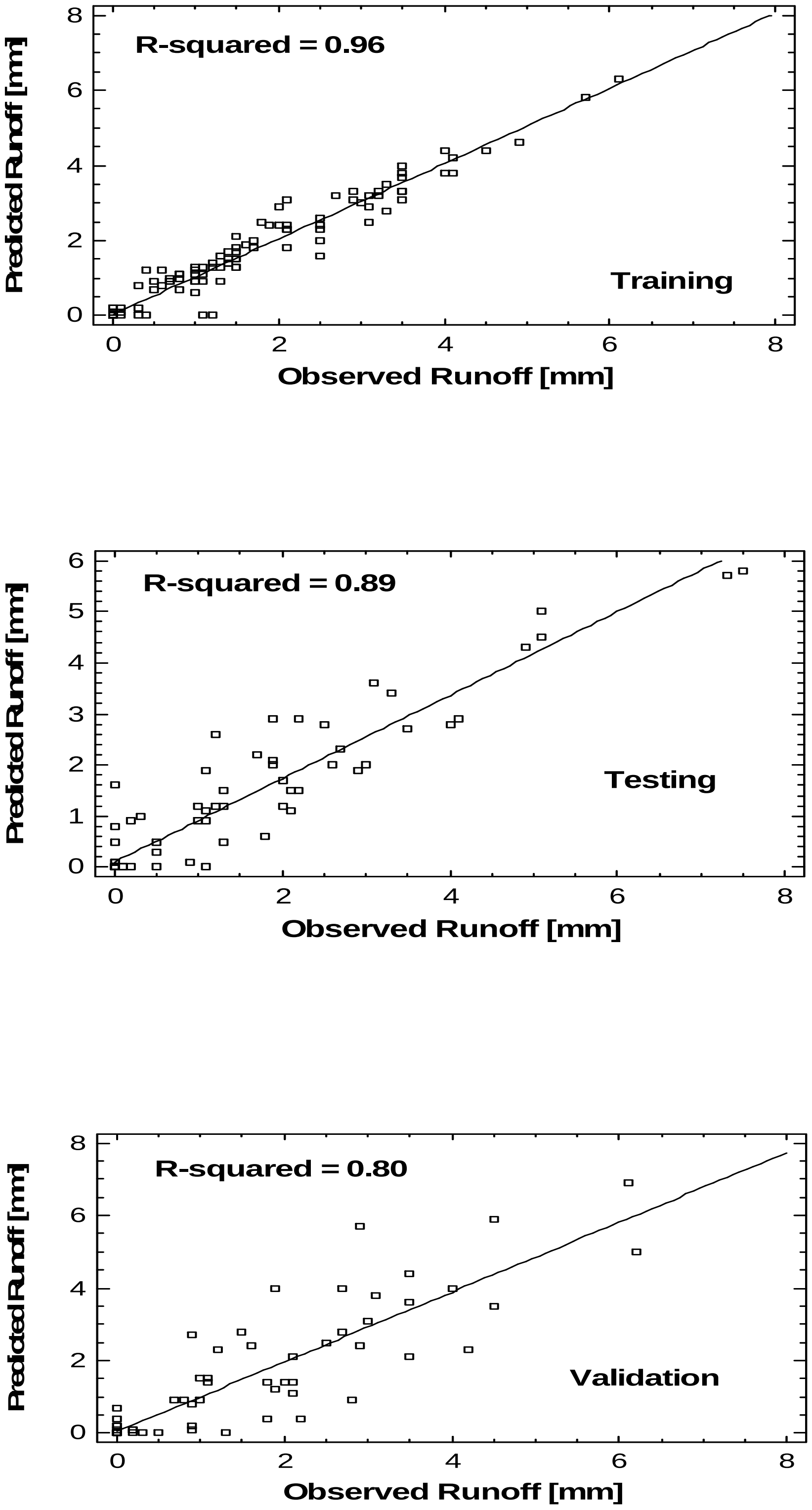
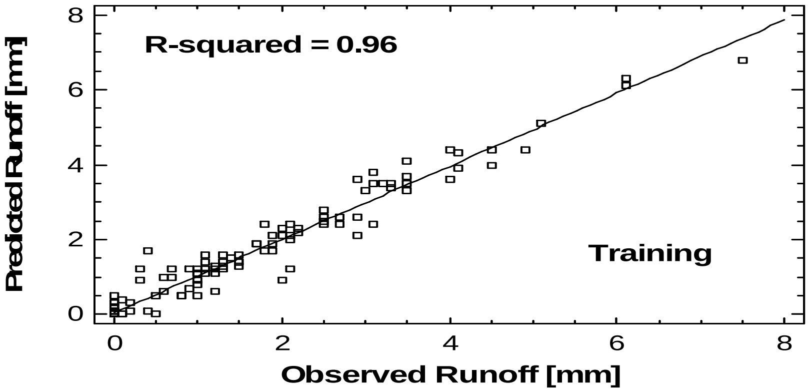
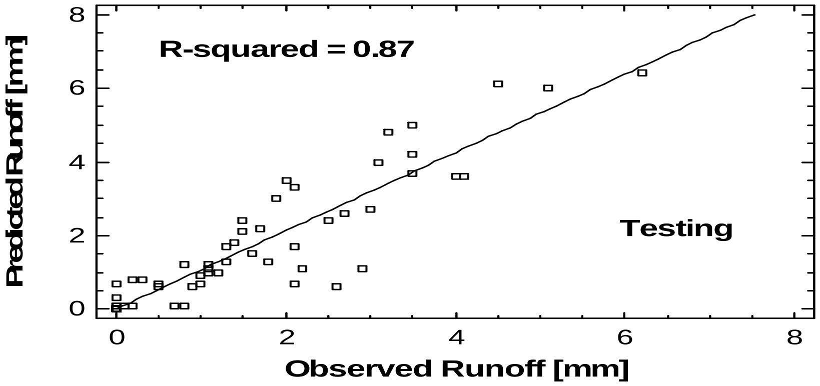


Figure 5.6.Measured versus predicted runoff values by Global NET1 model.





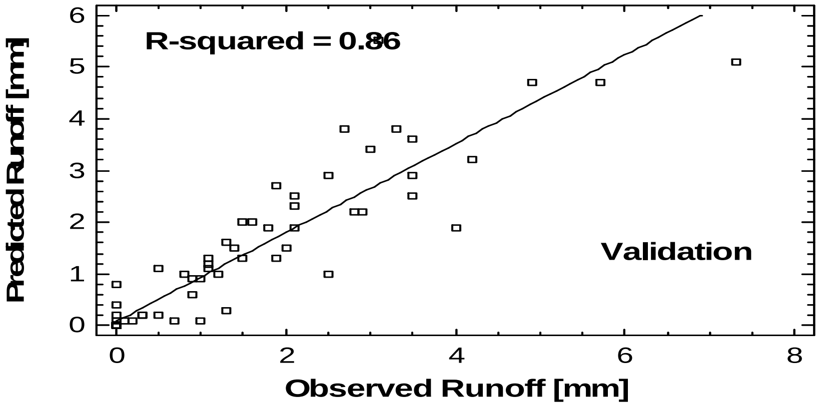


Figure 5.7.Measured versus predicted runoff values by Global NET2 model.

The plot of observed versus predicted soil loss values computed using NET1 and NET3 for the combined data from all land use types are shown in figure 5.8 and figure 5.9. Table 5.9 shows the performance and the efficiency of NET1 and NET3 in predicting the soil loss. It revealed that there is no significance difference between NET1 and NET3 in predicting soil loss at all the phases of the network development, and the both models almost perform similarly.

Table 5.9 Summary statistics of the global NET1 and NET3 of observed versus predicted soil loss.

	NET1			NET3		
Statistics	Training	Testing	Validation	Training	Testing	Validation
R2	0.98	0.86	0.91	0.98	0.84	0.90
Slope(b)	0,997674	0,997674	1,31079	0,98435	0,966492	1,25401
Ratio of variances	[0,754081; 1,3508]	[0,754081; 1,3508]	[1,23947; 2,8472]	[0,736612; 1,31951]	[0,731971; 1,68142]	[1,14728; 2,63542]

The slope of the best fit regression equation for all phases of network development for both NET1 and NET3 indicate that the predicted values are very well matching to the observed values and almost unbiased for both the training and testing data set of NET1 and Net3, and only slight over prediction of the few soil loss rainfall events for the validation data set for both of the models.

Table 5.9 also shows the values of ratio variance between the observed and predicted values of NET1 and NET3 for all phases of the network development. These values indicate that there is no significance difference between the predicted and observed values for all phases of the network, as the ratio contains the value of 1.

The result obtained from all the global nets (NET1, NET2 and NET3) are significant for both runoff and erosion prediction. Therefore these models performed very well and there results were highly significance. The phase of training was very well predicted by the 3 network, since it contain the largest portion of the data set (50%).

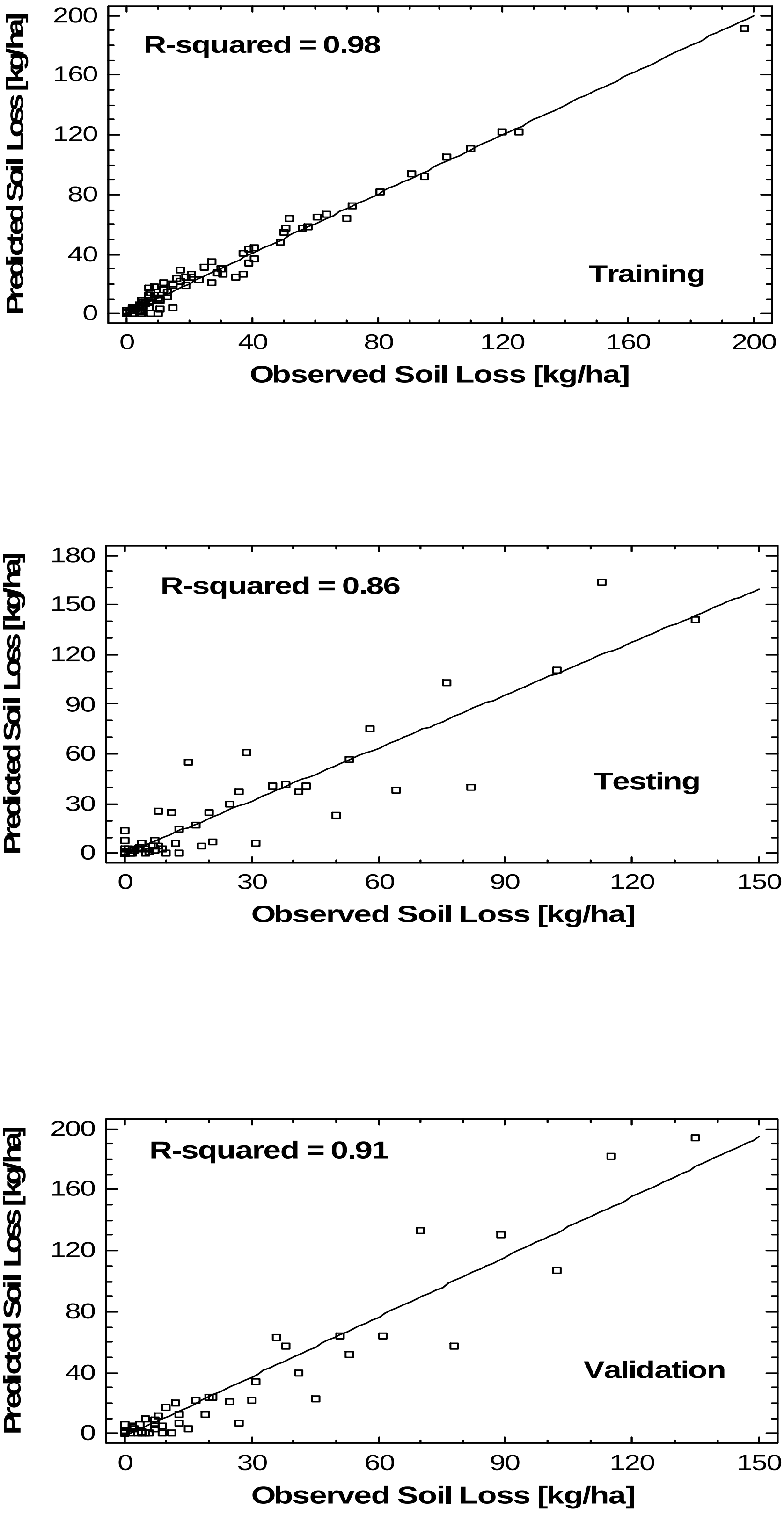


Figure 5.8.Measured versus predicted soil loss by Global NET1 model.

