THESIS

EROSION MAPPING AND SEDIMENT YIELD OF THE KABUL RIVER BASIN, AFGHANISTAN

Submitted by

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ABSTRACT

EROSION MAPPING AND SEDIMENT YIELD

OF THE KABUL RIVER BASIN, AFGHANISTAN

Soil erosion by water is a serious issue in Afghanistan. Due to the geographic landscape, soil and climatic conditions, and the latest deforestation activities, there has been intensive soil erosion which has resulted in prolonged and great impact on social and economic development of the region. In fact, recent environmental assessment shows that decades of war and continuous drought have resulted in widespread environmental degradation throughout the country; therefore, mapping of soil erosion at the basin scale is urgently needed. The Kabul River Basin was selected for the purpose of erosion and sedimentation modeling due to its great socio-economic impact. The main objectives of this study include: (1) calculations of the annual average soil loss rates at the basin level; (2) spatial distribution of soil erosion rates at the basin level; (3) predictions of deforestation effects on sediment losses under different land cover scenarios at the watershed level; and (4) calculation of sediment delivery ratios based on soil erosion rates, and sediment yields at the sub-watershed levels in the basin.

This study uses the Revised Universal Soil Loss Equation (RUSLE) model combined with Geographic Information System (GIS) techniques to analyze the gross soil loss rates and the spatial distribution of soil loss rates under different land uses. Digital elevation model (DEM), average annual precipitation data, land cover map and soil type map were used to define the parameters of the RUSLE model.

The annual average soil loss rate of the Kabul River Basin was estimated to be 19 tons/acre/year (4748 tons/km^2/year), and the gross mean annual soil loss rate found to be

47 million tons/year. By producing 57 % of the total annual average soil loss, rangelands were the primary contributor to the basin.

In case of the spatial distribution of erosion rates at the Kabul River Basin, the relationship between probability and annual average soil loss rates were analyzed. The analysis indicated that up to sixty percent of the mean annual soil loss rates are in the range of tolerable soil loss rate (0 - 5 tons/acre/year). Moreover, northern part of the basin is prone to more extensive erosion than the southern part.

The study predicted that if the forest region of the Kunar watershed is completely reduced to barren lands, the watershed will produce five times more sediment than the estimated soil loss rate from 1993's UN-FAO land cover map. The annual average soil loss rate in this watershed was about 29 tons/acre/year but it will increase to 149 tons/acre/year as deforestation continues to take place in the watershed.

The range of sediment delivery ratios for the basin's rivers is 2.5 -10.8 %. Based on this evaluation, the sediment delivery ratio for the sediment gauging stations in the basin are in the similar range of predicted values by the methods of Boyce, Renfro, Williams and Maner.

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A	Average annual soil loss (ton · $Acre^{-1}$ · yr)
C	Cover management factor (dimensionless)
E	Storm energy (ft. · .tons · $acre^{-1}$)
EI	Storm erosivity index (ft. · tons · $acre^{-1}$ · h^{-1}, or hundreds of ft · tons · $acre^{-1}$ · h^{-1})
I	Precipitation intensity (in · h^{-1})
I_{30}	Maximum 30-min intensity (in · h^{-1})
K	Soil erodibility factor (ton · acre · h · [hundreds of acre-ft · tons · in^{-1}]
L	Slope length factor (dimensionless)
OM	Organic matter (%)
P	Support Practice factor (dimensionless)
R	Average annual erosivity factor (hundreds of ft · tons · $acre^{-1}$ · yr^{-1})
S	Slope steepness factor (dimensionless)
S_{DR}	Sediment delivery ratio
SLR	Soil loss ratio (dimensionless)
SLP	Slope of the main stream (%)
R	Relief of watershed (m)
L	Maximum length of the watershed (m or km)
A_T	Gross erosion per unit area (tons · $acre^{-1}$ · yr^{-1})
Y	Sediment Yield (tons · yr^{-1})
SD	Specific degradation (tons · km^{-2} · yr^{-1})
m	Variable slope length exponent
P	Annual precipitation (mm)
	Greek Symbols
α	Slope
β	Scaling exponent
θ	Slope angle
σ	Slope gradient (%)
λ	Horizontal slope length (ft)

LIST OF ACRONYMS

AIMS	Afghanistan Information Management Services
ANSWERS	Areal Nonpoint Source Watershed Environmental Resources Simulation
CASC2D-SED	CASCade 2 Dimensional SEDimentation
CSU	Colorado State University
DEM	Digital Elevation Model
ESRI	Environmental System Research Institute
GAMES	Guelph Model for evaluating the effects of Agriculture Management Systems on Erosion and Sedimentation
IWMI	International Water Management Institute
MOTCA	Ministry of Transport and Civil Aviation
MUSLE	Modified Universal Soil Loss Equation
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
RUSLE	Revised Universal Soil Loss Equation
TREX	Two dimensional, Runoff, Erosion, and Export
U.S.	United State of America
UNEP	United Nations Environmental Programme
UN-FAO	Food and Agriculture Organization of the United Nations
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
USLE	Universal Soil Loss Equation
RUSLE	Revised Universal Soil Loss Equation
USPED	Unit Stream Power based Erosion Deposition
WASP/IPX	Water Quality Analysis Simulation Program/ In-Place Pollutant Export
WEPP	Water Erosion Prediction Project
SRTM	Shuttle Radar Topography Mission
SCS	Soil Conservation Services
NCSL	Non-Cumulative Slope Length
SLR	Soil Loss Ratio
NEPA	National Environmental Protection Agency

CHAPTER ONE

INTRODUCTION

1.1 Overview

Afghanistan is a landlocked country located in South Central Asia. It is bordered by Pakistan in the south and the east, Iran in the west, Turkmenistan, Uzbekistan and Tajikistan in the north, and China in the far northeast (Figure1.1). The rugged terrain of Afghanistan share the world's highest mountain ranges, Himalayas, Pamirs and Hindukush rising over 7000m, and running in a north east – south west direction.

Figure 1.1 - Location of Afghanistan on the World's Map

In Afghanistan, over 80% percent of the population relies directly on the natural resources of the basins to meet their daily needs. However, the United Nations Environmental Programme (UNEP) assessment shows that two-and-a-half decades of war and continuous drought have resulted in widespread environmental degradation throughout the country, which also poses a serious threat to the future Afghan livelihoods (UNEP 2003a). Environmental degradation causes extreme erosion and sedimentation problems in Afghan basins, which raises concerns among the international donor agencies, government organizations, and developers to invest on irrigation, water supply, and hydro power projects.

During the past decade the demand for water has dramatically increased in the cities. This is mainly due to the returning Afghan refugees majority of whom prefer to live in the cities. New reservoirs and dams are needed to be built in the basin for water supply and irrigation purposes. Erosion and sedimentation mapping of the basins is necessary to verify the region, extent, and severity of the environmental degradation problem. It can also be used as a primary tool for designers and developers to effectively evaluate the life expectancy of proposed dams.

Even though erosion is a major issue, there is no erosion and sedimentation mapping for the basins located in Afghanistan. Most of the available sedimentation data is on the sediment yield surveys measured during 1960 to 1980, prior to the construction of dams on the south-eastern rivers of Afghanistan. Since 2001, U.S. government has led efforts to collect and analyze climatic, geospatial, and remote sensing data to help assess Afghanistan's vulnerable natural resources. Utilization of the data from the U.S. National Oceanic and Atmospheric Administration (NOAA), the U.S. Geological Survey (USGS), the Food and Agriculture Organization of the United Nations (UN-FAO), and the Afghanistan government assessments are beneficial for erosion and sedimentation mapping of the basins.

As shown in Figure 1.2, there are five major river basins in Afghanistan: the Amu Darya, Northern, Harirod-Morghab, and the Kabul River Basin. Kabul River Basin covers 12% of the national territory and it drains about one-fourth (approx. 26%) of the total annual water flow in Afghanistan. The basin supports over seven million people where the majority of the population live in two main cities, Kabul and Jalalabad. The Kabul River Basin is selected for the purpose of erosion and sedimentation mapping due to its great socio-economic impact.

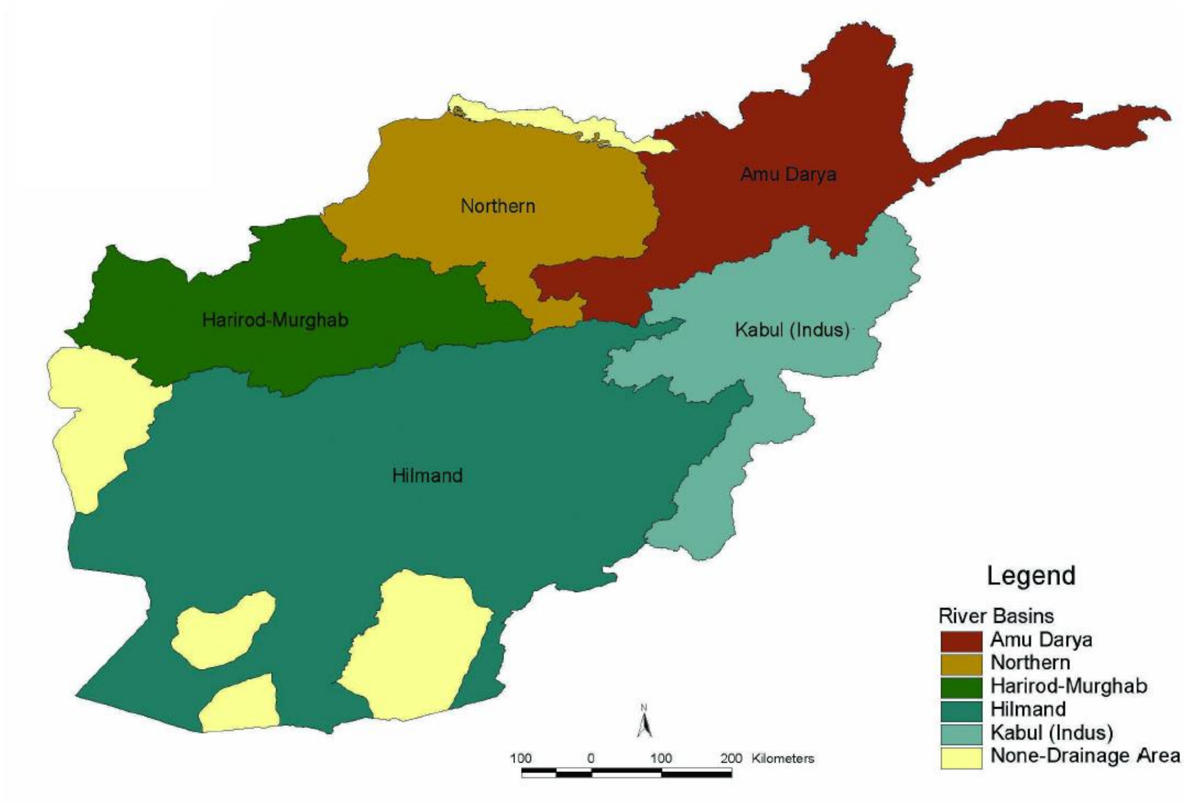


Figure 1.2 - Location of the major basins on Afghanistan's map (Favre and Kamal 2004)

Almost half of the Kabul River Basin is covered by rangelands, and barren soil is the second dominant land cover occupying 19% of the basin. The Hindu Kush Mountains in the northern part of the basin create a series of steep rugged valleys where the average slope is more than fifty percent (USGS 2000). Because of the land cover and topographic characteristics of the basin, most of the northern part of the basin is vulnerable to severe erosion. Soil erosion from steep upland areas causes high sediment yields in the rivers.

Massive destruction of forests, degradation of rangelands through fuel collection, and encroachment of pastureland for rainfed cultivation have resulted in increased incidence of flash flood, and soil erosions in the basin (Favre and Kamal 2004). In addition, illegal logging of the forest trees to neighboring countries is still a major challenge to the Afghan government. Demand for fuel wood for cooking and heating has increased as a result of widespread livestock decimation during past droughts. Figure 1.3 shows pastureland encroachment for rainfed cultivation and destruction of forest trees, where widespread changes of vegetation cover can be identified.

Figure 1.3 – a) Pastureland encroachment for rainfed cultivation b) destruction of forest trees in Kunar Province (Favre and Kamal 2004)

Sediment and storm flow along the rivers and streams are naturally balanced. Dam construction drastically changes this balance and creates an impounded river reach with extremely low flow velocities and efficient sediment trapping capacity. The impounded reach accumulates sediments and gradually decreases the storage capacity of the reservoir. The partially or completely "filled up" reservoir with sediments will no longer provide the benefits that depend on flow releases from the storage such as water supply, hydropower, recreation, and flood control. Due to lack of proper maintenance during destructive war in Afghanistan, many reservoirs have lost significant storage capacity as a result of sedimentation (Nouri 2012). The swift moving streams draining the barren watersheds carry a massive amount of suspended sediment and moving bedload. Figure 1.4 shows the excessive sedimentation in Hezarak irrigation storage dam located in the Kabul River Basin. Construction of the 10 m high Hezarak dam began in 2006 and was completed in June 2008. As of July 2009, the reservoir is almost completely filled of sediment with only 1 m of storage left (USACE 2009).