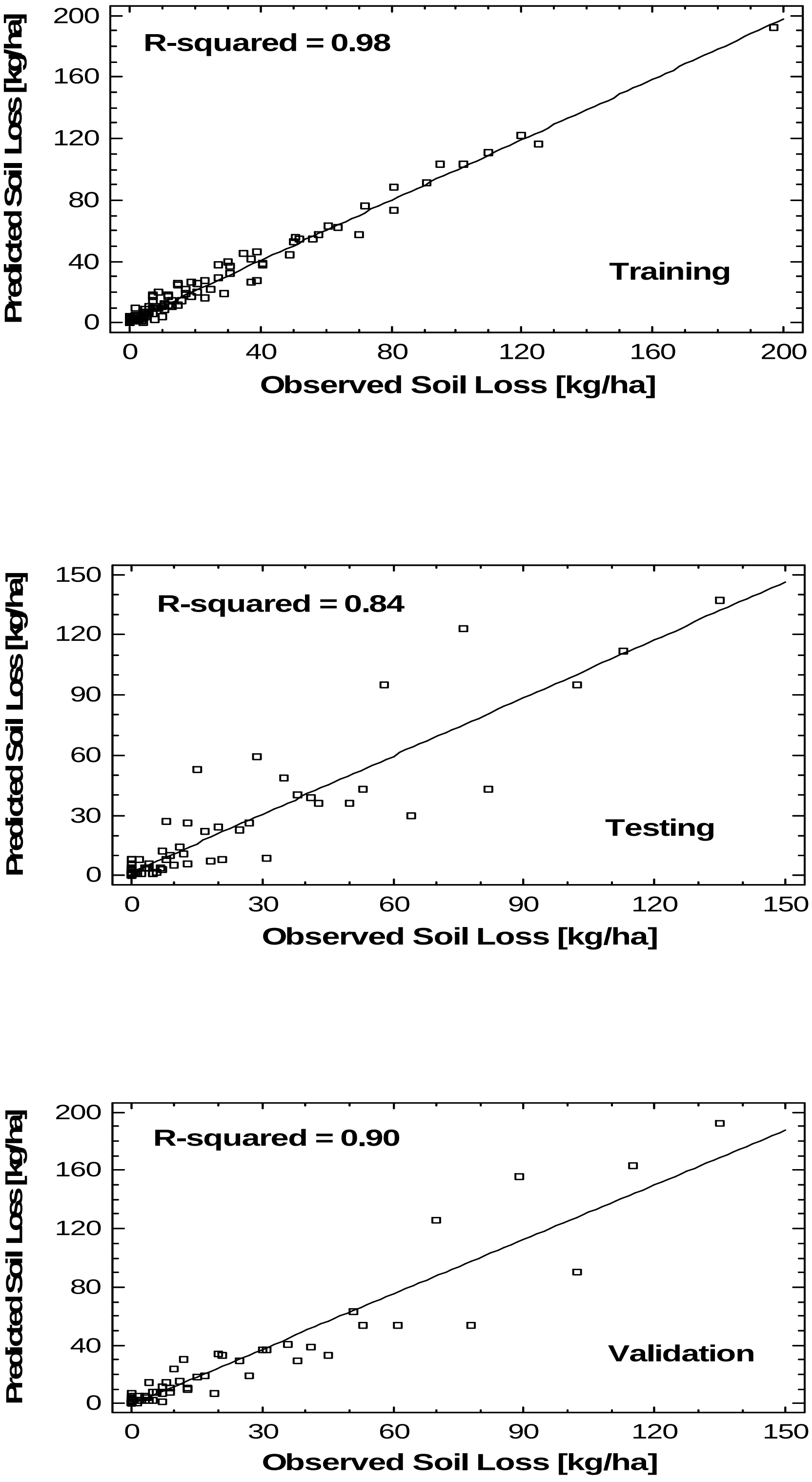


Figure 5.9. Measured versus predicted soil loss by Global NET3 model.

5.3.5.2 Individuals networks

Table 5.10 shows the optimal networks for all the individuals Networks type which predict the soil loss and runoff for each land use types individually. The optimal network is having been developed with 6 neuron in the hidden layer and 600 iteration for NETLU1. The network with a 2 neuron in the hidden layer and 400 iteration was found to have the best performance for NETLU2. Optimal network for NETLU4 and NETLU5 were developed with 5 neuron in the hidden layers and 300 and 500 iteration respectively. Finally NETLU3 developed with only 1 neuron in the hidden layer and 6200 iteration. Graphical representation of observed values for both runoff and soil loss for all the optimal individuals networks models are show in annex 1.

Table 5.10 Individuals land use type optimal network architecture

Net	Architecture	Iteration	Nbr.Initial hidden nodes	Nbr. Optimal Hidden nodes	ASE training	ASE testing
NETLU1	6-6-2	600	6	6	0.003298	0.016621
NETLU2	7-1-2	400	1	2	0.003084	0.005998
NETLU3	6—1-2	6200	1	1	0.006626	0.013180
NETLU4	7-5-2	300	5	5	0.002464	0.012266
NETLU5	7-5-2	500	5	5	0.004959	0.012367

The observed and predicted values of runoff and soil loss by NETLU1 are close to each other and there is no significance difference among theme in the phase of training and validation as indicated by the ratio of ratio of variances (Table 5.11). In other hand the predicted values in the testing phase were below the observed values and there was a significance difference between theme despite the high value of coefficient of determination (R^2=0.88).

Table 5.11 Summary statistics of the NETLU1 of observed versus predicted runoff and soil loss.

	RUNOFF			SOIL LOSS		
Statistics	Training	Testing	Validation	Training	Testing	Validation
R2	0.89	0.88	0.88	0.93	0.91	0.85
Slope(b)	0,909311	0,537736	0,844123	0,907995	0,32561	0,887231
Ratio of variances	[0,478143; 1,80347]	[0,122729; 0,877089]	[0,301512; 2,15477]	[0,453776; 1,71156]	[0,0434178; 0,310287]	[0,345196; 2,46695]

Comparison of observed and predicted values of runoff and soil loss of the NETLU2 (Table 5.12) indicate that there is no significance difference between the observed values for all phases of the model development, and observed values where very well predicted. As for the erosion there was no significance difference between the observed and predicted values for training and testing phase, and there was a significance difference between the observed and predicted values for the validation as indicated by the ratio of variances (Table5.12). Despite the significance difference between the observed and predicted erosion values in the validation phase, associations between the predicted and observed values were above 72% of the observed values.

Table 5.12 Summary statistics of the NETLU2 of observed versus predicted runoff and soil loss.

	RUNOFF			SOIL LOSS		
Statistics	Training	Testing	Validation	Training	Testing	Validation
R2	0.94	0.90	0.85	0.97	0.83	0.83
Slope(b)	0,972901	0,874377	0,798621	0,935775	1,04021	0,550974
Ratio of variances	[0,516503; 1,94816]	[0,317126; 2,26635]	[0,278626; 1,99121]	[0,465405; 1,75542]	[0,485661; 3,47079]	[0,136158; 0,973058]

The performance NETLU3, NETLU4 and NETLU5 are given in Table 5.13, Table 5.14 and Table 5.15 respectively. Testing the models performance for predicting both runoff and soil loss of these models for all phases of the model development indicate that the models perform well and it also shows that there is no significance differences between the predicted and observed values as indicated by the ratio of variances and the slope of the best fit regression line.

Table 5.13 Summary statistics of the NETLU3 of observed versus predicted runoff and soil loss.

	RUNOFF			SOIL LOSS		
Statistics	Training	Testing	Validation	Training	Testing	Validation
R2	0.90	0.84	0.79	0.90	0.78	0.80
Slope(b)	0,861514	0,749494	0,820047	0,880115	0,876627	0,803143
Ratio of variances	[0,42525; 1,60396]	[0,249798; 1,78519]	[0,318134; 2,27355]	[0,443516; 1,67286]	[0,368071; 2,63043]	[0,301021; 2,15126]

Table 5.14 Summary statistics of the NETLU4 of observed versus predicted runoff and soil loss.

	RUNOFF			SOIL LOSS		
Statistics	Training	Testing	Validation	Training	Testing	Validation
R2	0.95	0.81	0.87	0.96	0.95	0.83
Slope(b)	0,95251	0,745112	0,846105	0,89582	1,35372	1,46257
Ratio of variances	[0,489849; 1,84762]	[0,255402; 1,82524]	[0,309402; 2,21115]	[0,430792; 1,62487]	[0,720889; 5,15186]	[0,969592; 6,92922]

Table 5.15 Summary statistics of the NETLU5 of observed versus predicted runoff and soil loss.

	RUNOFF			SOIL LOSS		
Statistics	Training	Testing	Validation	Training	Testing	Validation
R2	0.95	0.82	0.83	0.90	0.83	0.90
Slope(b)	0,984676	1,04225	1,06396	0,932669	0,978406	1,14196
Ratio of variances	[0,52444; 1,97809]	[0,497497; 3,55538]	[0,513283; 3,6682]	[0,494827; 1,8664]	[0,430833; 3,07896]	[0,53881; 3,85062]

The significance difference between the observed and predicted values of NETLU1 in the testing phase for both runoff and erosion, and the significance difference between the observed and predicted values of soil loss prediction of the NETLU2 could be attributed to the relatively smaller number of events used in developing the network, which have made the training sub set of data too small for an optimal training of the networks. Despite that the result obtained from all the individuals networks for both runoff and soil losses were better than the result obtained from WEEP.

5.3.6 Conclusion

Result indicate that the artificial neural network model with single hidden layer and a feed forward back propagation , when provided with a sufficient amount of observation , can be trained to provide a relatively highly significant output for both runoff and soil loss. The simulated output for both runoff and soil losses of the global network were good and some what better than the result obtained by the individuals land use networks. The R^2 values for predicting soil loss and runoff by ANN was higher than the R^2 using the WEPP model, which indicate that the ANN predicting well the soil loss and run off as compared to the WEPP. Also the observed and predicted values by ANN were highly significant with no significant different between them. While in the case of WEPP, the predicted values and observed values for both the runoff and soil loss were highly significant.

The WEPP model has very low fits for the field data. Therefore, the model predictions under Central high land mountains are not very satisfactory. Consequently the overall suitability of the WEPP model for the study area is questionable. Furthermore, the

Application of this model for the study area needs detailed and accurate soil, topography, and vegetation and land use data. This means, its application requires a considerable work for collecting data, and such a task is time consuming and tedious. Since ANN models shows sufficiently reliable results, is relatively easy to use and it require low amount of data. Also the neural network can be developed with much less effort than that required for the development of the physically based erosion models such as WEEP. The study suggests that the ANN model is probably more suitable than the WEPP model for the purpose of the present study with a minimum a mount of observation.

Conclusion General and Recommendation

Conclusion General and Recommendation

Investigation of water induced soil erosion of two years duration were conducted at five different land use types in the semi arid Mediterranean Central High land mountainous area of the Palestinian territories. The investigated land uses comprise the major land use types practiced in the region. The study area is located in the northern part of the Hebron district. The study has the following aims: to study the affect of different land uses practices on soil erosion and runoff; to investigate the affect of these land uses on soil properties; and to apply and determine the ability and capability of physical process based erosion model (WEPP), and the artificial neural network in predicting soil loss and runoff.

Literature review indicate that loss of soil reflected in reduced crop production potential, lower surface water quality and damaged drainage networks. The rate and magnitude of soil erosion by water is controlled by the Rainfall Intensity and Runoff, Soil Erodibility, Slope Gradient and length, Vegetation and Conservation Measures. A wide range of models exists for use in soil erosion prediction. Few of these models have component to consider the hillslope erosion. These models differ in terms of complexity, processes considered, and the data required for model calibration and validation to a new condition. In general there is no ‘best’ model for all applications. The most appropriate model will depend on the intended use, availability of the data, and the characteristics of the study area being considered. Other factors affecting the choice of a model for an application include data requirements, accuracy and validity. Within the literature, the preferences of researchers for certain model types over others largely reflect two main viewpoints: emphasis on the processes at work or emphasis on the output.

Understanding the different factors that effect soil erosion problem in the Palestinian Central highland mountainous area, it is a prerequisite for modelling and predicting the soil loss under this condition. Therefore this understanding must be based on experimental data, to model the cause and effect of relationship of soil loss factors. In order to achieve that, soil loss; runoff and soil erosion factors were collected from a field study carried out for two years under five major land uses existing in the central highland. The data collected are the runoff, soil loss, vegetation cover, rainfall and rainfall intensity, topography including the slope and slope length, and the soil physical and hydraulic properties.

Rainfall characteristics revealed in general that, the rainfall intensity was very low, with only a few rainfall events with considerable intensity and kinetic energy, which may cause a real damage to the soil surface. Derived soil erodibility parameters under the different land use on the study area, showed that the soil erodibility is low. The presence of annual vegetation and plant residues on the soil surface and the terracing structures is responsible for the reduction of soil loss to very low values; and therefore further degradation of the land is restricted. The results confirm the existence of a strong positive relation between rainfall depth and runoff and sediment loss for particular different kinds of land use, and between runoff and soil loss with the presence or absence of the support practices as terraces in the region. The decrease in vegetation cover and increase in mechanical activities under the cultivated land use resulted in significant decrease in the soil organic matter, aggregate stability, and the hydraulic conductivity and total porosity and effective porosity of the soil.

The WEPP model has very low fits for the field data. Therefore, the model predictions under Central high land mountains are not very satisfactory. Consequently the overall suitability of the WEPP model for the study area is questionable. Furthermore, the application of this model for the study area needs detailed and accurate soil, topography, and vegetation and land use data. Result obtained by applying the artificial neural network model with single hidden layer and a feed forward back propagation, were very good with no significance difference between the observed and predicted values for both the runoff and soil loss. While in the case of WEEP, the predicted values and observed values for both the runoff and soil loss were highly significant

Given the high data demand of erosion prediction models and difficulties in obtaining such data of sufficient quality and special and temporal coverage, also all of the erosion prediction models that are considered deterministic, they are mainly developed based on the data of the empirical models. The artificial neural network could be used as predicting tool to estimate the soil loss and runoff with a few parameters and it provide a significance result as shown in our study. Therefore the ANN is recommended to be adopted as prediction tool to understand the problem of soil erosion in the Palestinian territories with minimum effort to collect a few numbers of parameters and to conduct a relatively low expensive experiment for data collection. Therefore, the result obtained from this work added to our knowledge the soil erosion research could be continue in the region in order to get a better understanding of this problem with minimum efforts and without the need of using the highly demanding input models that require high investment in collecting these input.

References

Refrences

Abed, A., 1999.Geology of Palestine. Palestinian Hydrology Group, Ramallah.

Abu Hammad, A. (2004). Soil erosion and soil moisture conservation under old terracing system in the Palestinian Central Mountains. PH.D Thesis, Agricultural University of Norway. Norway.

Abu Hammad, A., Borresen, T., and Haugen, L.E. (2004). Effects of Stonewalled Terracing Techniques on Soil-Water Conservation and Wheat Production under Mediterranean Conditions. Environmental Management Vol. 34, No. 5, pp. 701-710

Agassi, M. (ed.) 1995. Soil Erosion, Conservation, and Rehabilitation. Marcel Dekker, Inc. New York, 402 p.

Ahuja, L.R., J.W.Naney, R.E. Green and D.R. Nielsen. 1984. Macroporosity to characterize spatial variability of hydraulic conductivity and effects of land management. Soil Sci. Soc. America J., 48 : 699-702.

American Society of Civil Engineers (ASCE), Task Committee on Application of Artificial Neural Networks in Hydrology. (2000a). ‘‘Artificial neural networks in hydrology. I: Preliminary concepts.’’ *J. Hydrologic Eng.*, 5(2), 115–123.

Anon., 1995. In: Flanagan, D.C., Livingston, S.J. (Eds.), WEPP User Summary, NSERL Rep. 11. USDA-ARS-NSERL, West Lafayette, IN.

ARIJ (Applied Research Institute of Jerusalem), 1995. Environmental Profile for the West Bank, Volume 3, Hebron District. Bethlehem-West Bank-Palestine.

ASCE Manual 54. 1977. "Sedimentation Engineering," Vito A. Vanoni, Ed., ASCE Task Committee, American Society of Civil Engineers, New York.

Awadallah, W., and Owaiwi, M. (2005). Spring and Dung Well of Hebron District. Palestinian Hydrology Group (PHG).

Ayed, A. and Wishahi, S.K. (1999). Geology of Palestine. Palestinian Hydrology Group, Jerusalem, Palestine.

Bacchi, O.O.S., K. Reichardt, and G. Sparovek (2003). “Sediment spatial distribution evaluated by three methods and its relation to some soil properties.” Soil Till. Res. 69: 117-126.

Bar-Matthews, M.. Ayalon. A. Matthews, A. Sass, E. Halicz. L.1996. Carbon and oxygen isotope study of the active watercarbonate system in a karstic Mediterranean cave: implications for paleoclimate research in semiarid regions, Geochim. Cosmochim. Acta, 60. 337-347.

Barthès, B., Roose, E., 2002. Aggregate stability as an indicator of soil susceptibility to runoff and erosion; validation at several levels. Catena 47, 133–149.

Beasley, D. B., 1977, ANSWERS. A Mathematical Model for Simulating the Effects of Land Use and Management on Water Quality, Ph.D. thesis, Purdue University, West Lafayette, Indiana.

Beasley, D. B., L. F. Huggins and E. J. Monke (1980) ANSWERS: A model for watershed planning Trans. ASAE, 23 (4), 938-944.

Bergsma, E. (1980) Provisional rain-erosivity map of the Netherlands. In: Assessment of Erosion, ed M. De Boodt & D. Gabriels. Wiley, UK.

Berzegar, A. R., P. Rangasamy, and J. M. Oades. 1998. Factors affecting the strength and erodibility of salt-affected soils. In: Bushan, L. S., I. P. Arbol, and M. S. Rama Mohan Rao (eds.) Soil Erosion and Water Conservation ChaZZunges and Opportunities, Indian Association of Soil and Water Conservationists, Dehra Dun, India. Vol. 1 :248-262.

Bhuyan, S.J., P.K. Kalita, K.A. Janssen and P. L. Barnes, 2002. Soil loss predictions with three erosion simulation models. Environmental Modelling & Software 17: 137-146.

Bojo, J. (1996). Analysis - The cost of land degradation in Sub-Saharan Africa. Ecological Economics 16(196) 161-173.

Bowen, W., G. Baigorria, V. Barrera, J. Cordova, P. Muck and R. Pastor, 1998. A process-based model (WEPP) for simulating soil erosion in the Andes. Natural Resource Management in the Andes. CIP Program Report, p. 403-408.

Bowyer-Bower, T. A. S., 1 993. Effects of rainfall intensity and antecedent moisture on the steady-state infiltration rate in a semi-arid region. Soil Use and Management 9 (2): 69-76.

Bowyer-Bower, T. A. S., 1 993. Effects of rainfall intensity and antecedent moisture on the steady-state infiltration rate in a semi-arid region. Soil Use and Management 9 (2): 69-76.

Brazier, R. E., Beven, K. J., Freer, J. and Rowan, J. S., 2000, Equifinality and uncertainty in physically-based soil erosion models: application of the GLUE methodology to WEPP, the Water Erosion Prediction Project – for sites in the UK and USA, *Earth Surf. Process. Landf.*, 25, 825-845.

Brown, L.R. (Ed.), 1984. Conserving Soils: State of the World. Norton, New York, USA.
Bryan, R. B., G. Govers and J. Poesen, 1989. The concept of soil erodibility and some problems of assessment and application. Catena 16: 393-412.

Bryan, R.B. and Campbell, LA., 1986. Runoff and sediment discharge in a semi-arid drainage basin. Z. Geomorphol., 58: 121-143.

Bujan, A., O. J. Santanatoglia, C. Chagas, M. Massobrio, M. Castiglioni, M. S. Yanez, M. Ciarella and J. Fernandez, 2000. Preliminary study on the use of the 137Cs method for soil erosion investigation in the Pampean region of Argentina. Acta Geologica Hispanica 35(3-4):271- 277.

Castro, C. F., and T. Logan. 1991. Liming effect on soil stability and erodibility. *Soil Sci. SOC. Am. J. 55: 1407-1413.*

Celik, I., 2005. Land-use effects on organic matter and physical properties of soil in a southern Mediterranean highland of Turkey. Soil & Tillage Research 83, 270-277.

Cerda, A., 1996. Soil aggregate stability in three Mediterranean environments. Soil Technol. 9, 133-140.

Cerda, A., 1998c. Soil aggregate stability under different Mediterranean vegetation types. Catena 32, 73-86.

Chitrakar, S., 2004. Testing of the WEPP soil erosion model in the west Usambara mountains of Tanzania. MSc. Thesis. Erosion and Soil & Water Conservation Group. Wageningen Universiteit. The Netherlands.

Ciesiolka, C. A. A. and K. J. Coughlan, 1995. A framework for research on soil erosion by water. ACIAR Publication X-95, Australian Centre for International Agricultural Research, December, 1995.

Clark, E.H., 1985. The off-site costs of soil erosion. Journal of Soil and Water Conservation 40 1, pp. 19–22.

Dan, Y., Yaalon, D., Koymdlisky, H. and Raz, Z. (1976). The Soil of Israel- with 1:500,000 soil map of Israel, Pamphlet No.159. The Volcani Center, Beit Dagan, Israel.

Dan, Y., Yaalon, D., Koymdlisky, H. and Raz, Z. (1976). The Soil of Israel- with 1:500,000 soil map of Israel, Pamphlet No.159. The Volcani Center, Beit Dagan, Israel.

De Hoop, S., 1993. Feature Oriented Data Models for GIS: Concepts and Potentials. Processding of the 3rd International User Forum, Geographical Information System – New Perspectives, Munich, Germany.

den Biggelaar, C., Lal, R., Wiebe, K. and Breneman, V. (2001). Impact of soil erosion on crop yields in North America. Advances in Agronomy, 72: 1-52.

den Biggelaar, C., Lal, R., Wiebe, K. and Breneman, V. (2004a). The global impact of soil erosion on productivity I: Absolute and relative erosion-induced yield losses. Advances in Agronomy, 81: 1-48.

den Biggelaar, C., Lal, R., Wiebe, K. and Breneman, V. (2004b). The global impact of soil erosion on productivity II: Effects on crop yields and production over time. Advances in Agronomy, 81: 49-95.

Dickey E.C., D.P. Shelton, and P.J. Jasa. 1986. Residue management for soil erosion control. Neb Guide G81-544. Nebraska Cooperative Extension Service. Lincoln, Nebraska.

Dudeen, B. (1999). The Soils of Palestine (West Bank and Gaza Strip) Current Status and Future Perspective. Arab Studies Society, Land Research Centre, Soil Office Palestine.

Dudeen, B. (2001). Land degradation in Palestine. Land Research Center. Jerusalem .