Figure 1.4 - Hezarak Dam, a) Upstream of the Filled Reservoir b) Along Top of the dam (USACE 2009)

1.2 Objectives

The overall objective is to determine the soil erosion rates using the RUSLE model and ArcGIS 10.1 at the Kabul River Basin. The specific objectives are:

1. Calculating the annual average soil loss rate using the Precipitation, Digital Elevation Model (DEM), Soil Type Map, and Land Cover Map data.
2. Analyzing the spatial distribution of soil erosion rates at the Kabul River Basin.
3. Predicting the effect of deforestation on sediment losses under different land cover scenarios at the Kunar watershed located in the Kabul River Basin.
4. Determining the sediment delivery ratio using the annual average soil loss rates, and the sediment yield of sub-watersheds on the Kabul River Basin.

Background information about the soil erosion processes, soil erosion models, sediment delivery ratio and Geographic Information Systems (GIS) are provided in Chapter 2. A brief description of the Kabul River Basin area along with the data set needed to study soil erosion and sedimentation in the basin is given in Chapter 3. The procedure to estimate the annual average soil loss rate using the RUSLE model parameters is described in Chapter 4. Spatial distribution of soil erosion rates due to effect of deforestation on the watersheds will be discussed in Chapter 5. Finally, a summary of conclusions is presented in Chapter 6.

CHAPTER TWO

LITERATURE REVIEW

Introduction

In this chapter, soil erosion is briefly overviewed in section 2.1. A discussion on the soil erosion models is provided in section 2.2. The sediment delivery ratio is covered in detail in section 2.3. The last section of this chapter covers the geographic information system (GIS) where Revised Universal Soil Loss equation (RUSLE) method is used for soil erosion modeling.

2.1 Soil Erosion

Soil erosion is the removal of the soil surface material by wind or water (Kirkby and Morgan 1980). Water is the most dominant agent of erosion where the process includes detachment, transportation and deposition of individual particles (sediment) by raindrop impact and flowing water (Foster and Meyer 1977; Wischmeier and Smith 1978; Julien 2002). Erosion is one of the major problems in agriculture and natural resources management. It reduces soil productivity, pollutes the streams and fills the reservoirs (Fangmeier et al. 2006). Human activity such as construction of roads, highways, and dams, control works on streams and rivers, mining, and urbanization usually accelerate the process of erosion, transport, and sedimentation (Julien 2010).

Erosion and sedimentation process is shown in Figure 2.1. Erosion process starts when raindrops hit the ground surface and detach soil particles by splash (Julien 2002). Detached particles are laterally transported to the rills by a thin overland flow and this process is called sheet erosion or interrill erosion (Foster and Meyer 1977). Most downslope sediment transport is carried through flow in the rills. Rill erosion occurs when water from sheet erosion combines to form concentrated small channels. This type of erosion is the prevalent form of surface erosion and is small enough to be removed by normal tillage operation (Frangmeier 2006). As seen in the figure, rills gradually join together to form larger channels and this results in gully erosion which is similar to rill erosion, except larger in scale. Unlike rill erosion, gully erosion cannot be obliterated by tillage.

Stream channel erosion results from concentrated water which forms from rills and gullies, and contains sediment removal from streambed and stream banks. Bank erosion in stream channels lead to form channel meandering which results in excessive erosion and deposition within the floodplain (Foster and Meyer 1977; Fangmeier 2006). It should be noted, if the amount of detached soil is more than the transport capacity, only the transportable amount will be carried downslope and the rest will be deposited on the segment.

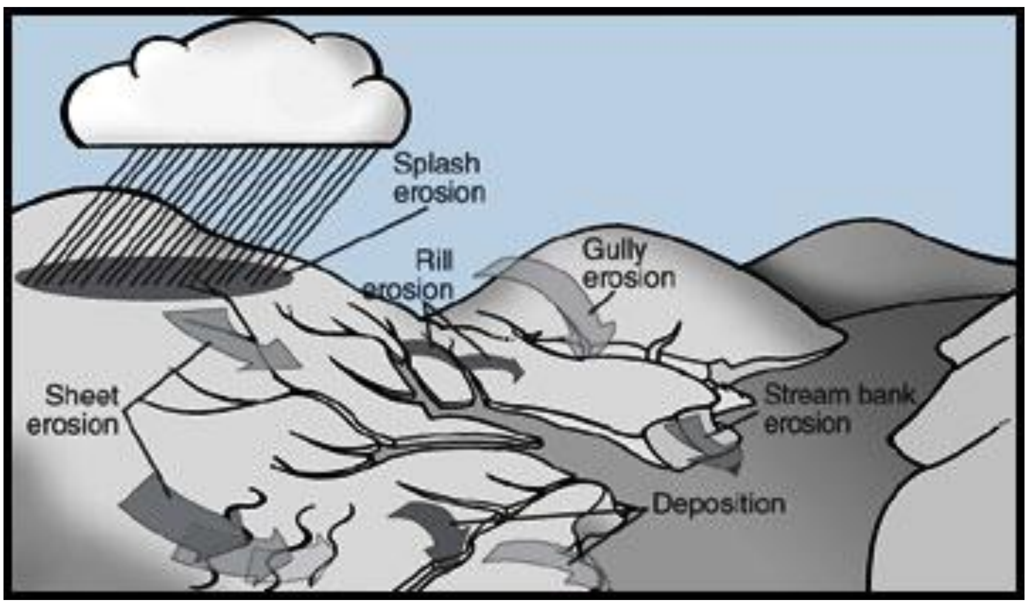


Figure 2.1 - Soil Erosion Processes (Broz et al. 2003)

2.2 Soil Erosion Models

It is possible to instrument a few individual farms or catchments in order to obtain the desired data, but it is not feasible to study every location on the Earth's surface in detail. Instead, predictive tools are needed to be applied. Erosion models can fulfill this function (Morgan 2011).

The Universal Soil Loss Equation (USLE) is one of the major developments in soil and water conservation in the 20th century. This empirical model has been applied around the world to estimate soil erosion by raindrop impact and surface runoff. USLE model is the result of decades of soil erosion experimentation conducted by university faculties and federal scientists across the U.S. It was initially proposed by Wischmeier and Smith (1965) based on the concept of detachment and transportation of particles from rainfall in order to calculate soil erosion rates in agriculture areas. They developed the model based on the data catalogued from more than 10,000 test plot-years throughout U.S. in 20 years (Wischmeier and Smith 1978). The test plots were designed to accurately estimate soil erosion under different conditions. The experimental plots were 6 feet wide by 72.6 feet long and comprised 1% of an acre. Research studies verified a variety of factors affecting soil erosion including climate, slope steepness, slope length, soil type, crop type, and conservation practices.

Additional research and findings by the scientists in the last 30 years has further upgraded and improved the model. The Modified Universal Soil Loss Equation (MUSLE) (Williams 1975), the Areal Nonpoint Source Watershed Environmental Resources Simulation (ANSWERS) (Beasley et al. 1980), the Guelph Model for evaluating the effects of Agriculture Management Systems on Erosion and Sedimentation (GAMES) (Rudra et al. 1986), the Unit Stream Power – based Erosion Deposition (USPED) (Mitasova et al. 1996), and the Revised Universal Soil Loss Equation (RUSLE) (Renard et al. 1997) are based on USLE and represent great improvements in the original model.

In 1997, the U.S. Department of Agriculture (USDA) developed a new model to predict long term, average annual soil loss erosion by water for a broader range of farming, conservation, mining, construction, and forestry. Revised Universal Soil Loss Equation (RUSLE) was announced to be the upgraded version of USLE (Renard et al. 1997) which incorporates improvements in factors based on new data but keeps the basis of USLE equation. The improvements were based on the revisions of USLE factors including development of a new procedure to calculate vegetation factor, introducing new algorithms to reflect rill to interrill erosion in slope length and steepness factors, and revision of climatic factors based on expanded database of rainfall-runoff in Western U.S. RUSLE model is enhanced with a computer program to facilitate the calculations.

The USDA-Water Erosion Prediction Project (WEPP) model was initiated in 1985 to develop a new and improved soil erosion prediction technology for use in soil and water conservation planning and assessment (Foster and Lane 1987). This model is a process-based, distributed parameters, both continuous and single-event simulation erosion prediction model. WEPP is based on the fundamentals of stochastic weather generation, infiltration theory, hydrology, soil physics, plant science, hydraulics and erosion mechanics (Flanagan et al. 1995). The model does not rely on USLE relationships for parameter estimation. Erosion processes within the model include erosion, sediment transport, and deposition across the landscape. This model uses a steady-state sediment continuity equation for predicting rill and interrill erosion processes and can be used for common hillslope applications or small watersheds.

The two-dimensional soil erosion model CASC2D-SED was initiated at Colorado State University (CSU) to simulate the dynamics of upland erosion during single rainstorms (Julien et al. 1995; Johnson et al. 2000; Johnson 1997). It is a physically based, gridded, distributed, hydrology, and erosion model. It uses color graphics to display the sediment flux, the amount of suspended sediment, and the net erosion and deposition calculated for upland sediment transport using the size fractions (sand, silt, and clay). The model is linked to the Geographic Information System (GIS) to visualize and develop the spatial and temporal input and output data.

The two-dimensional runoff erosion and export (TREX) is the latest family of watershed models developed at Colorado State University (CSU) to simulate chemical transport and fate process at the watershed scale. TREX (Velleux et al. 2008; England et.al. 2007) is a physically-based, spatially-distributed, hydrologic, and soil erosion model that simulates the hydrologic and chemical response of a watershed. TREX combines surface hydrology and sediment transport features from CASC2D watershed model with chemical transport feature from the WASP/IPX series of water quality models (Ambrose et al. 1993; Velleux et al. 2001).

2.3 Sediment Delivery Ratio

Sediment Delivery Ratio (S_{DR}) is defined as the ratio of the sediment yield at a given stream cross-section to the gross erosion from the watershed upstream of the measuring point (Julien 2010). It is a dimensionless scalar and conventionally expressed as:

$$S_{DR} = \frac{Y}{A_T} \tag{2.3.1}$$

where Y is average annual sediment yield per unit area and A_T is average annual erosion over that same area (Walling 1983; Richards1993). Observations show that only a small fraction of the eroded sediment within a drainage basin will find its way to the basin outlet and it is represented as the sediment yield. Sediment yield from catchments are often about an order of magnitude lower than the soil erosion rates measured from hillslope plots (Edwards 1993; Wasson et al. 1996). This signifies that most of the sediments travel only a short distance (Parsons and Stromberg 1998) and are deposited.

Factors that influence S_{DR} include hydrological inputs (mainly rainfall), landscape properties (such as: vegetation, topography, and soil properties) and their complex interaction at the land surface (Walling 1983; Richards 1993). It is difficult to identify the dominant controls on sediment response due to catchment to catchment variability and hence S_{DR} regionalization remains largely empirical.

Many empirical equations have been developed since the 1940's to estimate mean annual sediment yield in small catchments and watersheds. They are often statistically derived from the regional data to transfer the results of gauged to ungauged basins in the same region (Hadley and Schumm 1961). A widely used method to estimate S_{DR} is through the empirical S_{DR}-area power equation given below:

$$S_{DR} = \alpha A^{\beta} \qquad (2.3.2)$$

Where A is the catchment area (in km^2), α and β are empirical parameters (Maner 1958; Roehl 1962). The scaling exponent β contains key physical information about catchment sediment processes and its relationship with rainfall-runoff processes. Statistical regressions based on field sediment measurements show that the exponent β is mainly in the range of -0.01 to -0.25 (Walling 1983; Richards1993). However, Ferro and Minacapilli (1995) observed a lower value of -0.7 in one of former USSR catchments. This implies that S_{DR} decreases primarily with the size of the drainage area. According to one of the studies the exponent β also decreases with the increasing aridity (Richards 1993). Field data (Figure 2.2) indicates that the relationships between S_{DR} and drainage area changes considerably between different catchments over the world.

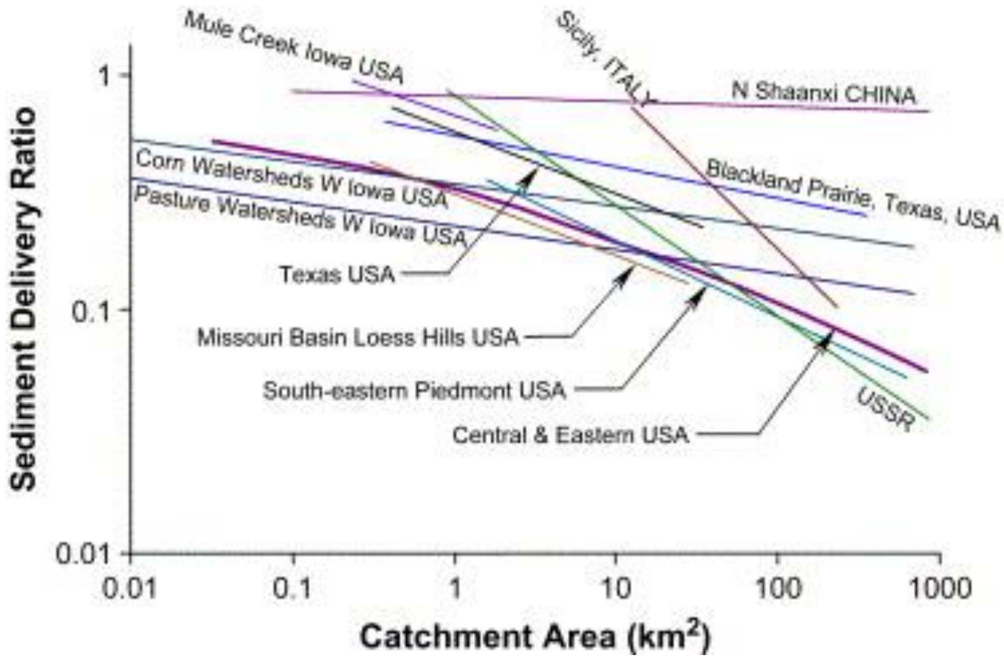


Figure 2.2 - Sediment delivery ratio versus catchment area relationships obtained from different areas around the world. (Hua Lu et al. 2003)

Boyce (1975) observed that the decrease in delivery ratio with increase in watershed size violates the Playfair's law and sediment balance equation because it implies continual floodplain deposition of sediment. The sediment balance equation is based on the hypothesis that sediment production which arrives from a given morphological unit or sediment source into a stream reach can be transported to the basin outlet. He concluded that S_{DR} versus drainage area curves are not adequate to represent the low slope portions of larger watersheds. Figure 2.3 shows the relationship between S_{DR} and size of drainage area (modified after Boyce 1975).

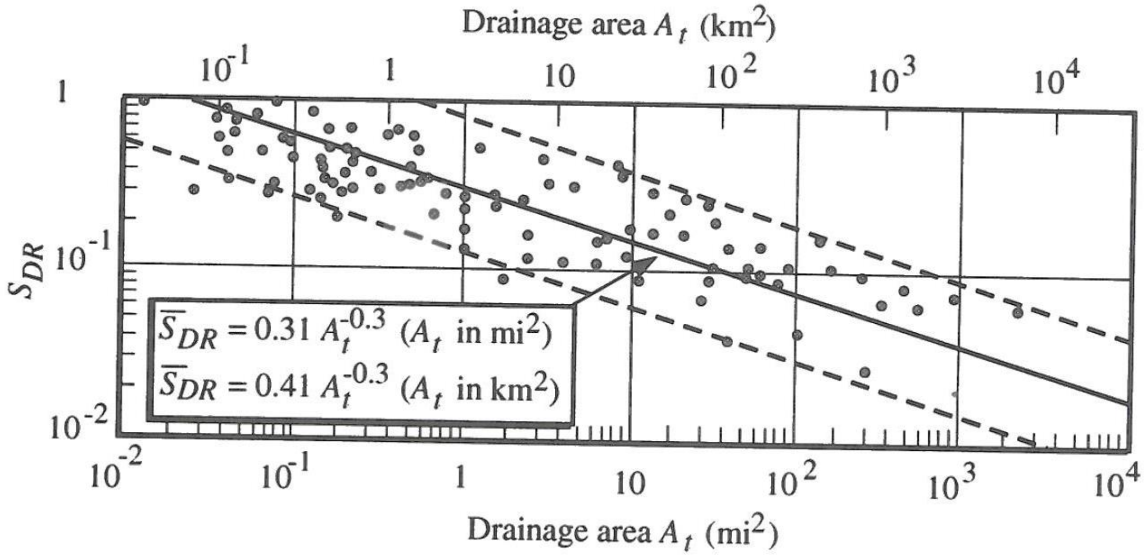


Figure 2.3- Relationship between S_{DR} and size of drainage area (Julien 2002)

It is important to note that there is some limitation related to S_{DR} method. Roehl (1962) stated that the values of α and β are different in various regions of the watersheds with the similar areas. S_{DR} has the problem of temporal and spatial lumping and lack of physical bases. It does not take into account the local factors affecting the sediment delivery such as rainfall, topography, vegetation, and soil characteristics (Richards, 1993). This is the reason that S_{DR} method cannot explicitly predict the location and rate of sediment deposition in lowland regions.

There are other methods available to predict sediment delivery and deposition through calculation of sediment transport capacity, avoiding the need for a lumped S_{DR} (Morgan et al. 1998; Van Rompaey et al., 2001). Although those methods are based on improved physical understanding of sediment transport processes, they require high resolution digital elevation models (DEMs) to route the flow and sediment and are restricted by availability of model inputs and parameters. They also rely on detailed sediment transport or runoff data to calibrate parameters, for example sediment transport capacity coefficients. Therefore, in view of the limitations of the other physical models, S_{DR} is considered an appropriate method to model large scale sediment delivery processes.

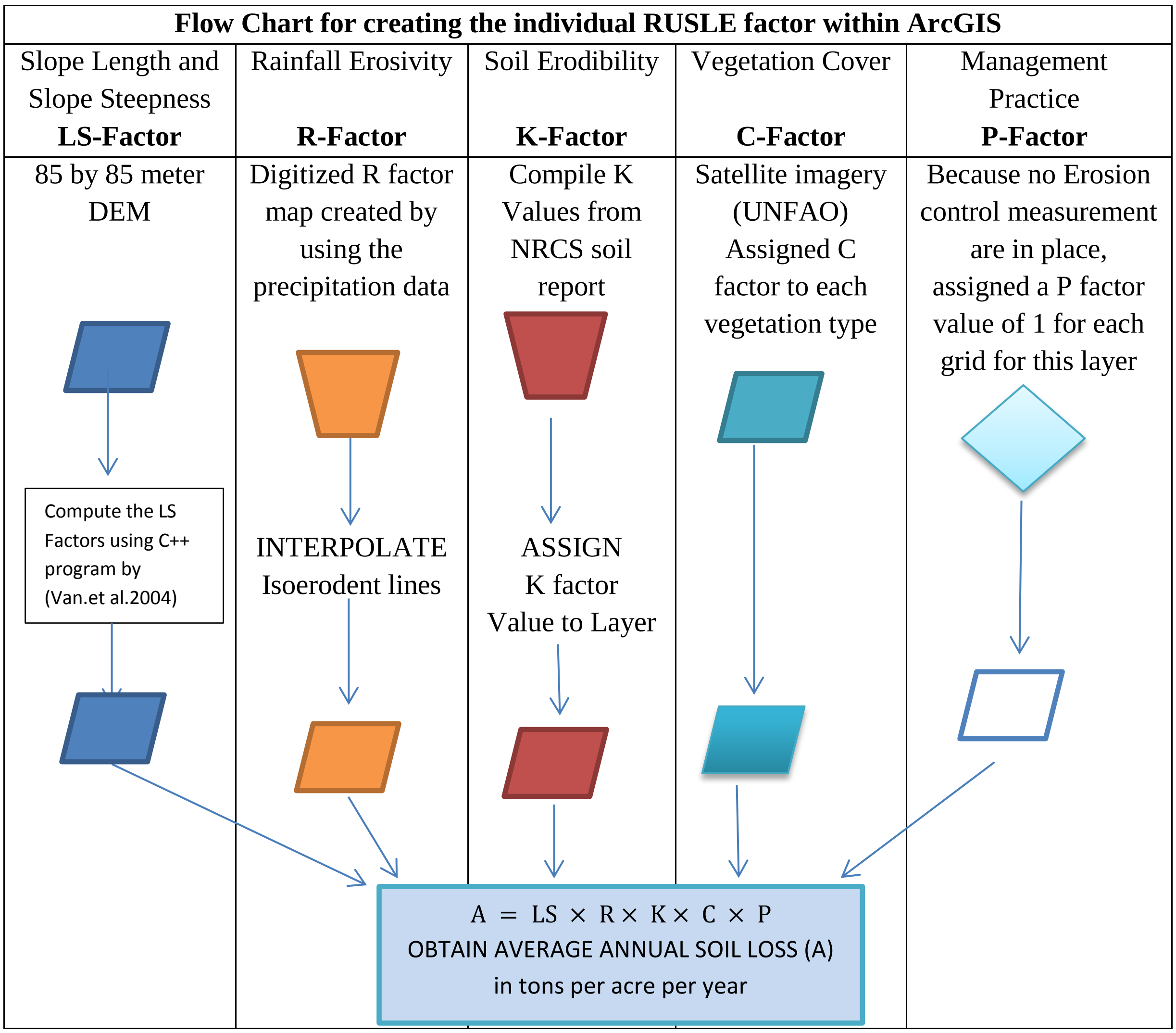
2.4 Geographic Information System (GIS)

Geographic Information System (GIS) is a computerized database management system which enables the user to capture, store, retrieve, analyze, manage, and visualize the spatial data that are linked to the real-world coordinates (ESRI 2005). GIS is enhanced with a set of geospatial tools that can perform statistical analysis, identify relationships, and determine patterns and trends.

GIS has been used as early as the 1960's. However, extensive application of GIS in environmental field particularly in hydrologic and hydraulic modeling, flood mapping, and watershed management did not begin until early 1990's (Coppock and Rhind, 1991; Maidment and Djokic, 2000; Moore et al., 1991). It has emerged as a powerful tool for handling spatial information and interaction with erosion models to provide extensive problem solving capabilities useful for effective decision-making processes (Renschler and Harbor, 2002).

Table 2.1 shows diagram of implementing the USLE factors within ArcGIS software. The table indicates which data were used to create the RUSLE parameters and how the annual average soil loss map was generated.

Table 2.1 – Diagram of implementing the USLE factors with ArcGIS software



CHAPTER THREE

STUDY AREA AND DATASET

Introduction

This chapter contains a brief description of the Kabul River Basin area along with the data set needed to study erosion and sedimentation in the basin. Application of soil erosion modeling, topography, precipitation, soil type, and land use are discussed in detail.

3.1 Overview of Kabul (Indus) River Basin

The Kabul River Basin is located in the eastern part of Afghanistan, which is between 36° 3' 7" to 31° 34' 33" latitude and 67° 36' 50" to 71° 41' 27" longitude. Drainage area of the Basin is about 71,139 sq. km., and thirteen provinces including Kabul are located in this basin. The basin is divided into eight watersheds, Kabul, Chak wa Logar Rod, Ghorband wa Panjshir, Alingar, Kunar, Shamal, Gomal, and Pishin Lora watershed that are shown in Figure 3.1.

Figure 3.1 - Location of watersheds in the Kabul River Basin

The basin includes all Afghan rivers that eventually join the Indus River in Pakistan. These rivers are: Kabul, Kunar, Panjshir, Ghorband, Alishing, Alinegar, Logar, Maidan, and Shutol. UN-FAO estimates show that the basin has the potential of 22 billion cubic meters per year in surface water (Favre and Kamal 2004). This basin has a great hydropower potential that has only been partially developed. A number of hydroelectric stations along the river are: Jabul Saraj (Completed in 1918 by American engineers), Surobi (completed in 1953 with German assistance), Mahipar (completed in 1966 with German assistance), Naghlu (completed in 1967, a joint Afghan-Soviet project), and Darunta hydropower plant (completed in 1967 by USSR and China). Recently four out of eight proposed irrigation and hydropower dams in Afghanistan are planned on the Kabul River Basin to further explore its great potential (MEW 2013). Figure 3.2 presents the location map of the Kabul River Basin. It also includes the river system, existing dams, proposed dams, and the major cities along the basin.

Furthermore, based on the DEM model provided by USGS (USGS 2000), average elevation of the Kabul River Basin is estimated about 2430 m above the sea level and the average basin slope is 30.56 %. The average annual temperature is extremely variable along the basin; it is almost 1℃ in the north where a series of high mountains are located and 16℃ in the south where the landscape of basin gets milder and wider (IWMI 2013). Average annual precipitation of the basin is around 400 mm and it is extremely variable. About two third of annual precipitation is concentrated in three months of the year, between Feb and April when most of the flooding occurs.