Duiker, S.W., Rhoton, F.E., Torrent, J., Smeck, N.E., Lal, R., 2003. Iron (hydr)oxide crystallinity effects on soil aggregation. Soil Sci. Soc. Am. J. 67, 606-611.

Edwards K (1987) Runoff and soil loss studies in New South Wales. Technical Handbook No. 10, Soil Conservation Services of NSW, Sydney, NSW.

Eila, S.M., 2005.Sustainability: An effective approach for land use management-application to Gaza city. PhD thesis, Lille Laboratory of Mechanics, University of Lille for Science and Technology.

Elliot, W. J., A. M. Liebenow, J. M. Laflen and K. D. Kohl, 1989. A compendium of soil erodibility data from WEPP cropland soil field erodibility experiments 1987 & 88. NSERL Report No 3, Agricultural Research Service, U.S. Department of Agriculture, National Soil Erosion Research Lab., West Lafayette, Indiana. 316 p.

Elliot, W.J. and Laflen, J.M. 1993. A process-based rill erosion model. Trans. ASAE 36(1): 65-72

Elliot, W.J., D.E. Hall, and D. L. Scheele. 2000. WEPP Interface for Disturbed Forest and Range Runoff, Erosion, and Sediment Delivery: Technical Documentation. USDA Forest Service Rocky Mountain Research Station and San Dimas Technology and Development Center.

Ellison, W. D. (1947) Soil detachment hazard by raindrop splash In Soil Erosion Studies II Agric. Eng., pp. 197-201.

Elrick, D. E., Reynolds, W. D., 1992. Methods for analysing constant-head well permeameter data. Soil Science Society of America Journal. 56(1), 320-323 p.

El-Swaify, S.A. and E. W. Dangler, 1977. Erodibility of selected tropical soils in relation to structural and hydrologic parameters. In Soil Erosion: Prediction and Control. Soil and Water Conservation Society, Ankeny, Iowa. Pp 105-114.

Elwell, H. A. (1981) A soil loss estimation technique for southern Africa In Soil Conservation:Problems and Prospects. (Ed, Morgan, R. P. C., Wiley, Chichester, Sussex), pp. 281-292.

Emmett, W.W. (1970): Hydraulics of overland flow on hillslopes; *usgs Professional Paper* 662-A, 68 pp.

FAO. (1979). A Provisional Methodology for Soil Degradation Assessment. FAO, Rome.

Felipe Zapata, The use of environmental radionuclides as tracers in soil erosion and sedimentation investigations: recent advances and future developments. Soil and Tillage research, Volume 69, Issues 1-2 , February 2003, Pages 3-13.

Flanagan DC and Frankenberger JR (2002) Water Erosion Prediction Project (WEPP) Windows Interface Tutorial USDA-Agricultural Research Service & Purdue University National Soil Erosion Research Laboratory, West Lafayette, Indiana, USA.

Flanagan, D.C. and Nearing, M.A. 1995. USDA-Water Erosion Prediction Project (WEPP). WEPP users summary. NSERL Report No. 10. USDA-ARS National Soil Erosion Research Laboratory, West Lafayette, Indiana.

Formanek, G. E., E. Ross and J. Istok (1987) Subsurface drainage for erosion reduction on croplands of north western Oregon. In Irrigation Systems for the 21st CenturyAmerican Society of Civil Engineers, New York, pp. 25-31.

Foster G.R., L.J. Lane, J.D. Nowlin, L.M. Laflen, and R.A. Young. 1981. Estimating erosion and *sediment yield on field-sized areas. Trans. of the ASAE, 24 (5): 1253-1262.*

Foster, G. R. (1982) Modelling the erosion process In Hydrologic Modelling of Small Watershed. (Ed, Hann, C. T., Johnson, H.D., Brakensiek, D.L.) American Society of Agricultural Engineers, St Joseph, Michigan.

Foster, G. R. and L. D. Meyer (1972) A closed-form soil erosion equation for upland areas. In Sedimentation. (Ed, Shen, H. W.) Department of Civil Engineering, Colorado State University, Fort Collins.

Foster, G. R., D. C. Flanagan, M. A. Nearing, L. J. Lane, L. M. Risse and S. C. Finkner (1995) Chapter 11: Hillslope Erosion Component In USDA- Water Erosion Prediction Project : Hillslope Profile and Watershed Model Documentation. (Eds, Flanagan, D. C. and M. A. Nearing) USDA-ARS national Soil Erosion Research Laboratory.

Foster, G.R. 1988. Modeling soil erosion sediment yield. In: R. Lal (ed.) Soil erosion Research Methods. Soil and Water Conservation Society, Netherlands.

Foster, G.R., & L.J. Lane (1987). WEPP: User Requirements- USDA Water Erosion Prediction Project (WEPP). NSERL Report 1, U.S. Department of Agriculture, Agricultural Research Service, West Lafayette, IN. U.S.A.

Francis, CF. and Thomes, J.B., 1990. Runoff hydrographs from three Mediterranean vegetation cover types. In: J.13. Thomes (Editor), Vegetation and Erosion, Processes and Environments. Wiley, Chichester, pp. 363-:84.

Gat. J.R.. 1982. Precipitation. groundwater and surface waters. In: Paleoclimates and Paleowaters. International Atomic Energy Agency, Vienna, pp. 3- 12.

Gat. J.R.. 1996. Oxygen and hydrogen isotopes in the hydrologic cycle. Ann. Rev. Earth Planet. Sci.. 24, 225-262.

George E. P. Box, William G. Hunter, and J. Stuart Hunter (2005). Design of experiments: Statistics for Experimenters: Design, Innovation and Discovery, 2nd edition. John Wiley and Sons, New York.

Ghidey, F., E. E. Alberts and L. A. Kramer, 1995. Comparison of runoff and soil loss predictions from the WEPP hillslope model to measured values for eight cropping and management treatments. ASAE Paper No. 95-2383. ASAE, St. Joseph, MI

Gnagey, R. W. (1991) Calculating erosion reduction with INDERSOSI International Workshop for Sustainable Hillslope Farming, Solo Indonesia.

Grønsten, H.A., Lundekvam, H., 2006. Prediction of surface runoff and soil loss in southeastern Norway using the WEPP Hillslope model. Soil & Tillage Research 85 (2006) 186–199

Hajabbasi, M.A., Lalalian, A., Karimzadeh, R., 1997. Deforestation effects on soil physical and chemical properties, Lordegan, Iran. Plant Soil 190, 301-308.

Harris, T.M. and Boardman, J. (1998) Alternative approaches to soil erosion prediction and conservation using Expert Systems and Artificial Neural Networks. In: Boardman, J. and Favis-Mortlock, D.T. (eds) Modelling Soil Erosion by water, NATO-ASI Series I-55. Springer, Berlin, PP. 461-478.

Hassan, A. E., 2001. Prediction of plume migration in heterogeneous media using artificial neural networks. Water Resources Research 37 (3), 605–623.

He, 2003. Integration of geographic information systems and simulation model for watershed management. Environmental Modelling & Software. v18. 809-813.

Helsel, D.R., Hirsch, R.M., 1992. Statistical methods in water resources. US Geological Survey, Water Resources Division, Reston, Virginia 22092, USA.

Hoogmoed, W.B. (1999). Tillage for soil and water conservation in the semi-arid tropics. Doctoral Thesis. Wageningen University, the Netherlands, (xii+184pp.)

Hoogmoed, W.B. and L. Stroosnijder (1984). Crust formation on sandy soils in the Sahel. I. Rainfall and infiltration. Soil & Tillage Research, 4 (1984) 5-23.

Hornik, K., M. Stinchcombe and H. White, (1989).Multilayer feedforward networks are universal approximators. Neural Networks 2, pp. 359–366.

Hsu, K., X. Gao, S. Sorooshian, and H.V. Gupta, 1997: Precipitation estimation from remotely sensed information using artificial neural networks. Journal of Applied Meteorology, 36, 1176-1190.

Hudson, N. 1995. Soil Conservation. Fully Revised and Updated Third Edition. BT Bastford Ltd. London, : 93 - 153.

Idowu, O.J., 2003. Relationships between aggregate stability and selected soil properties in humid tropical environment. Commun. Soil Sci. Plant Anal. 34, 695-708.

ISRIC (2003). What is the Glasod? (http://www.isric.org search term: glasod 05/09/05)

J.C. Ritchie and J.R. Mc Henry , Application of radiation fallout 137Cs for measuring soil erosion and sediment accumulation rates and patterns: a review. J. Environ. Qual. 19 (1990), pp. 215–233.

J.M. Bernard and T.A. Iiavri , Sediment damages and recent trends in the United States. Int. J. Sediment Res. 15 (2000), pp. 135–148.

Johnson, Y. N. (1943) Distribution Graph of Suspended matter concentration Trans. Of ASCE, 108, 941-964.

Kessler, Y. 1994, Climatic Characteristics of Judea and Samaria, Report from Civil Adminstration of Judea and Samaria.

Kothyari, U. C., A. K. Tiwari, and R. Singh. 1994. Prediction of sediment yield. J. Irrigation and Drainage Engineering 120(6): 1122- 1131.

Kramer, L. A. and E. E. Alberts, 1995. Validation of WEPP 95.1. Daily erosion simulation. ASAE Paper No. 95-2384. ASAE, St. Joseph, MI

Kunwar, L.B., Bergsma, E., Shrestha, D.P., 2003. Rain erosion hazard evaluated from microtopographic erosion features on arable fields and forest: a case study in Nepal. Geografiska Annaler 85 A (3/4), 313–321.

Laflen, J. M., L. J. Lane and G. R. Foster, 1991a. WEPP - A new generation of erosion prediction technology. J. Soil Water Conserv., 46, 334-338.

Laflen, J.M., and E.J. Roose, 1997. Methodologies for Assessment of Soil Degradation Due to Water Erosion. In R. Lal, W.H. Blum, C. Valentine, and B. A. Stewart (Editors), Methods for Assessment of Soil Degradation. CRC Press LLC, U.S.A.

Laflen, J.M., W.J. Elliot, R. Simanton, S. Holzhey, and K.D. Kohl. 1991. WEPP soil erodibility experiments for rangeland and cropland soils. J. Soil Water Conserv. 46:39–44

Lal, R. (1990) Soil Erosion in the Tropics, Principles & Management. McGraw-Hill, Inc., New York.

Land Research Center, (2000). Land System Classification of the West Bank and Gaza Strip. Jerusalem.

Land Research Center, (2002). Hebron Governarate, land and people. Jerusalem.

Lane, L. J., E. D. Shirley and V. P. Singh (1988) Modelling Erosion on Hillslopes In Modelling Gepgraphical System. (Ed, Anderson, K. G.) John Wiley and Sons Ltd, pp. 287-308.

Lawrence. J. (1994). Introduction to Neural Networks: Design, Theory, and Applications, California Scientific Software, Nevada City, CA.

Licznar, P., Nearing, M. A. (2003): Artificial neural networks of soil erosion and runoff prediction at the plot scale. Catena 51, 89-114.

Lippmann. R., (1987). An introduction to computing with neural nets. IEEE ASSP Magazine, 4(22).

Liu, J., Savenije, H.H.G., Xu, J., 2003. Forecast of water demand in Weinan City in China using WDF-ANN model. Physics and Chemistry of the Earth 28, 219-224.

Loch, R. J. and Rosewell, C.J. (1992). Laboratory methods for measurement of soil erodibility (K factors) for the Universal Soil Loss Equation. Australian Journal of Soil Research, 30: 233-48.

Loch, R. J., B. K. Slater, B. K. and Devoil, C. (1998). Soil erodibility (K_m) values for some Australian soils. Australian Journal of Soil Research, 36: 1045-55.

Lu et al., 2004. Mapping soil erosion risk in Rondonia, brazilian amazonia: using RUSLE. Rem. Sens. GIS. Land Degrad. Dev. v15. 499-512.

Maier, H.R., Dandy, G.C., 2000. Neural networks for the prediction and forecasting of water resources variables: a review of modelling issues and applications. Env. Model. Software 15, 101-123.