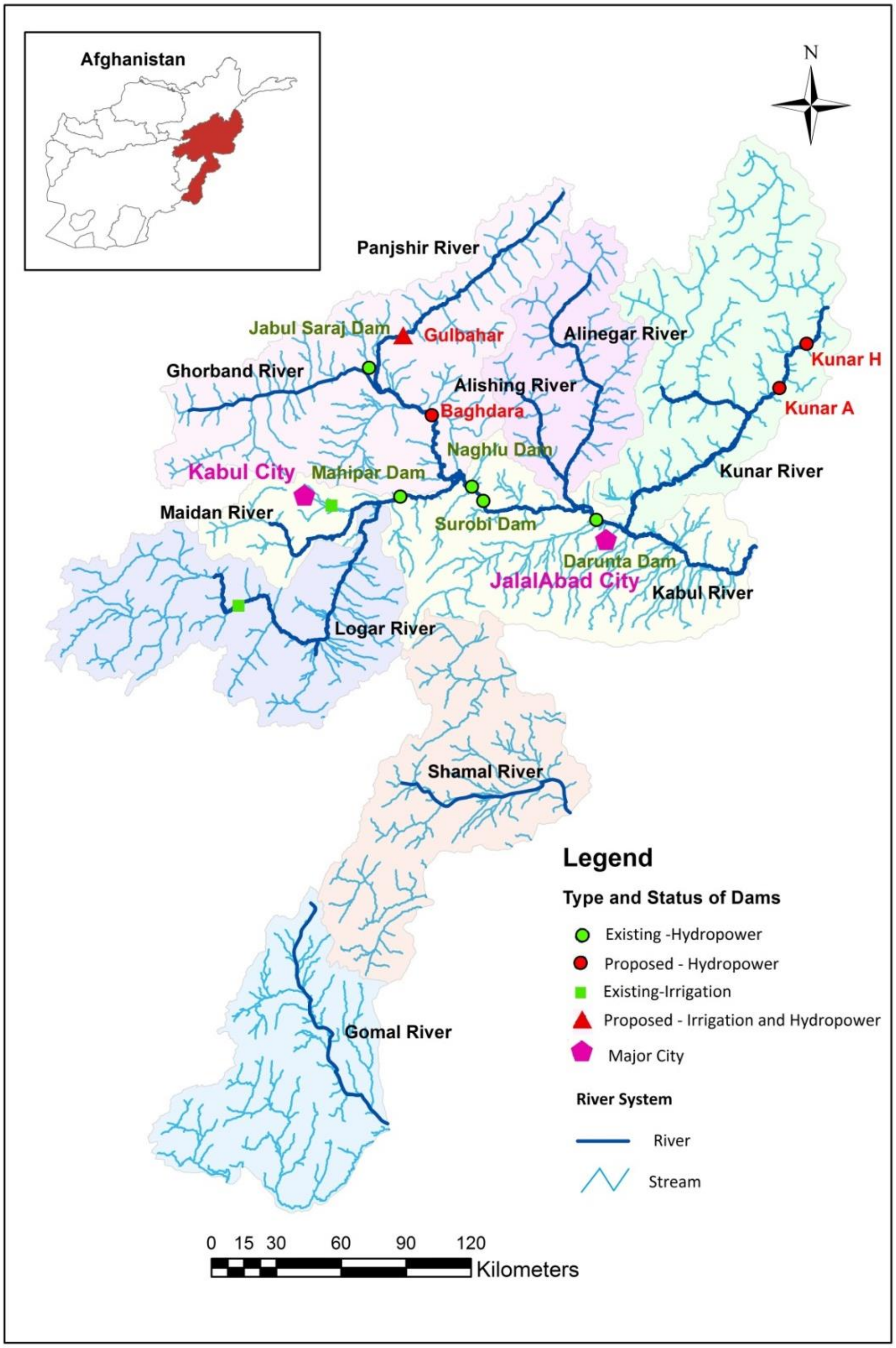


Figure 3.2 - Location map of the Kabul River Basin

3.2 Dataset of the Kabul (Indus) River Basin

Soil erosion by water is a serious global problem, and it is influenced by range of different factors such as rainfall intensity and distribution, topography of the watershed, soil type, land use, and vegetation cover. These factors are temporally and spatially well represented by using GIS techniques and through combining GIS with soil erosion models.

Since the first hydroelectric station was built in Afghanistan in 1918 by the American engineers, U.S continued assisting the Afghan government in creating a primary dataset to estimate and control erosion and sedimentation in the main basins. However, during the Russian invasion and civil war in Afghanistan most of the datasets were lost, and research institutions were closed. There are some gaps in precipitation data, so three different datasets were used to create monthly and yearly precipitation data.

The sediment yield data are based on 1940 to 1970's sedimentation survey reports from the basin. However, part of the dataset is based on the recent studies performed by various organizations. Since 2002 the United Nations Food and Agricultural Organization (UN-FAO), U.S Department of Agriculture (USDA), and U.S Army Corps of Engineers (USACE) have compiled, analyzed and, improved a relatively large dataset on Afghanistan's watersheds. Thematic maps including land cover, soil type, lakes and watersheds, population and settlements are available at their respective websites. A collection of these maps can also be found at Afghanistan Information Management Services website (AIMS 2013).

The following dataset are used to predict soil erosion and sediment delivery ratio in the Kabul River Basin:

1) Digital Elevation Model (DEM) (Data source: USGS, cell size: 85 by 85m)

2) Average Annual precipitation data (Data Source: MOTCA and IWMI, and NOAA)

3) Land cover types map (Data source: UN-FAO and AIMS, vectorized map)

4) Soil types map (Data source: USDA-NRCS, vectorized map)

5) Sediment yield reports in the Kabul River Basin (Data source: Montreal, 1980; UN-FAO, Thackev et.al; U.S. Army 2009)

3.2.1 Digital Elevation Model

A DEM can be used to identify different basin characteristics such as: drainage area, elevation, slope steepness, slope length, and streams relief ratio. DEM of the Kabul River Basin produced by the USGS is presented in Figure 3.4, (USGS 2000). This DEM is based on the Shuttle Radar Topography Mission (SRTM) data and 1:200,000 scale Soviet General Staff Topographic Maps. The purpose of this data set was to provide a single consistent elevation model to be used for national scale mapping, GIS, remote sensing applications, and natural resources assessment of Afghanistan.

As seen in the Figure 3.3, terrain of the Kabul River Basin ranges from 378 m to 6077 m with an average elevation of 2430 m. This DEM will be used to calculate the slope length and slope steepness factors in RUSLE model for the purpose of this study,

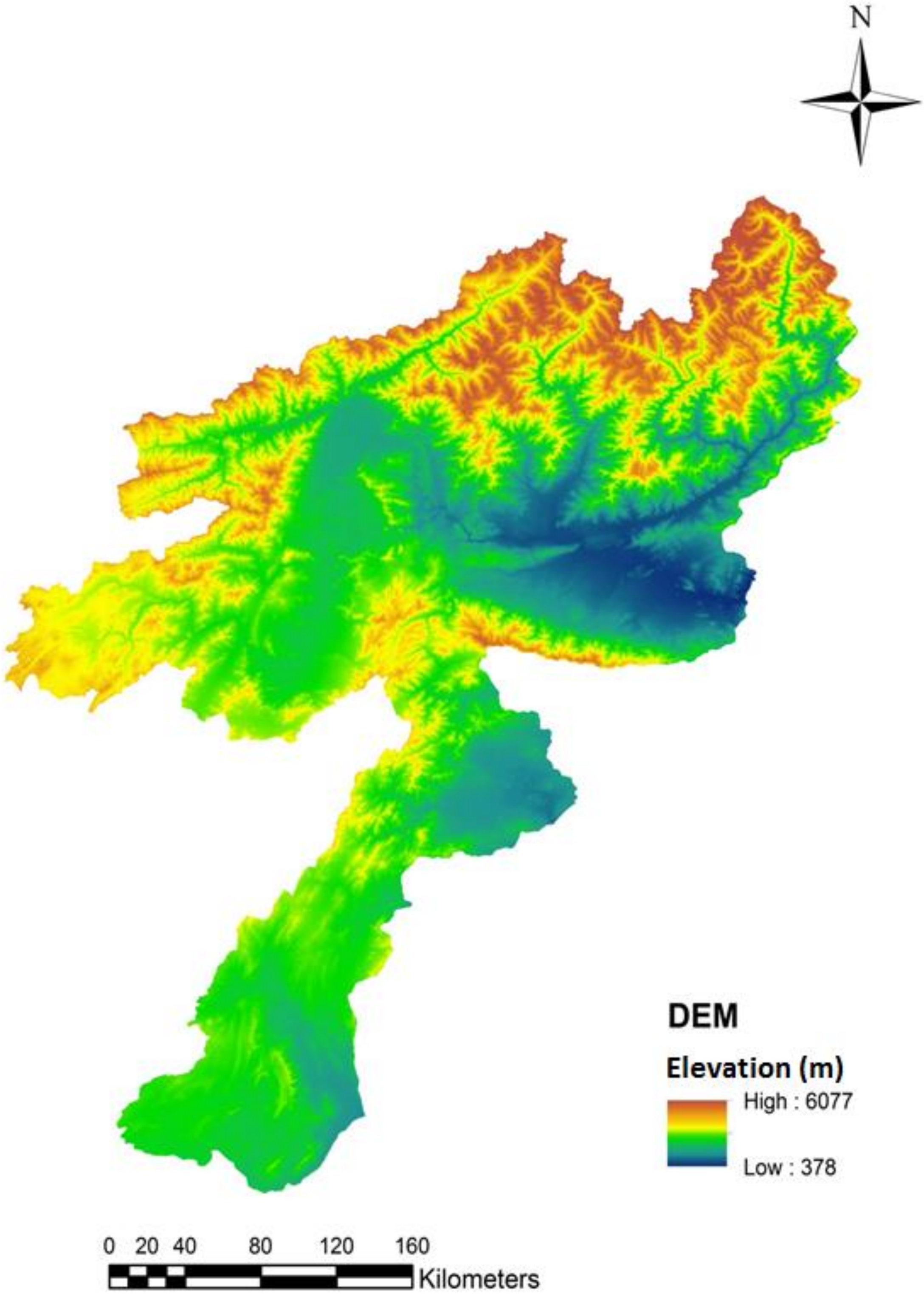


Figure 3.3: The digital elevation model of the Kabul River Basin (USGS, 2000)

3.2.2 Precipitation Data

Since the 1950's, National Oceanic and Atmospheric Administration (NOAA) – U.S. – has collected most of Afghanistan's monthly and annual precipitation data. These data were obtained from yearbook of meteorological elements prepared by the Ministry of Transportation and Civil Aviation of Afghanistan. For the gauge stations located in Afghanistan, the average annual rainfall values were obtained from NOAA's central library (NOAA 2012) and for the gauge stations located in Pakistan, the data were gathered from the World Water and Climate Atlas of the International Water Management Institute (IWMI). (IWMI 2013)

Fifty one rainfall gauge stations were selected for the study area, where the number of gauges inside and outside the basin area is 30 and 21, respectively. The stations located outside of the basin area were selected to help with interpolating the precipitation data for the gauge stations located far from the edges of the basin. Table 3.1 presents the name, identification number, location, beginning time, and average annual precipitation of each observatory station located in the Kabul River basin. Based on the stations data shown in the table the annual average precipitation in the Kabul River Basin is calculated about 400 mm.

Wischmeier and Smith (1978) recommended that at least 20 years of rainfall data is required to capture the natural climatic variation. Therefore, there is some limitation on calculating the rainfall-runoff erosivity factor for the Kabul River Basin. Figure 3.4 presents the location and the available recorded years of the rainfall gauge stations in the Kabul River Basin.

Table 3.1 - Rainfall Gauge Stations in the Kabul River Basin

Station	Code	Location		Observatory Stations			Precipitation mm/year
		Longtitude	Latitude	Begin_Date	End_Date	Country	
ASADABAD_FOB	692414	71.1400	34.8500	11/10/1987	4/28/2013	AFG	734
BAGRAM	409450	69.2830	34.9500	5/30/1973	11/15/1987	AFG	305
CAMP_AIRBORNE_HLZ	696714	68.8830	34.4000	2/16/2000	4/28/2013	AFG	287
CAMP_BLESSING_NANGA	692246	70.9000	34.9830	12/3/2007	2/9/2011	AFG	664
CHITRAL	415205	71.8000	35.8830	7/27/2005	10/10/2005	PAK	574
COP_CARWILE	691764	68.6500	33.8670	3/12/1985	7/2/2010	AFG	280
COP_CHAMKANI	692514	69.8170	33.8000	4/27/1987	2/22/2013	AFG	495
COP_CURRY	694594	68.8670	32.5170	10/19/1982	7/23/1991	AFG	185
COP_HONAKER_MIRACLE	692464	71.0830	34.9160	4/4/1984	4/8/2013	AFG	695
COP_MONTI	692644	71.3500	35.0330	9/23/2012	4/11/2013	AFG	843
COP_WILDERNESS	690176	69.4170	33.3670	12/28/2007	4/28/2013	AFG	295
DIR	415080	71.8500	35.2000	10/20/1980	4/28/2013	AFG	997
DROSH	415150	71.7830	35.5670	7/1/1957	4/28/2013	AFG	709
FAOZABAD	409040	70.5170	37.1170	3/4/1973	10/14/2012	AFG	452
FOB KUNDUZ	691984	68.9000	36.6600	1/16/1986	5/10/2013	AFG	263
FOB_BAMYAN	691774	67.8330	34.8170	11/23/2009	4/2/2013	AFG	287
FOB_BOSTIC	647094	71.5170	35.2170	2/6/1991	7/31/2012	AFG	774
FOB_CONNOLLY	692544	70.2000	34.2670	12/7/1985	4/18/2013	AFG	340
FOB_KALAGUSH	696704	70.3830	34.9670	2/15/2000	10/13/2012	AFG	485
FOB_KUTSCHBACH	690684	69.6330	34.8670	3/1/2009	4/28/2013	AFG	334
FOB_NAGHLU	695474	69.7000	34.6170	6/16/1999	4/28/2013	AFG	100
FOB_SHANK	692814	69.0600	33.9400	1/22/1985	4/28/2013	AFG	231
FOB_SHINWAR	696494	70.8170	34.1830	3/1/2009	7/28/2012	AFG	424
FOB_TILLMAN	694604	69.4500	32.9330	10/30/2009	11/15/2012	AFG	352
GARDEZ_1	696504	69.2500	33.5670	1/1/2005	4/24/2013	AFG	325
GHAZNI_1	692804	68.4170	33.5000	2/1/1985	4/28/2013	AFG	176
HAJIGAK	409330	68.1000	34.5830	2/2/1979	7/9/1979	AFG	458
HERRERA_HLZ	691324	69.7170	33.9330	10/11/2000	11/30/2012	AFG	455
ISHKASHIM	389570	71.6000	36.7170	1/3/1960	2/23/2005	AFG	663
JABUL_SARAJ	409320	69.2500	35.1330	3/19/1973	4/6/1990	AFG	368
JALALABAD_1	409540	70.4670	34.4330	1/8/1973	4/9/1992	AFG	158
Avg	-	-	-	-	-	-	**398**

Detailed information on rainfall gauge stations dataset can be found in Appendix A.

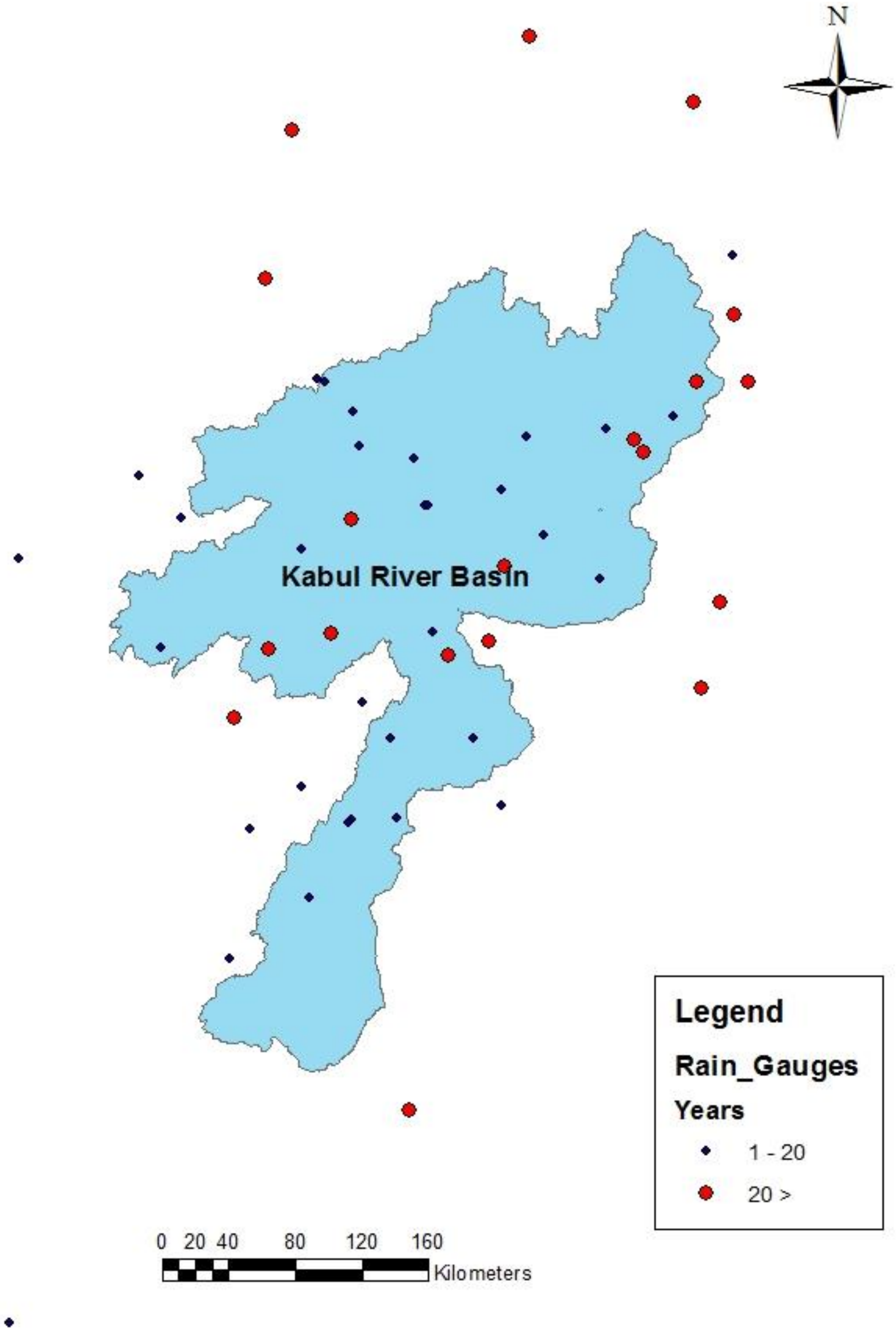


Figure 3.4 – Precipitation gauge stations with the years of recorded data in the Kabul River Basin

3.2.3 Land Cover Map

The first national land cover map of Afghanistan was published in 1972. It was derived from digitization of a set of hand-drawn hard copy maps, based on visual interpretation of aerial photographs acquired between years 1960 and 1970 by Afghanistan Geodesy and Cartography Head Office. The aerial surveys were combined with extensive ground surveys to improve the quality and presentation of the map.

The national land cover database was further improved by the Food and Agriculture Organization of United Nations through interpretation of image data recorded by the Earth observation satellites Landsat Thematic Mapper from 1990 to 1993(UN-FAO 1993). 45 to 50 images with 30 m spatial resolution were used for the purpose of classification that included 11 main land classes with a number of mixed classes and are as follows:

1. Urban Areas
2. Orchards/Fruit Trees, with 3 sub-classes
3. Irrigated Agricultural land, with 3 sub-classes
4. Rain Fed Agricultural Lands, with 2 sub-classes
5. Pistachio Forests
6. Natural Forests, with 2 sub-classes
7. Rangeland, with 2 sub-classes
8. Barren lands, with 3 sub-classes
9. Marsh/Swamp Areas, with 2 sub-classes
10. Water Bodies
11. Permanent Snow

The developed map by UN-FAO is used for the purpose of this study. Figure 3.5 represents land cover classification map of the Kabul River Basin. As seen in the figure, the basin consists of 18 classes that are defined as follows: Degenerate Forest/High Shrubs

(>1.5m in height), Fruit Trees, Gardens, Irrigated- Intensively Cultivated (1 Crop/year), Intensively Cultivated (2 Crops/year), Intermittently Cultivated-, Marshland Permanently inundated, Seasonal Marshland, Natural Forest with Closed cover (>60% cover), Natural Forest with Open Cover (20%-60% cover), Permanent Snow, Rainfed Crops (flat laying areas), Rainfed Crops (sloping areas), Rangeland (grassland/forbs/low shrubs), Rock outcrop/Bare land, Settlements, Vineyards, and Water Bodies.

As observed in Figure 3.5, Rangeland is the most extensive land cover in the basin, occupying about 51% of the basin area. Barren soil is second behind rangeland covering about 19%, followed by Forest, the most valuable natural resource for the residents along the basin, covering only about 16 %. Barren Soil and the Rangeland are the major contributors of erosion and sedimentation in the basin.

Land cover assessment and monitoring are essential for sustainability of natural resources. It is essential to tackle environmental degradation and regional climate change at the basin. National land cover maps of can be found at the (UN-FAO) Website: http://dwms.fao.org/~draft/home_en.asp

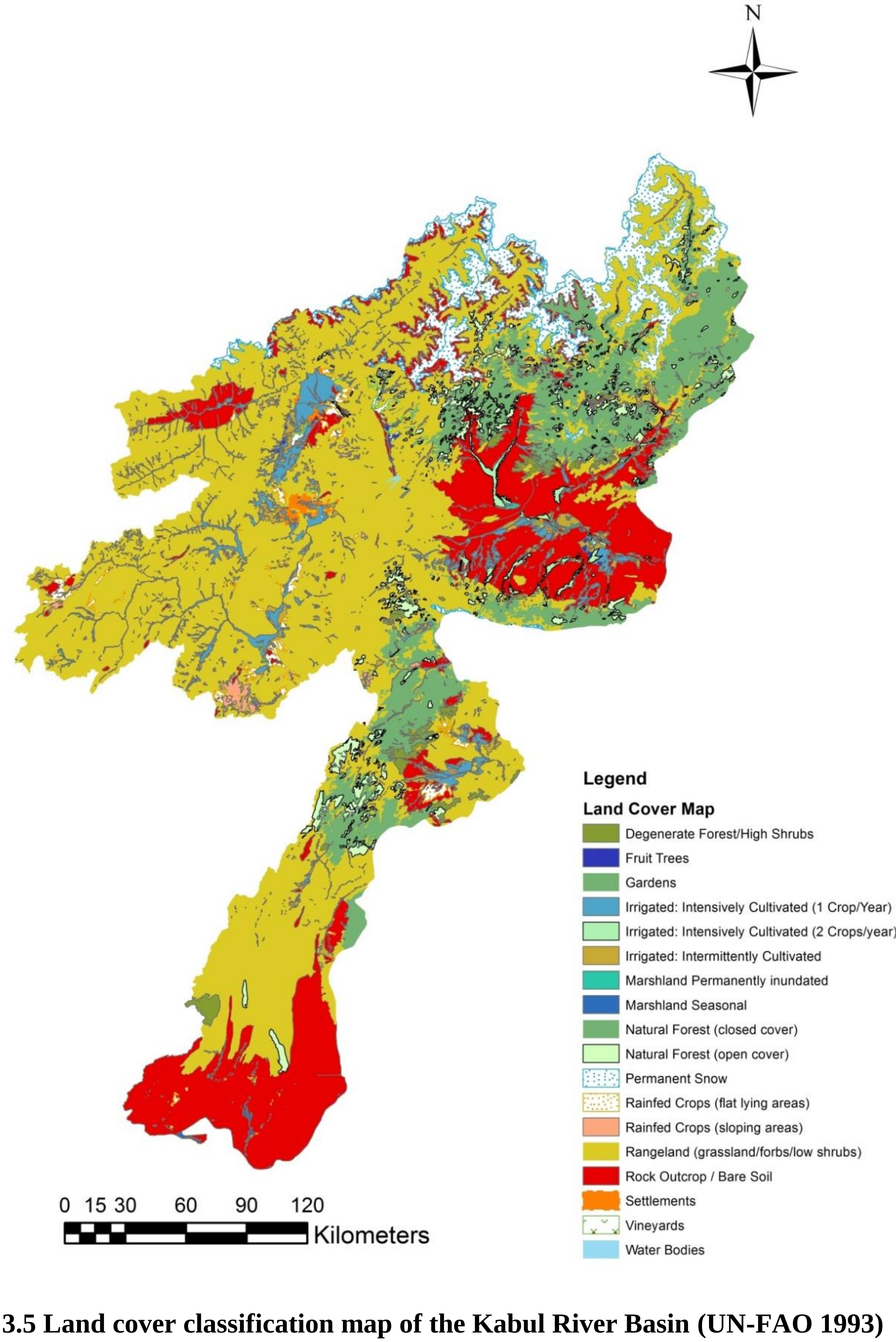


Figure 3.5 Land cover classification map of the Kabul River Basin (UN-FAO 1993)

3.2.4 Soil Classification Map

The primary source of soil classification map of Afghanistan is from the 1:1,000,000 World Soil Map Series developed by the U.S. Department of Agriculture-Soil Conservation Services (USDA-SCS) during the 1950s and 1960s. These maps were subsequently modified during the 1970s, 1980s and recently in 2001.

Based on the digitized USDA-SCS Soil Classification Map, shown in Figure 3.6, the Kabul River Basin is divided into 11 soil regions. Classification and soil texture detail are provided in Table 3.2. Rock with very fine sand is prevalent soil texture, covering about 35 % of the basin while silty clay loam with cobbly loam is the second widespread soil texture covering 23% of the basin area. In view of the given data, rock is an essential soil component influencing the soil erosion rate by resisting the surface erosion in the basin.