Mainguet, M 1994. Desertification: Natural Background and Human Mismanagement. Springer, Berlin, Heidelberg.

McCool, D. K., G. R. Foster, C. K. Mutchler and L. D. Mayer (1989) Revised Slope length factor for Universal Soil Loss Equation. Trans. ASAE, 32, 1571-1576.

McCool, D. K., L. C. Brown, G. R. Foster and et al. (1987) Revised slope steepness factor for the Universal Soil Loss Equation Trans. ASAE, 30, 1387-1396.

MEnA, 2000. Country Report on Biodiversity, Ministry of Environmental Affairs, Palestine. Unpublished report.

Merrit, W.S., R.A. Letcher and A.J. Jakeman, 2003. A review of erosion and sediment transport models. Environmental Modelling & Software 18: 761-799.

Meyer, L. D., 1994. Rainfall simulators for soil erosion research. In R. Lal (Editor): Soil Erosion Research Methods. Second Edition. Soil and Water Conservation Society, Ankeny, Iowa. Pp.83-103.

MEYER, L. y W. WISCHMEIER. 1969. Mathematical simulation of the process of soil erosion by water. Trans. ASAE. Vol. 12(6): 754-758,762.

Meyer, L.D. 1980. Soil Conservation Problems and Prospects. Ed. R.C.P. Morgan. International Conference on Soil Conservation, the Natural College of Agricultural Engineering, Silsoe, Bedford, UK.

Middleton, N. and Thomas, D.S.G. (eds.) (1992). World Atlas of Desertification. UNEP. Edward Arnold, London.

Miller CL & RA Laflamme (1958). The digital terrain model - theory & application. Photogrammetric Engineering 25, 433–442.

Ministry of Agriculture (2004). A Strategy for Sustainable Agriculture in Palestine. Ramallah, Palestine.

Ministry of Agriculture (MOA). (2001).Strategic option for sustainable natural resources management in Palestine. Rammallah.West Bank.

Ministry of Agriculture (MOA). (2004). Rainfall data base. (Unpublished data).

Ministry of Environmental Affairs, (2000). “Palestinian Environmental Strategy (PES)”. Al-Bireh, Palestine.

Ministry of Transport (2004).Department of Meteorological Stations. Unpublished Reports, Ramallah, Palestine.

Moore, D. C., and M. J. Singer. 1990, Crust formation effect on soil erosion processes. Soil Sci. Soc. Am. J. 54: 1117 - 1123.

Morgan, R. P. C. (2005) Soil Erosion and Conservation. Longman Group Limited, London.

Morgan, R. P. C., J. N. Quinton and R. J. Rickson (1992) A soil erosion prediction model for the europian community In Soil Conservation for Survival. (Ed, Hurni, H. a. T. K.) Soil and water Conservation Society, Ankeny, Iowa.

Morgan, R. P. C., J. N. Quinton, R. E. Smith, G. Govers, J. W. A. Poesen, G. Chisel and D. Torri, 1998. The EUROSEM Model *In* Modelling Soil Erosion by Water by J. Boardman and D. Favis-Mortlock (eds.), Springer, published in co-operation with NATO Scientific Affairs Division (NATO ASI Series: Series1, Global and Environmental Change) Vol.55, 389-398.

Morgan, R.C.P. (1995). Soil erosion & conservation. Second Edition. Longman Group UK Limited.

Morin, J., Karen, R., Benyamini, Y., Ben-Hur, M., Shainberg, I.,1989. Water infiltration as affected by soil crust and moisture profile. Soil Sci. 148, 53-59.

Mutchler, C.K., C.E. Murphree and K.C. McGregor. 1994. Laboratory and field plots for erosion research. In: Lal, R. 1994. Soil erosion. Research methods. Second Edition. Soil and Water Conservation Society. 340 p.

Najjar Y. and Zhang X., 2000. Characterizing the 3D stress-strain Behavior of sandy Soils: ANeural-Mechanistic Approach. Geotechnical Special Publication No. 96, American Society of Civil Engineers: USA; 43-75.

Najjar, Y., 1999. Quick Manual for the Use of ANN program TR-SEQ1. Department of Civil Engineering, Kansas State University, Manhattan, Kansas, USA.

Najjar, Y., Basheer, I., Hajmeer, M., 1997. Computational Neural Network for predictive microbiology: Methodology. International Journal of food microbiology volume 34, pp. 27-49.

National Weather Service, 1995. Federal Meteorological Handbook No.1: Surface Weather Observations and Reports, 5th ed. December 1995. National Oceanic and Atmospheric Administration, Washington, DC. After Whiteman, C.D. (2000). Mountain meteorology. Fundamentals and applications. Oxford University Press. 355 pp.

Nearing, M. A., L. J. Lane and V. L. Lopes (1994) Modeling Soil Erosion In Soil Erosion Research Method. (Ed, Lal, R.) Soil and Water Conservation Society, Ankeny IA, pp. 127-156.

Nearing, M.A., Foster, G.R., Lane, L.J., Finkner, S.C., 1989. A process-based soil erosion model for USDA-water erosion prediction project technology. Trans. ASAE 32, 1587-1593.

Nelson, R.G. 2002. Resource assessment and removal analysis for corn stover and wheat straw in the Eastern and Midwestern United States – rainfall and wind-induced soil erosion methodology. Biomass and Bioenergy 22:349-363.

Newson, M.D., 1985. Forestry and water on the uplands of Britain - the background of hydrological research and options for harmonious land use. J. For., 79: 113-120.

Nill, D., U. Schwertmann, U. Sabel-Koschella, M. Bernhard, J. Breuer, 1996. Soil Erosion by Water in Africa: Principles, Prediction and Protection. Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH.

Novotny V. and G. Chesters.1989. Delivery of sediment and pollutants from nonpoint sources: a water quality perspective. Journal of Soil and Water Conservation, Nov.-Dec., 1989. pp. 568-576.

Oldeman, L. R. (1992) Global extent of soil Degradation, International Soil Reference and Information Centre, Wageningen, The Netherlands pp. 19-36.

Oldeman, L.R., Hakkeling, R.T.A., and Sombroek, W.G. (1991). "World Map of the Status of Human-Induced Soil Degradation: A Brief Explanatory Note". International Soil Reference and Information Centre/United Nations Environmental Programme, Wageningen/Nairobi.

Onstad, C. A. and G. R. Foster (1975) Erosion modeling on a watershed Trans. ASAE, 18(2), 288-292

Pachepsky, Y. A., Timlin, D. & Varallyay, G. (1996) Artificial neural networks to estimate soil water retention from easily measurable data. Soil Sci *Soc. Am. J.* **55,** 938-943.

Palestinian Environmental Authority (PEnA). (1999). National Biodiversity Strategy and Action Plan for Palestine. Hebron. Palestine.

Palestinian Land Research Centre (LRC), 2002. Palestinian Soil data base. Personal communication.

Peuquet, D.J., 1984. A Conceptual Framework and Comparison of Spatial data Models. Cartographica, Vol. 21, 4, 66-113.

Poff, L. N., Tokar, A. S., and Johnson, P. A. (1996). ‘‘Stream hydrological and ecological responses to climatic changes assessed with an artificial neural network.’’ *Limnology and Oceanography*, 41(5), 857–863.

Ponce-Hernandez, R. (2004). Soil Management and Conservation. ERSC 365 Course notes. Environmental and Resource Studies Program, Trent University, Canada.

Ravikovitch, S. (1992). The soil of Israel, Formation, Nature and Properties with 1 :250,000 soil map of Israel. Hakibbutz Hameuchad Publishing House, Tel-Aviv.

Reich, P., Eswaran, H. and Beinroth, F. (2005). Global Dimensions of Vulnerability to Wind and Water Erosion. Natural Resources Conservation Service, United States Department of Agriculture.

Renard, K. G. and G. R. Foster (1983) Soil Conservation: Principles of erosion by water. In Dryland Agriculture. (Ed, Dregne, H. E. a. W., W.O.) American Society of Agronomy, Crop Science Society of America and Soil Science Society of America.

Renard, K.G., Foster, G.A., Weesies, D.K., McCool, D.K. and Yoder, D.C. (1996). Predicting soil erosion by water: A guide to conservation planning with the revised universal soil loss equation. United States Department of Agriculture, Agriculture Handbook 703, United States Government Printing Office, Washington DC.

Rendon-Herrero, O. (1974) Estimation of washload produced by certain small watersheds Journal of Hydraulic Division, ASCE, 109(HY7), 835-848.

Rey F. 2003. Influence of vegetation distribution on sediment yield in forested marly gullies. Catena ,50(2-4):549-62

Risse, L.M., Nearing, M.A., Savabi, M.R., 1994. Determining the Green–Ampt effective hydraulic conductivity from rainfall-runoff data for the WEPP model. Trans. ASAE 37, 411–418.

Rofeand Raffety Consulting Engineers (1963): Jerusalem DistrictWater resourcesSurvey, Geological and HydrogeologicalReport, prepared for the HashemiteKingdomof Jordan, Central Authorityof Jordan. Westminster, London

Romero León, C.C., 2005. A multi-scale approach for erosion assessment in the Andes. Doctoral Thesis Wageningen University.

Rose, C. W., K. J. Coughlan, C. A. A. Ciesiolka and B. Fentie. 1997. The role of cover in soil conservation. In Coughlan and Rose (eds.) A New Soil Conservation Methodology and Application to Cropping Systems in Tropical Steeplands. ACIAR Technical Reports 40: 59-78.

Rose, C.W., 1988. Research Progress on Soil Erosion Processes and a Basis for Soil Conservation Practices. In: R. Lal (Editor), Soil Erosion Research Methods. Soil and Water Conservation Society, Ankeny, Iowa, U.S.A.

Rosewell, C. J. (1993) SOILOSS: A program to assist in the selection of management practices to reduce erosion, The soil conservation service, Department of Conservation and Land Management.

Rozanski. K.. Amguas-Araguas. L. and Gontiantini, R..1993. Isotopic patterns in modem global precipitation. In: P.K. Swan, K.L. Lohman, J.A. McKenzie and S. Savin (Editors), Climate Change in Continental Isotopic Record, Geophys. Monogr.Vol. 78. Am. Geophy. Union, Washington, DC. pp. l-37.

Salles, C., Poesen, J., Sempere-Torres, D., 2002. Kinetic energy of rain and its functional relationship with intensity. J. Hydrol. 257, 256–270.

Schawb, G., D. Fangmeier, W. Elliot and R. Frevert. (1993). Soil and water conservation engineering. Fourth Edition. John Wiley & Sons, Inc.

SCSA (1982) Resource Conservation Glossary Soil Conservation Society of America, Ankeny, Iowa, pp. 193.

Singh, S., Singh, J.S., 1996. Water-stable aggregates and associated organic matter in forest, savanna, and cropland soils of a seasonally dry tropical region. India Biol. Fert. Soils 22, 76–82.

Six, J., Paustian, K., Elliott, E.T., Combrink, C., 2000. Soil structure and organic matter: I. Distribution of aggregate-size classes and aggregate-associated carbon. Soil Sci. Soc. Am. J. 64, 681-689.

Smith, D. D. (1941) Interpretation of soil conservation data for field use. Agricultural Engeneering, 22, 173-175.

Soil and Water Conservation Society. 1994. Soil erosion research methods. St. Lucie Press, Ankeny, Iowa

Soto, B., Dı`az-Fierros, F., 1998. Runoff and soil erosion from areas of burnt scrub: comparison of experimental results with those predicted by the WEPP model. CATENA 31, 257–270.

Starrett, S. K., Najjar, Y. M., and Hill, J. C. (1996). ‘‘Neural networks predict pesticide leaching.’’ Proc., North American Water and Environmental Conf., ASCE, New York, 1693–1698.

Tan, Kim. H. 1994. *Environmental Soil Science.* Marcel Dekker, Inc. New York : 12-13.

UNEP (1991) Status of desertification and implementation of UN plan of action to combat desertification UNEP, Nairobi, Kanya, pp. 344.

UNEP (United Nations Environment Programme), 1992. Global Assessment of Soil Degradation. ISRIC, Wageningen; UNEP, Nairobi, Kenya

UNEP, 2003. Desk Study on the Environment in the Occupied Palestinian Territories. United Nations Environmental Development Program. 2003.

Uvo, C. B. Tolle, U. & Berndtsson, R. (2000) Forecasting discharge in Amazonia using artificial neural networks. Int.J. Climatol. 20: 1495–1507.

van Doren, C. A., R. S. Stauffer, et al. (1950). "Effect of contour farming on soil loss and runoff." Soil Science Society of America 15: 413-417.

Viney, N. R., M. Sivapalan and D. E. Deeley (2000). A conceptual model of nutrient mobilisation and transport applicable at large catchment scales. *Journal of Hydrology*, Vol. 240, No. 1-2, pp. 23-44.

Viney, N.R. and M. Sivapalan (1999). A conceptual model of sediment transport: Application to the Avon River Basin in Western Australia. *Hydrological Processes*, Vol. 13, No. 5, pp. 727-743.

WALLING, D.E., QUINE, T.A., The use of caesium-137 measurements to investigate soil erosion on arable fields in the UK: Potential applications and limitations, J. Soil Sci. 42 (1991) 147-165.

Whalen, J.K., Chang, C., 2002. Macroaggregate characteristics in cultivated soils after 25 annual manure applications. Soil Sci. Soc. Am. J. 66, 1637-1647.

Wheater, H. S., Jakeman, A. J. & Beven, K. J. (1993) Progress and directions in rainfall–runoff modelling, Chapter 5. In: *Modelling Change in Environmental Systems* (ed. by A. J. Jakeman, M. B. Beck & M. J. McAleer), 101–132. John Wiley & Sons, Chichester, UK.

Whiteman, C. D. (2000). Mountain meteorology. Fundamentals and applications. Oxford University Press. 355 pp.

William, J. R. and R. W. Hann, Jr. (1978) Optimal operation of large agricultural watershed with water quality constrains, Texas Water Resource Research Institute, pp. 152.

William, J. R., C. A. Jones and P. T. Dyke (1984) A modeling approach to determining the relationship between erosion and soil productivity .American Society of Agricultural Engineers, 27.

Wischmeier WH, Smith DD. Predicting rainfall erosion losses. USDA agricultural handbook, vol. 537; 1978. Washington, DC

Wischmeier, W. H. and D. D. Smith (1965) Predicting rainfall-erosion losses from cropland east of the rockey mountains- Guide for selection of Practices for Soil and water Conservation, Agricultural Research Service, US Department of Agriculture Agricultural Handbook 282.

Wischmeier, W.H. and Smith, D.D. (1978). Predicting rainfall erosion losses: A guide to conservation planning. United States Department of Agriculture, Agriculture Handbook 537, United States Government Printing Office, Washington DC.

Wischmeier, W.H., (1959). A rainfall erosion index for a universal soil loss equation. Soil Sci. Soc. Am. Proc. 23 (3), 246–249.

Yaalon, D.H,(1997). Soils in the Mediterranean region: what makes them different?. Catena 28 (1997) 157-169.

Young, et al., 1988. AGNPS, an agricultural nonpoint source model. A watershed analysis tool. Conservation Research Report 35., U.S. Department of Agriculture, Washington, D.C.

Yu, B. and C. J. Rosewell. 2001. Validation of WEPP for runoff and soil loss prediction at Gunnedah, NSW, Australia. Australian Journal of Soil Research, Vol. 39, No. 5, 1131-1145.

Zhang, X.C., Nearing, M.A., Risse, L.M., McGregor, K.C., 1996. Evaluation of WEPP runoff and soil loss predictions using natural runoff plot data. Transactions of the ASAE 39 (3), 855-863.

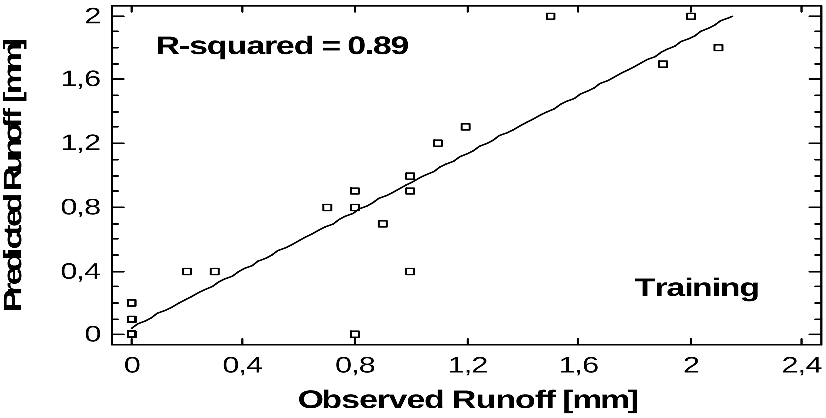
Zingg, R. W. (1940) Degree and length of land slope as it affects soil loss in runoff. Agriculture Engineering, 21, 59-64.

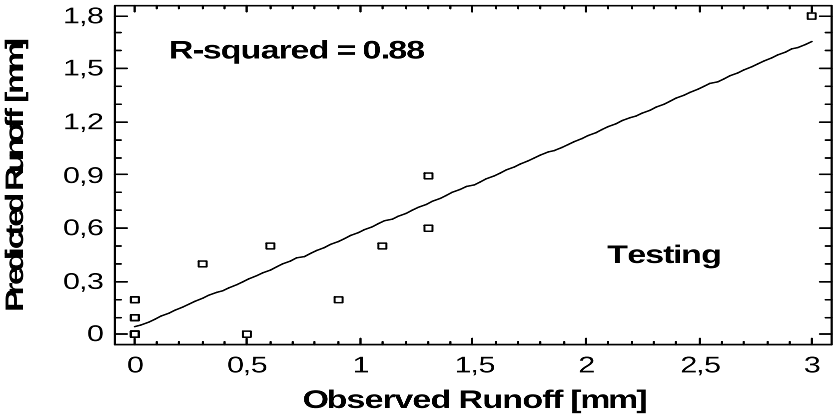
Zohary, M. (1947). A vegetation map of western Palestine. *Journal of Ecology* 43:1-19.

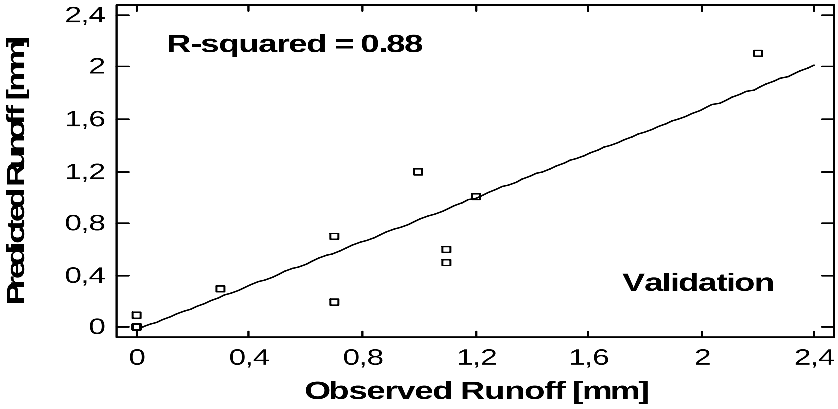
Annex

Annex 1

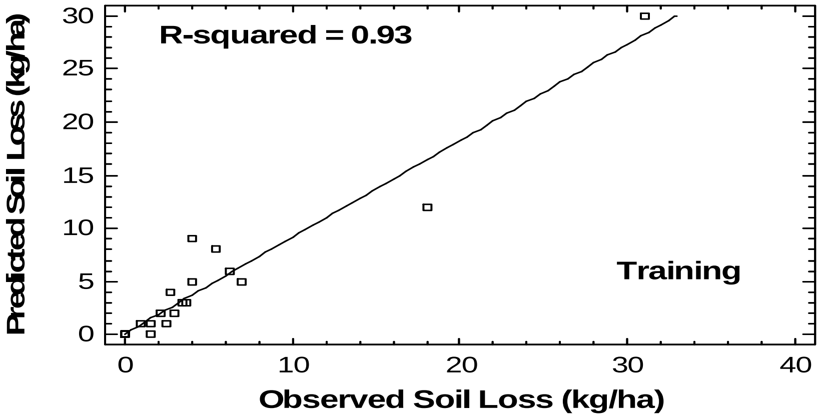
Annex 1.1 Measured versus predicted runoff by NETLU1 model.

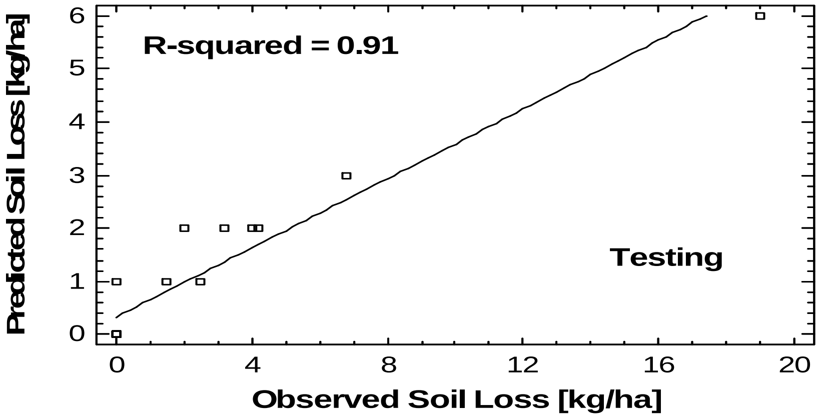


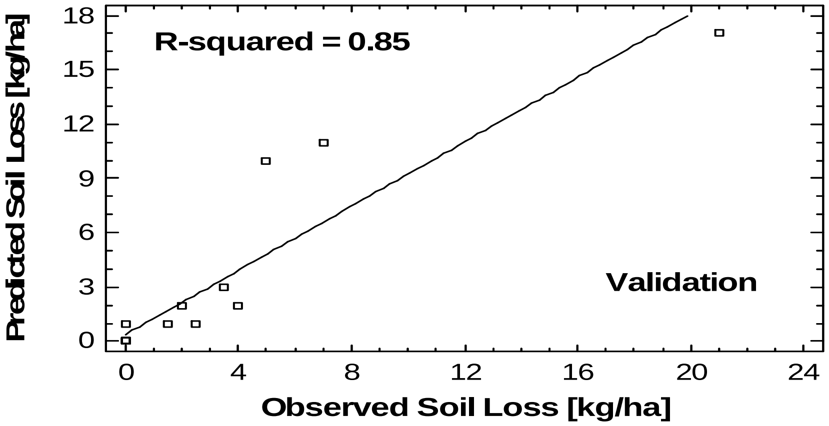




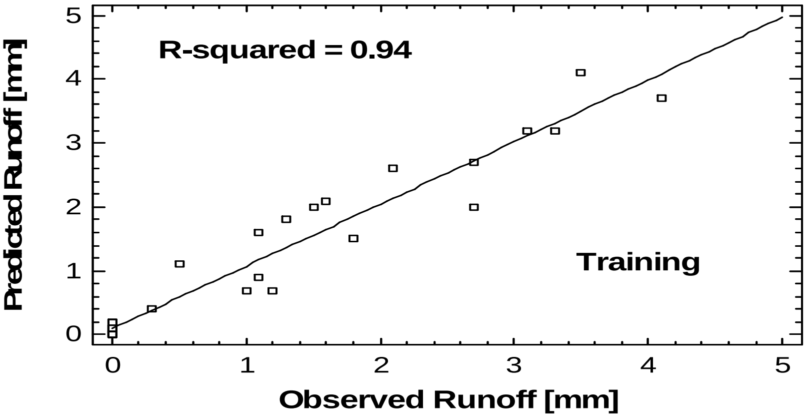
Annex 1.2 Measured versus predicted soil loss by NETLU1 model.