Table 3.2 - Soil classification of the Kabul River Basin

NO	Soil Classification	Soil Texture	Covered Area (%)
1	Calcixeralfs with Xerochrepts	Silt Loam with Silty Clay Loam	4.6
2	Haplocambids with Torriorthents	Silt Loam	12.5
3	Haplocambids with Torripsamments	Silt Loam with Fine Sand	0.1
4	Rocky Land with Lithic Cryorthents	Bare Rock with Loamy Very Fine Sand	17.8
5	Rocky Land with Lithic Haplocambids	Rock with Loamy Very Fine Sand	17.4
6	Rocky Land with Lithic Haplocryids	Rock with Silt Loam	18.3
7	Rocky Land with Ice-Capped Bare Rock	Bare Rock	1.5
8	Torifluvents with Torripsamments	Silt Loam with Fine Sand	2.1
9	Torriorthents with Torifluvents	Silt Loam	0.9
10	Xerochrepts with Xerorthents	Silty Clay Loam with Cobbly Loam	23.4
11	Xerorthents with Xeropsamments	Cobbly Loam with Fine Sand	1.4

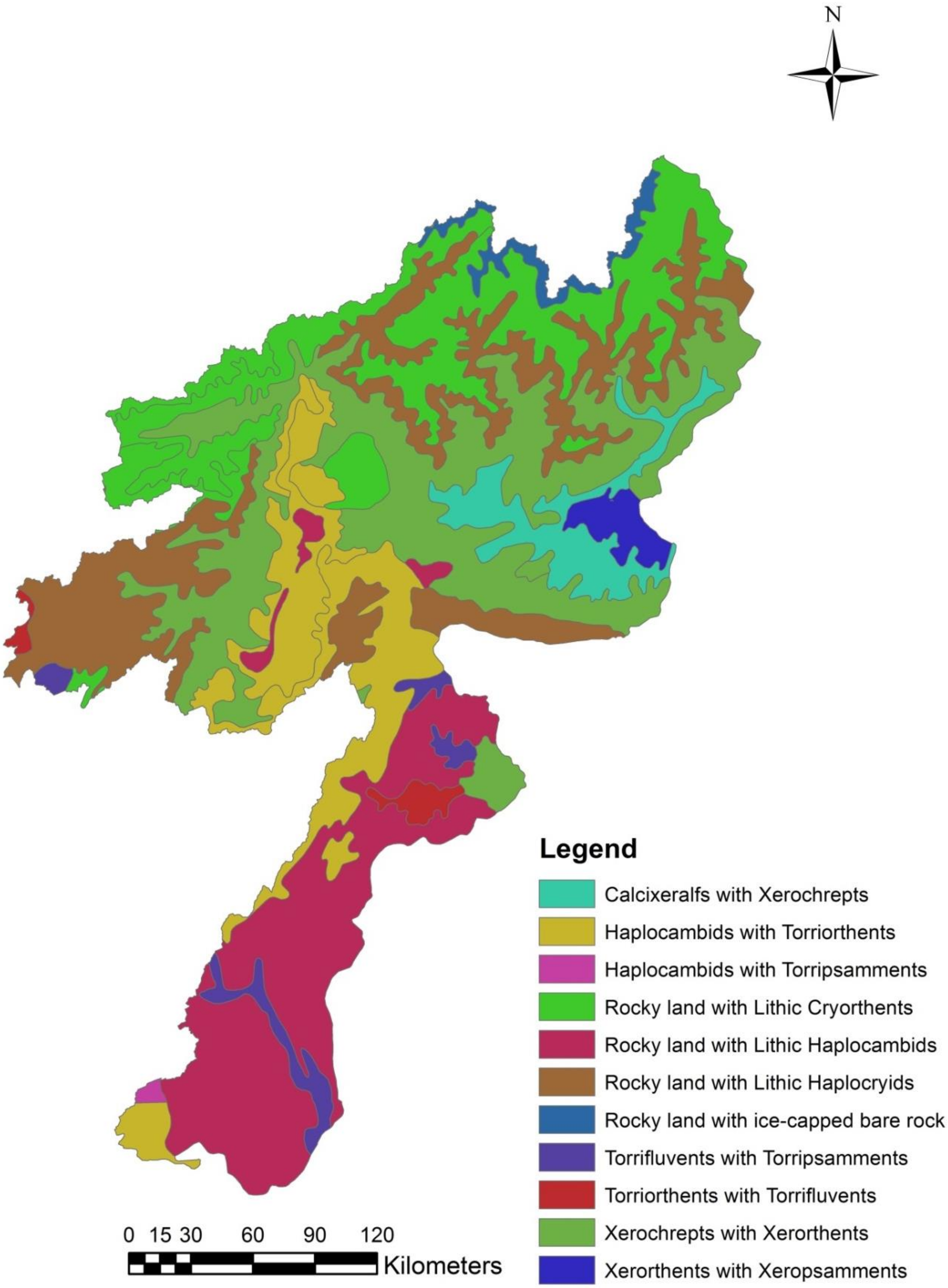


Figure 3.6 - The soil classification map of the Kabul River Basin (USDA-SCS 2001)

3.2.5 Sediment Yield Data

The most extensive study of sediment yield in the Kabul River Basin was performed by Montreal Engineering Company. This study estimated sediment yields at proposed dam sites on the Logar, Maidan, Panjshir, Ghorband, and Kabul rivers. The study was based on two-week sediment measurements surveys combined with the data collected at established stream gauge stations by the Afghan Ministries during the1960’s and 1970’s. The study did not specifically state how bedload amounts were accounted for the sediment yield. Sediment yield data was obtained from the master plan “Kabul River Valley Development Project” (Montreal 1980). Sediment yield data is also obtained from the Global River sediment Yields Database maintained by the UN-FAO (UN-FAO 2013).

Figure 3.7 shows location of the sediment gauge station along the basin and Table 3.3 presents sediment yield for the stations located in the Kabul River Basin. The unit for sediment yield for the river is given in ton of sediments per square kilometer of the watershed area per year. Panjshir and Kunar rivers have the highest sediment yield in the basin and this is due to their locations in the upper region of the basin with steeper slopes and higher rainfall intensity. There is also a local variation in sediment yield along the rivers. For instance, Kabul river at Tangi Gharu has the lowest sediment yield of 148 tons/sq.km/year. However, it increases to its highest yield value of 410 tons/sq.km/year when the river joins other tributary rivers near Naghlu Dam (about 80 km downstream).

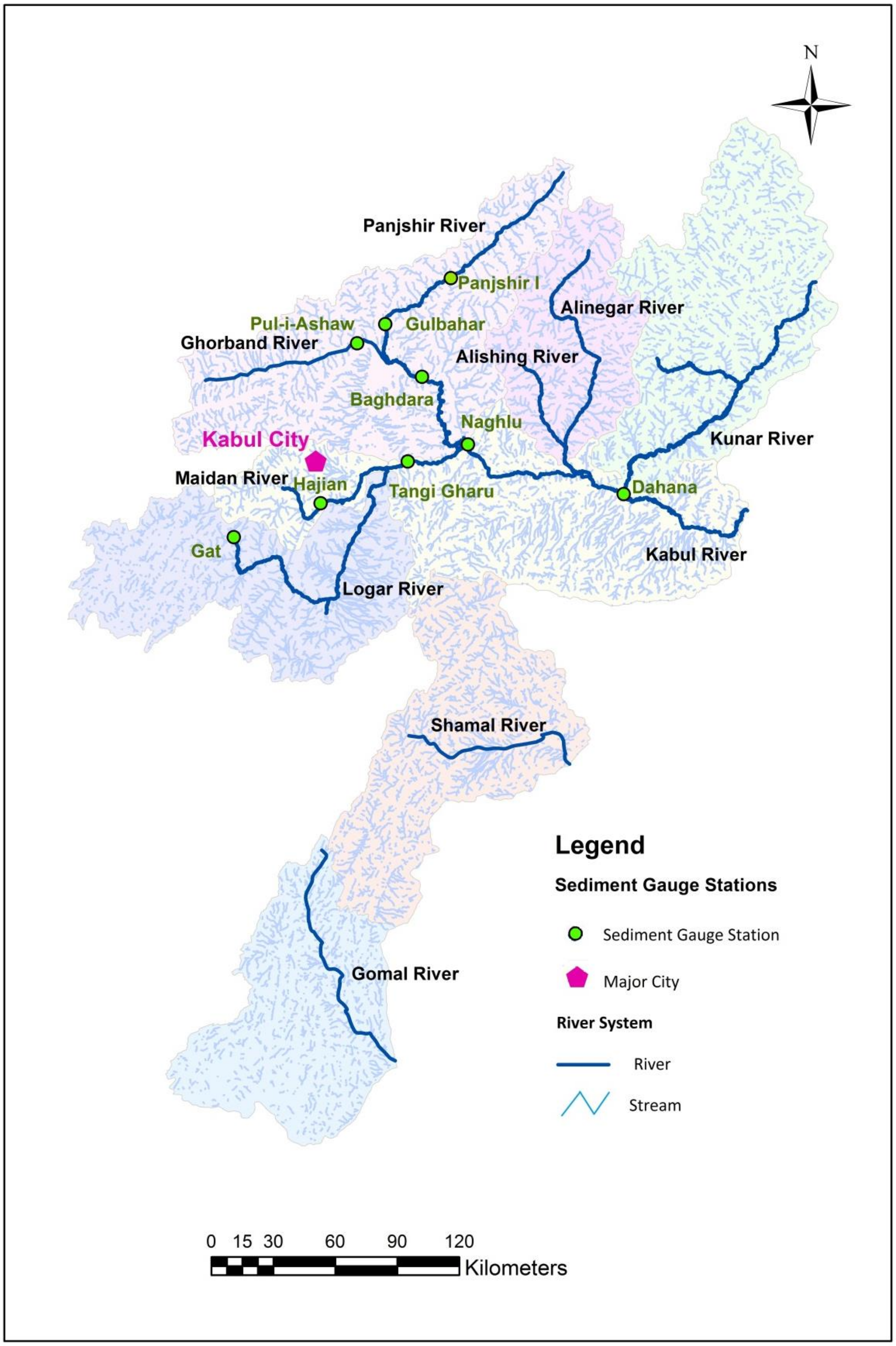


Figure 3.7 – Location map of sediment gauge stations at the Kabul River Basin

Table 3.3 – The sediment yield data of the stations located in the Kabul River Basin

No	River	Location			Drainage Area	Sediment Yield/Area
		Station Name	**Longitude**	**Latitude**	**Sq.km**	**tons/sq.km/year**
1	Panjshir	Panjshir I	69.6333	35.3666	1280	275
2	Panjshir	Baghdara	69.4833	34.9333	10850	455
3	Maidan	Hajian	68.9400	34.3852	1520	250
4	Logar	Gat	68.4833	34.2356	3780	150
5	Kabul	Tangi Gharu	69.4000	34.5666	12850	148
6	Kunar River	Dahana	70.5361	34.4151	11664	780
7	Ghorband	Pul-i-Ashawa	69.1333	35.0833	4020	420
8	Kabul	Naghlu	69.7174	34.6396	26046	410
9	Panjshir	Gulbahar	69.2833	35.1666	3565	750

3.3 Summary:

Chapter 3 presents the site description and data sets including topography, average annual precipitation, soil types, land use cover, and sediment yield survey data of the Kabul River Basin. These data are required to analyze and estimate the Revised Universal Soil Loss Equation- RUSLE- method erosion factors. Chapter 4 will present the use of these data. Topography data –DEM- is used to estimate the slope length (L) and slope steepness (S) factors. Average annual precipitation is used to calculate the rainfall-runoff erosivity factors (R). Vectorized soil type map is transformed into raster data with 85m grid cell size to compute the soil erodibility factor (K). The land cover map, extracted from Landsat Thematic Mapper, is used to predict the cover management factor (C).

CHAPTER FOUR

METHODOLOGY AND MAPPING

Introduction

This chapter describes the procedure to estimate the annual average soil loss rate using the RUSLE model. Section 4.1 presents the basic concepts of RUSLE parameter estimation; Section 4.1.1-4.1.6 covers the estimation and reasonability analysis of the six parameters used in RUSLE model. A summary and discussion on the results of the parameters used in soil erosion estimation is provided in section 4.2.

4.1 RUSLE Parameters Estimation

The erosion rate for a given location results from combination of many physical variables and management practices. True measurement of soil loss is not possible for each variable under field conditions. Therefore, soil-loss equations were developed to enable conservation planners, environmental scientists, and others concerned with soil erosion to extrapolate the limited erosion data to many localities and conditions that have not been directly represented in the research (Morgan 2011).

Scientists have been involved in soil erosion research for a long time, and many models for soil erosion loss estimation have been developed (Wischmeier and Smith 1978; Nearing et al. 1989; Veihe et al. 2001; Shen et al. 2003). However, in practice, the Universal Soil Loss Equation (USLE) and later the Revised Universal Soil Loss Equation (RUSLE) has been the most widely used model in predicting soil erosion loss. The Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1965) was based on many years of data from about 10,000 small test plots from throughout the US. Each test plot had about 22 m flow lengths and were all operated in a similar manner, allowing the soil loss measurements to be combined into a predictive tool. The USLE was originally developed for soil erosion estimation in croplands on gently sloping topography (Wischmeier and Smith 1978) and later the RUSLE broadened its application to different situations, including forest, rangeland, and disturbed areas (Renard et al. 1997).