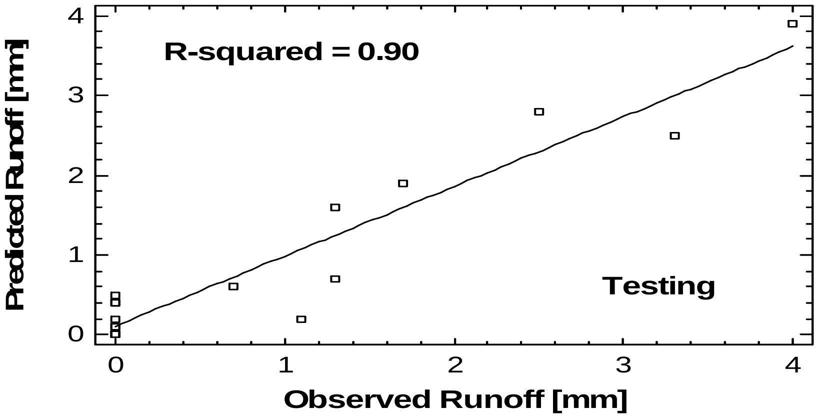


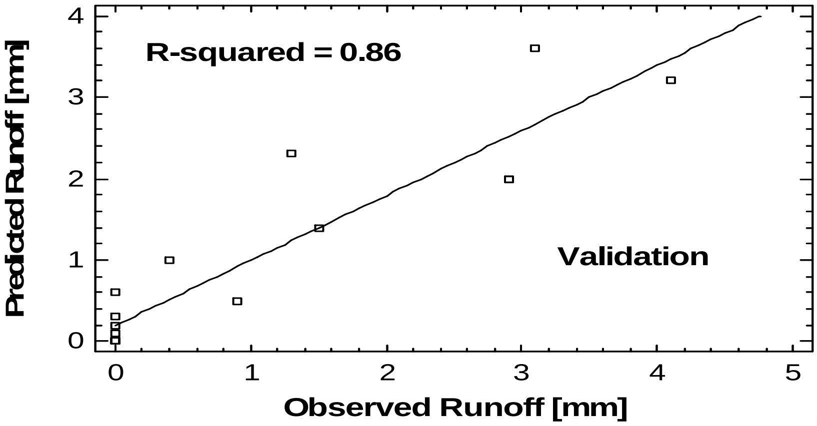




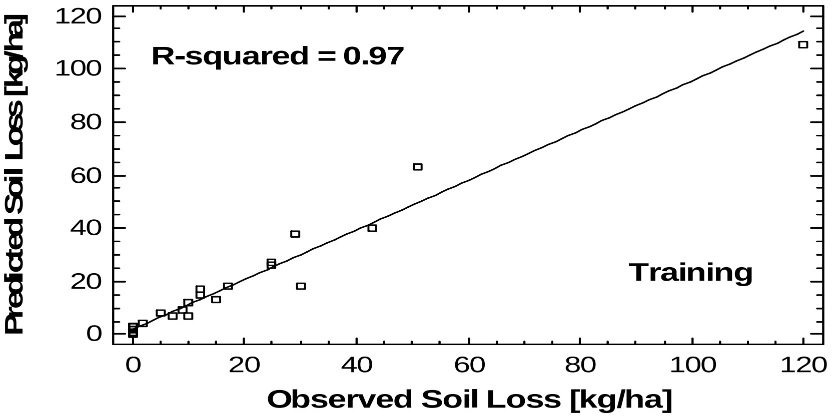
Annex 1.3 Measured versus predicted runoff by NETLU2 model.

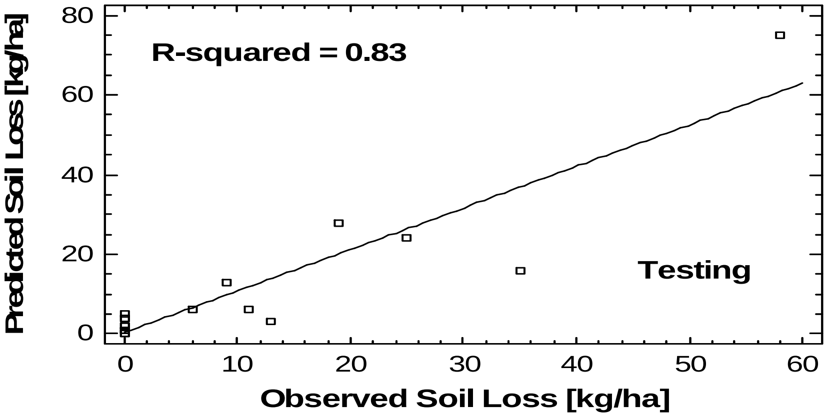


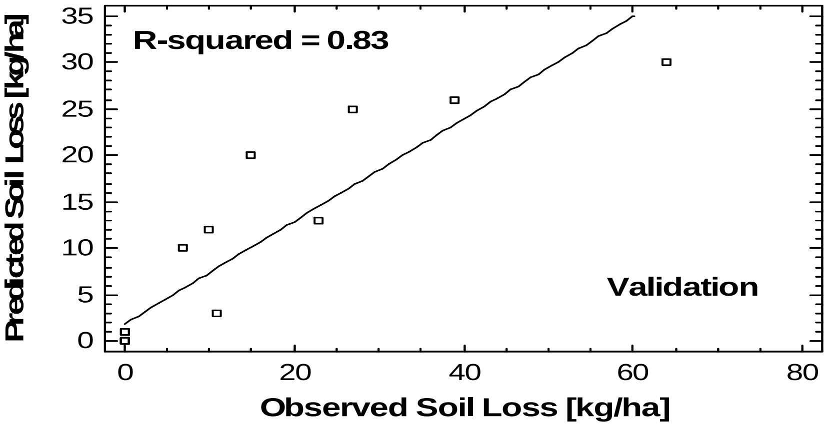




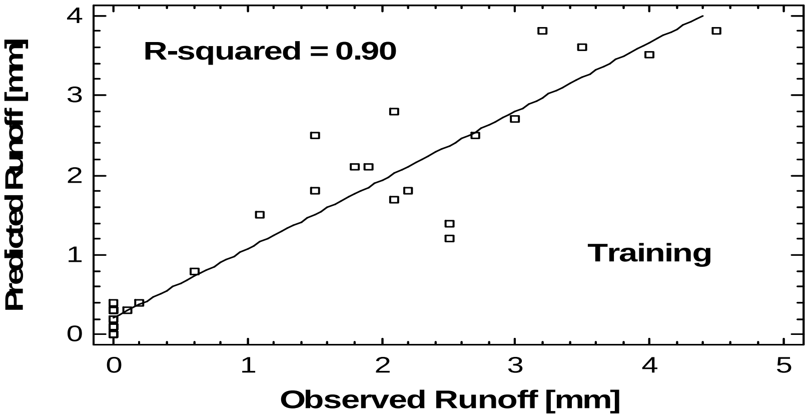
Annex 1.4 Measured versus predicted soil loss by NETLU2 model.

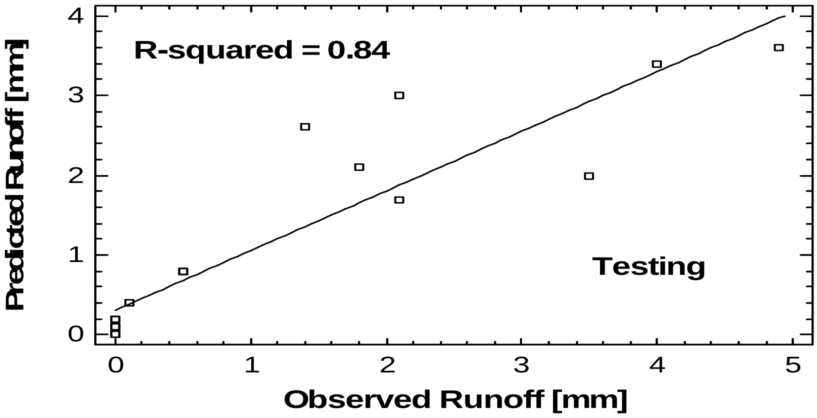


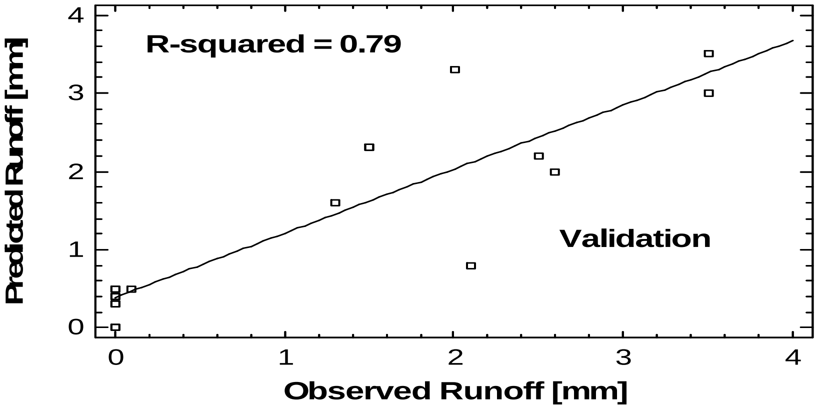




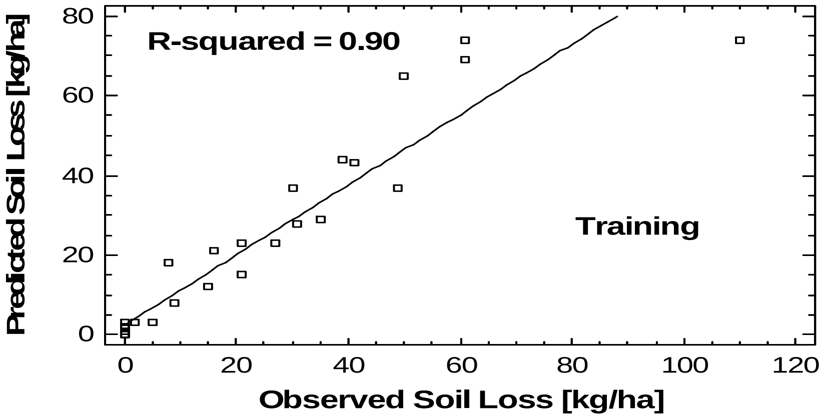
Annex 1.5 Measured versus predicted runoff by NETLU3 model.