The RUSLE model represents how climate, soil, topography, and land use affect rill and interrill soil erosion caused by raindrop impact and surface runoff (Renard et al. 1997). It has been extensively used to estimate soil erosion loss, assess soil erosion risk, and guide development and conservation plans in order to control erosion under different land-cover conditions (Millward and Mersey1999; Boggs et al. 2001; Mati and Veihe 2001; Angima et al. 2003). The underlying assumption in the RUSLE is that detachment and deposition are controlled by the sediment content of the flow. The erosion process is not source limited; however, it is limited by the carrying capacity of the flow. When the sediment load reaches the carrying capacity of the flow, detachment can no longer occur. Both USLE and RUSLE estimate the average annual erosion using the same equation, but RUSLE is based on the latest modification in different parameters that are shown in equation 4.1:

$$A = R \cdot K \cdot L \cdot S \cdot C \cdot P \qquad \text{(Eq 4.1)}$$

Where:

A = computed spatial average soil loss and temporal average soil loss per unit of area, expressed in the units selected for K and for the period selected for R. In practice, these are usually selected so that A is expressed in tons/ (acre× yr.), but other units can be selected (that is, tons / (ha× yr.) ;

R = rainfall-runoff erosivity factor—the rainfall erosion index plus a factor for any significant runoff from snowmelt (100ft×tons/ (acre× yr.) ;

K = soil erodibility factor – the soil-loss rate per erosion index unit for a specified soil as measured on a standard plot, which is defined as a 72.6-ft (22.1-m) length of uniform 9% slope in continuous clean-tilled fallow;

L = slope length factor – the ratio of soil loss from the field slope length to soil loss from a 72.6-ft length under identical conditions;

S = slope steepness factor – the ratio of soil loss from the field slope gradient to soil loss from a 9% slope under otherwise identical conditions.

C = cover management factor – the ratio of soil loss from an area with specified cover and management to soil loss from an identical area in tilled continuous fallow

P = support practice factor – the ratio of soil loss with a support practice like contouring, stripcropping, or terracing to soil loss with straight-row farming up and down the slope.

L and S factors are dimensionless parameters which represent the impact of topographic effects on soil erosion rates. C and P factors stand for dimensionless impacts of cropping and management systems on soil erosion control practices. All parameters are normalized with respect to the unit plot conditions, as illustrated in Agriculture handbook 703.

4.1.1 Rainfall-Runoff Erosivity Factor (R)

Rainfall erosivity is a numerical description of the potential of rainfall to erode soil (Wischmeier 1960) and is one of the key input parameters for RUSLE modeling. Rainfall erosivity (R factor or EI_{30}) is defined as the long-term average product of the total rainfall energy (E) and the maximum 30 min rainfall intensity (I_{30}) for storm events (Wischmeier and Smith 1978; Renard et al., 1997).

To compute rainfall energy and the maximum 30 min rainfall intensity (EI_{30}), continuous rainfall intensity data are needed. It is recommended that at least 20 years of rainfall data is required to accommodate the natural climatic variation (Wischmeier and Smith, 1978); however, such data are not available for many places in the world. Even when sufficient rain gauge data are available, calculation of the rainfall erosivity factor is difficult due to its complicated and tedious computational procedure. Numerous researchers have proposed methods to estimate rainfall erosivity from annual precipitation data, and the studies have reported good correlation between these factors for many locations around the world (Lee and Heo 2011). In each of these studies, models were optimized and calibrated for a specific location and included site specific coefficients. The main advantage of this simplified model is that annual precipitation data are relatively easy to obtain in most places and are reliable to a great extent.

In 1994, Renard and Freimund proposed a method for estimating R-values for stations without long-term rainfall intensity data. After analyzing available R-factor from isoerodent maps and the annual precipitation data from 155 gauge stations in the continental U.S., the following equations were suggested for estimating the R factor:

$$\mathrm{R} = 0.04830\, P^{1.610}, \qquad P < 850\, mm \qquad \textit{(Eq 4.2)}$$

$$\mathrm{R} = 587.7 - 1.219P + 0.004105P^2, \qquad P \geq 850\, mm \qquad \textit{(Eq 4.3)}$$

Where R is annual rainfall erosivity ($\mathrm{MJ} \cdot \mathrm{mm} \cdot \mathrm{ha}^{-1} \cdot \mathrm{h}^{-1} \cdot \mathrm{year}^{-1}$) and P is annual precipitation (mm). Since the current version of RUSLE requires input in U.S. customary units, values obtained from the equations should be divided by 17.02 to obtain the value in units of hundreds of $\mathrm{ft} \cdot \mathrm{tons} \cdot \mathrm{inch} \cdot \mathrm{acre}^{-1} \cdot \mathrm{h}^{-1} \cdot \mathrm{year}^{-1}$ (Foster et al., 1981).

There is no site specific rainfall intensity or rainfall-runoff erosivity data available for the Kabul River Basin. Therefore, Renard and Freimund's (1994) equations (4.2 and 4.3) were used to estimate the rainfall-runoff erosivity factor for the basin. Table 4.1 presents the rainfall runoff erosivity factor both in SI and U.S customary units for the rain gauge stations located inside the basin. Detailed information on erosivity factor (R) estimation for all stations located inside and outside the basin can be found in Appendix B.

Table 4.1 – Rainfall-runoff erosivity factor

NO	Station	Code	Location		Precipitation mm/year	R-factor SI Units	R-factor U.S. Units
			Longtitude	Latitude			
1	ASADABAD_FOB	692414	71.1400	34.8500	734	1986	117
2	BAGRAM	409450	69.2830	34.9500	305	482	28
3	CAMP_AIRBORNE_HLZ	696714	68.8830	34.4000	287	437	26
4	CAMP_BLESSING_NANGA	692246	70.9000	34.9830	664	1690	99
5	CHITRAL	415205	71.8000	35.8830	574	1337	79
6	COP_CARWILE	691764	68.6500	33.8670	280	421	25
7	COP_CHAMKANI	692514	69.8170	33.8000	495	1054	62
8	COP_CURRY	694594	68.8670	32.5170	185	217	13
9	COP_HONAKER_MIRACLE	692464	71.0830	34.9160	695	1818	107
10	COP_MONTI	692644	71.3500	35.0330	843	2482	146
11	COP_WILDERNESS	690176	69.4170	33.3670	295	458	27
12	DIR	415080	71.8500	35.2000	997	3456	203
13	DROSH	415150	71.7830	35.5670	709	1876	110
14	FAOZABAD	409040	70.5170	37.1170	452	909	53
15	FOB KUNDUZ	691984	68.9000	36.6600	263	379	22
16	FOB_BAMYAN	691774	67.8330	34.8170	287	437	26
17	FOB_BOSTIC	647094	71.5170	35.2170	774	2161	127
18	FOB_CONNOLLY	692544	70.2000	34.2670	340	576	34
19	FOB_KALAGUSH	696704	70.3830	34.9670	485	1019	60
20	FOB_KUTSCHBACH	690684	69.6330	34.8670	334	559	33

Renard and Freimund's (1994) estimated (R) factor were used as a data point in the basin. Each data point requires spatial interpolation along the basin to make the same grid cell size as the other thematic maps: DEM, Soil type map, Land use map, and Topographic map. Therefore, the average annual rainfall and R factor for each data point were inserted into ArcGIS and spatially interpolated using the Ordinary Kriging method found in the ArcGIS Spatial Analyst toolbox. Kriging is a common method used by researchers in many studies around the world to interpolate between the available data points. The method is based on statistical models that include autocorrelation-that is, statistical relationships between the measured data points. As a result, geostatistical techniques are not only capable of producing a prediction surface but they also provide some measure of the certainty or accuracy of the predictions.

Figure 4.1 and 4.2 present isohyetal and isoerodent maps of the Kabul River Basin, respectively. For the average annual precipitation distribution in the basin, the maximum value of 31.2 in. (792 mm) and the minimum values of 7.2 in. (182 mm) were observed in the eastern and the southern part of the basin, respectively. The eastern part of the basin is under the influence of monsoon rains reaching from the Indian Ocean in the summer. As shown in Figure 4.2, the average rainfall-runoff erosivity (R) factors ranges from 11.6 to 150.2 along the basin.

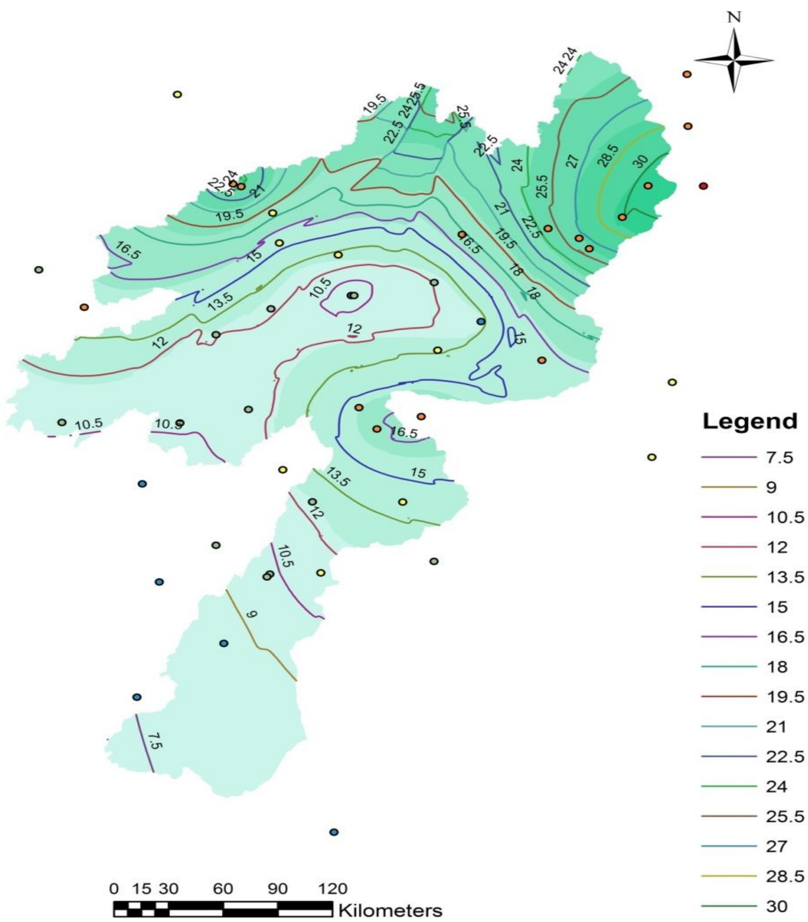


Figure 4.1 – Precipitation (Isohyet) map of the Kabul River Basin (inches)

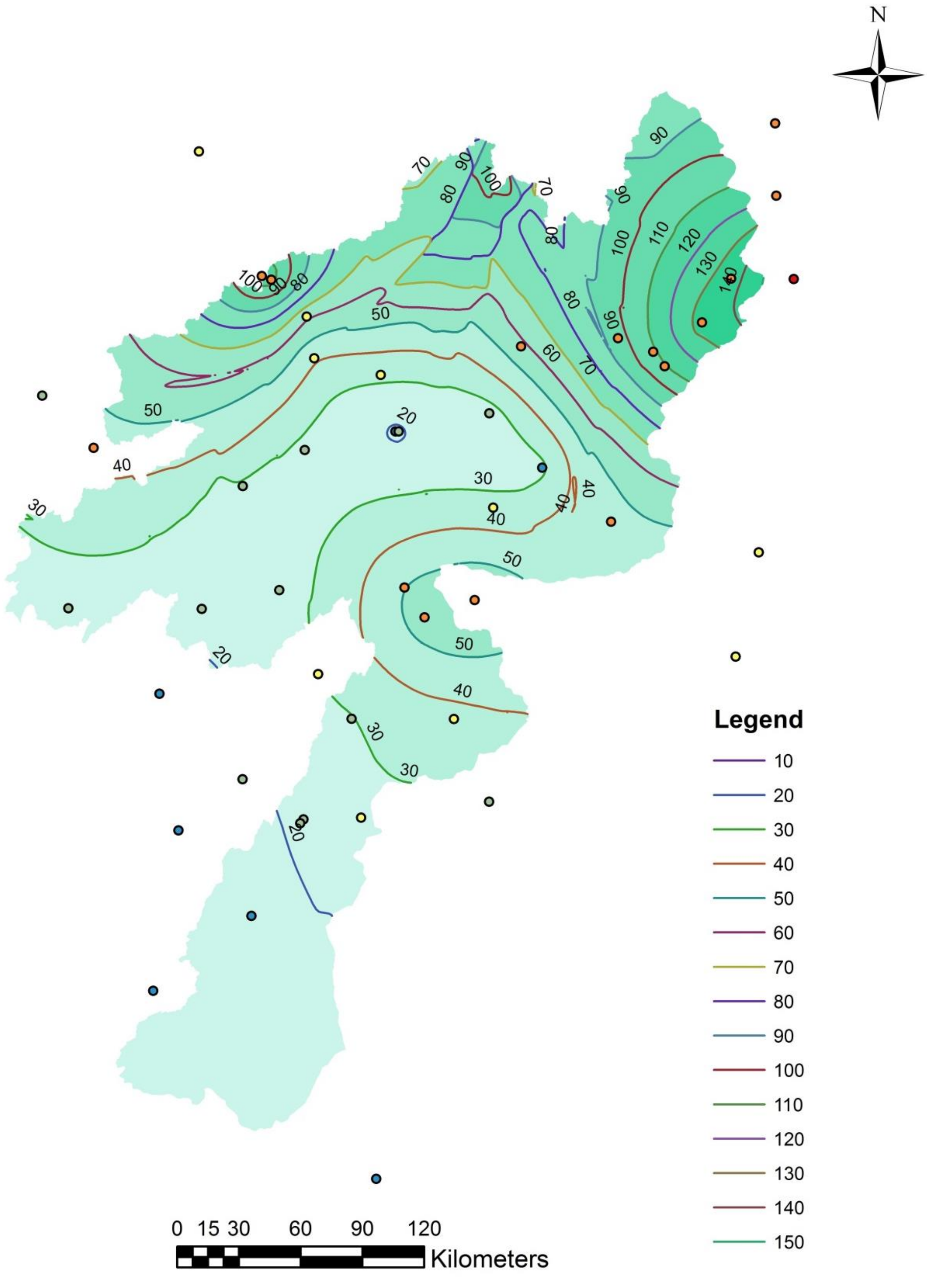


Figure 4.2 – Isoerodent map of the Kabul River Basin (hundreds ft.tons.in/acre.year)

It was considered important to verify reasonability of the R factor estimated for the Kabul River Basin before using in the RUSLE model. For this purpose, calculated values were compared to the rainfall runoff erosivity (R) factors collected from 430 climatic stations located in Colorado, New Mexico, Nevada, Oregon, Arizona, California, Indiana, and Kansas in the U.S. These R values were obtained from Climate City Database of USDA Natural Resources Conservation Services (NRCS). The main reason for selecting these states was the similarity in annual average precipitation and range of elevation to the Kabul River Basin. As it is shown in Figure 4.3, R values computed for the Kabul River Basin have a similar trend compared to the R values obtained for these eight states. The location and R value of the climatic stations on the U.S. map based on the similar range of precipitation and elevation of the Kabul River Basin can be found in Appendix C.