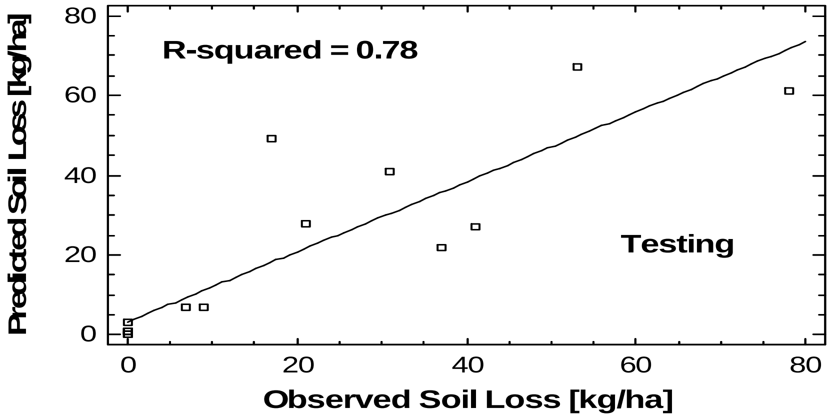


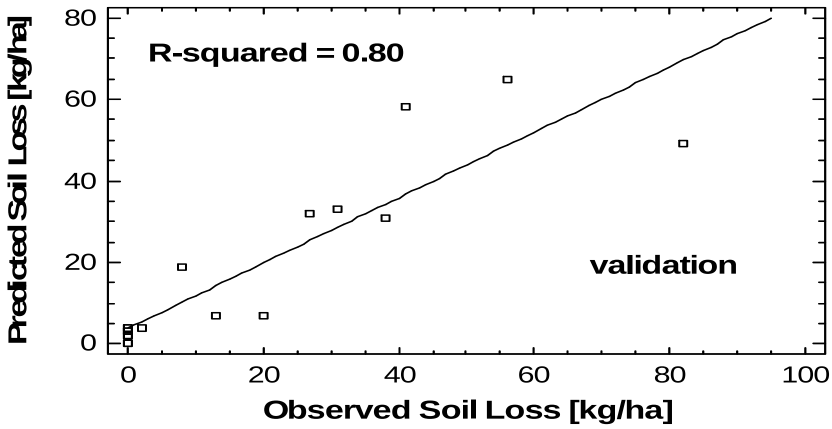




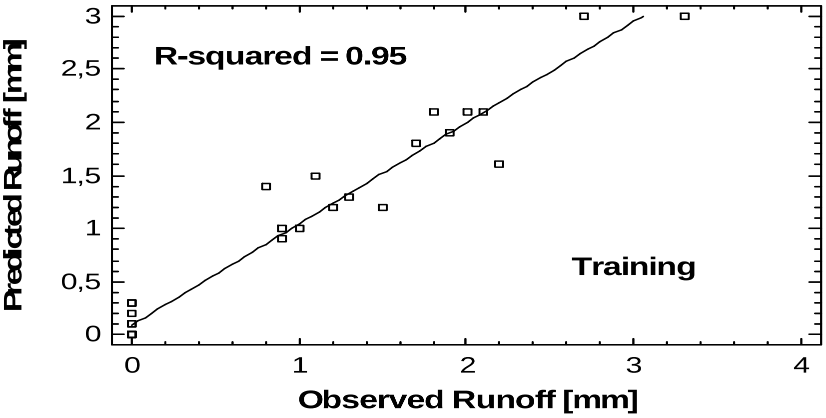
Annex 1.6 Measured versus predicted soil loss by NETLU3 model.

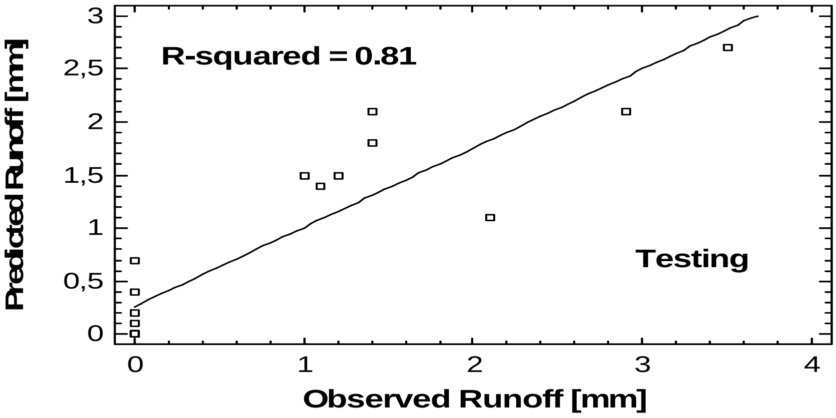


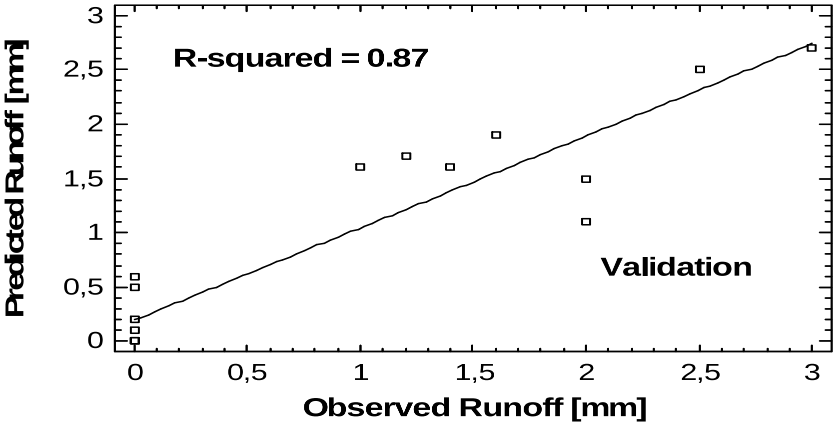




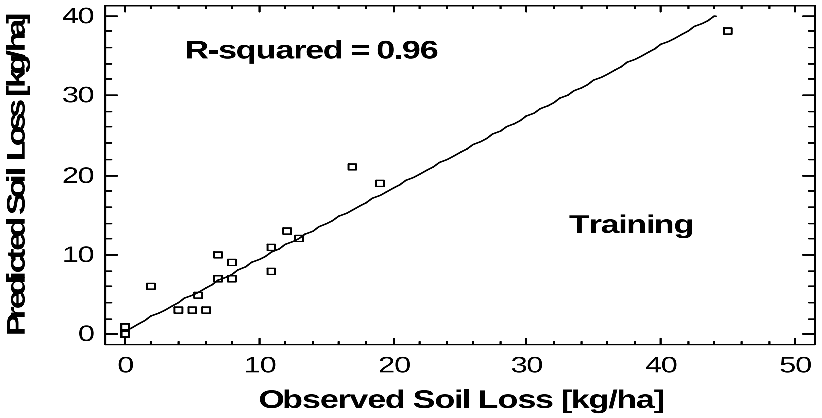
Annex 1.7 Measured versus predicted runoff by NETLU4 model.

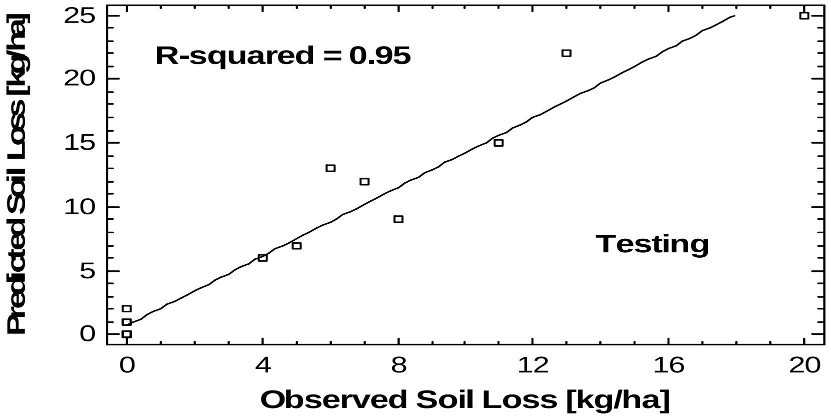


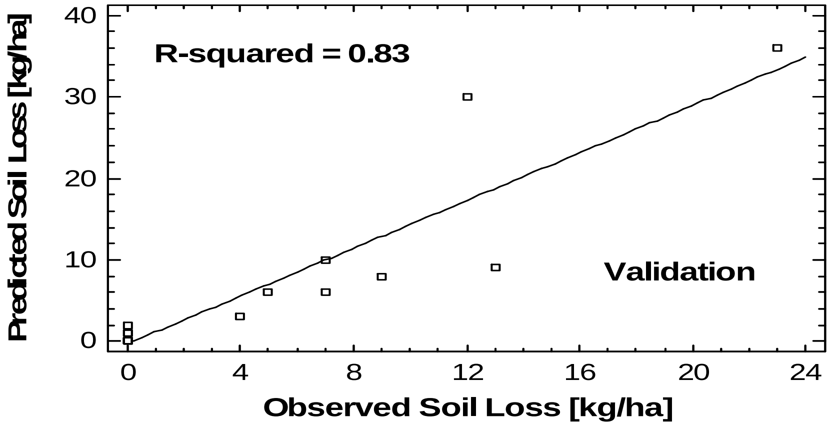




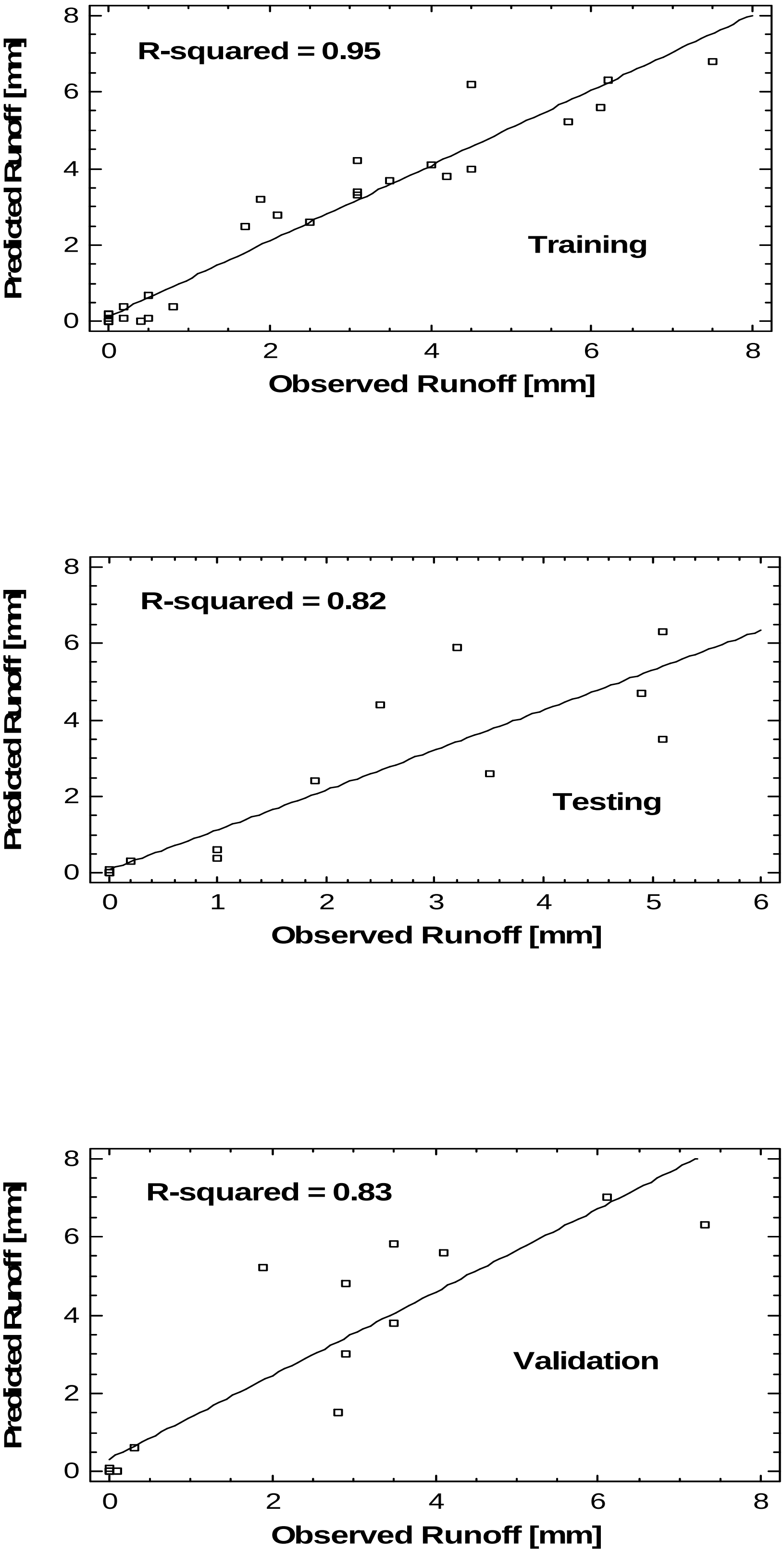
Annex 1.8 Measured versus predicted soil loss by NETLU4 model.







Annex 1.9 Measured versus predicted runoff by NETLU5 model.



Annex 1.10 Measured versus predicted soil loss by NETLU5 model.