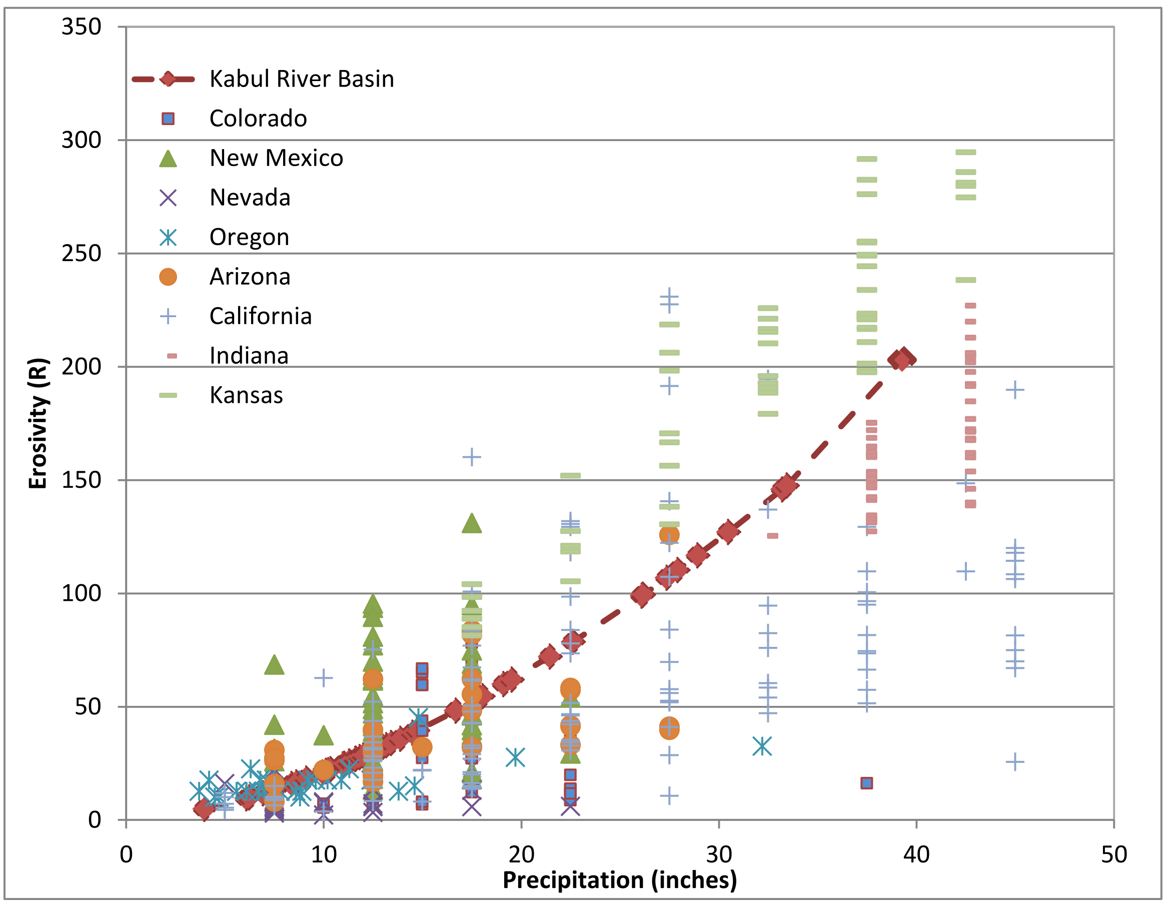


Figure 4.3 – Comparison of the rainfall-runoff erosivity factor between USA and the Kabul River basin

4.1.2 Soil Erodibility Factor (K)

Soil erodibility factor (K) is related to the integrated effect of rainfall, runoff, and infiltration on soil loss. This factor accounts for the influences of soil properties on soil loss during storm events on upland areas (Renard et al. 1997). In practical sense, K is a lumped parameter representing an integrated relationship between annual average erosion, profile reaction to erosion, and hydrological processes. For a particular soil, the soil erodibility factor is the rate of erosion per unit erosion index obtained from a unit plot $[\mathrm{ton.acre.h(hundreds\ of\ acre.ft-tons.in)^{-1}}]$. A unit plot is 72.6 ft long, with a uniform lengthwise slope of 9 percent, in a continuous fallow, tilled up and down the slope (Weesies, 1998). The purpose of continuous fallow is that the land should be kept free of vegetation and it should be plowed each spring to prevent surface crusting and vegetation growth. Referring to equation (4.1), when all these conditions are met, L, S, C, and P variables are set equal to 1, and K is calculated through A/R. The best erodibility factors are obtained from long-term direct soil loss measurement on natural plots. The minimum adequacy of the observation period for soil erodibility is taken as two years, but longer periods provide better results due to covering broader range of climatic and soil condition changes (Morgan 2011). Therefore, researchers have paid considerable attention to estimate soil erodibility from soil properties such as particle size distribution, organic matter content, soil structure and permeability (Wischmeier et al. 1971).

The soil erodibility factor ranges in value from 0.02 to 0.69 (Goldman, Jackson, and Bursztynsky 1986). Soils with high clay content have low K values, about 0.05 to 0.15, which is mainly due to their resistance to detachment. Texture is the principal factor affecting the K values. Courser texture soils, such as sandy soils, have low K values that range from

0.05 to 0.2. It is due to low surface runoff caused by excessive infiltration even though these soils are easily detached. Medium texture soils, such as the silt loam soils, have moderate K values which typically range from 0.25 to 0.4. It is due to their moderate susceptibility to detachment and moderate runoff.

Soils having high silt content are most erodible of all soils. They are easily detached, tend to crust and produce high rates of runoff. K values for these type of soils are tend to be greater than 0.4. Organic matter content reduces erodibility, decreases susceptibility of the soil to detachment, and increases infiltration rates, which in turn reduces runoff and erosion. Figure 4.4 represents the nomograph used to determine K factors based on the soil texture, percentage of silt plus very fine sand (0.002-0.1mm), percentage of sand (0.1-2mm), percentage organic matter, soil structure and permeability.

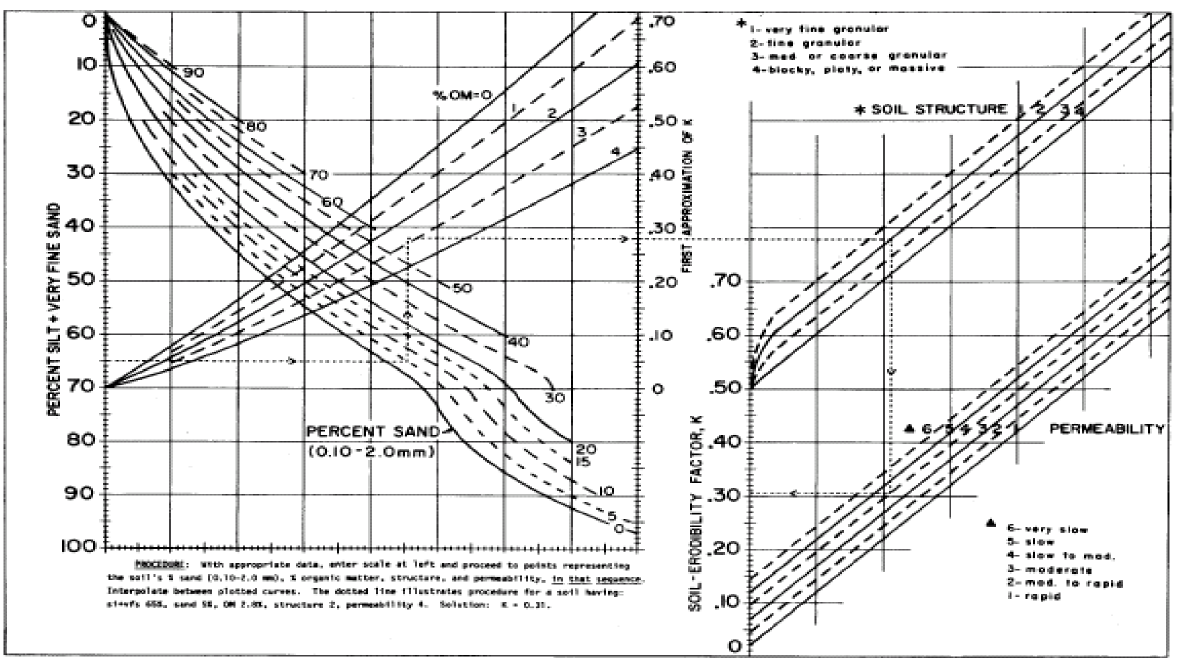


FIGURE 3.—The soil-erodibility nomograph. Where the silt fraction does not exceed 70 percent, the equation is $100\ K = 2.1\ M^{1.14}\ (10^{-4})\ (12 - a) + 3.25\ (b - 2) + 2.5\ (c - 3)$ where M = (percent si + vfs) (100 − percent c), a = percent organic matter, b = structure code, and c = profile permeability class.

Figure 4.4 – Soil erodibility nomograph (after Wischmeier and Smith 1978).

Table 4.2 shows the soil erodibility factor (K) based on the soil texture classes and organic matter content of the soils as defined by Schwab et al. (1981). In this study, soil erodibility factors (K) of the Kabul River Basin are defined based on the relationship between soil texture class and organic matter shown in Table 4.2. Soil classification of the basin is divided into 11 soil regions with each soil region made of two soil textures. Therefore, the average soil erodibility (K) values were calculated and assigned for a particular soil region. Since there is no survey data on the organic matter content in the basin, it is assumed to be 0.5%.

Table 4.2- Soil Erodibility Factor (K) (Schwab et al. 1981)

Textural Class	Organic Matter Content (%) 0.5	2
Fine sand	0.16	0.14
Very fine sand	0.42	0.36
Loamy sand	0.12	0.10
Loamy very fine sand	0.44	0.38
Sandy loam	0.27	0.24
Very fine sandy loam	0.47	0.41
Silt loam	0.48	0.42
Clay loam	0.28	0.25
Silty clay loam	0.37	0.32
Silty clay	0.25	0.23

Table 4.3 presents the results of K values in the Kabul River Basin. These values range from 0 for the bare rock land to 0.48 for the silt loam area. The Kabul River Basin soil map shape file was obtained from the U.S. Department of Agriculture-Soil Conservation Services USDA_SCS. After the soil map shape file was added as a layer into ArcGIS, the soil map attribute table was edited and K factors were assigned from Table 4.3 to each soil classification regions. Then, the shape file was converted to grid form by using the

Conversion to Raster tool in ArcGIS with cell size of 85m. Figure 4.5 presents the soil erodibility (K) map of the basin.

Table 4.3 – Soil erodibility factor (K) of the Kabul River Basin soil regions

NO	Soil Classification	Soil Texture	Average K factor
1	Calcixeralfs with Xerochrepts	Silt Loam with Silty Clay Loam	0.42
2	Haplocambids with Torriorthents	Silt Loam	0.48
3	Haplocambids with Torripsamments	Silt Loam with Fine Sand	0.32
4	Rocky Land with Lithic Cryorthents	Bare Rock with Loamy Very Fine Sand	0.22
5	Rocky Land with Lithic Haplocambids	Rock with Loamy Very Fine Sand	0.22
6	Rocky Land with Lithic Haplocryids	Rock with Silt Loam	0.24
7	Rocky Land with Ice-Capped Bare Rock	Bare Rock	0
8	Torifluvents with Torripsamments	Silt Loam with Fine Sand	0.32
9	Torriorthents with Torifluvents	Silt Loam	0.48
10	Xerochrepts with Xerorthents	Silty Clay Loam with Cobbly Loam	0.32
11	Xerorthents with Xeropsamments	Cobbly Loam with Fine Sand	0.22

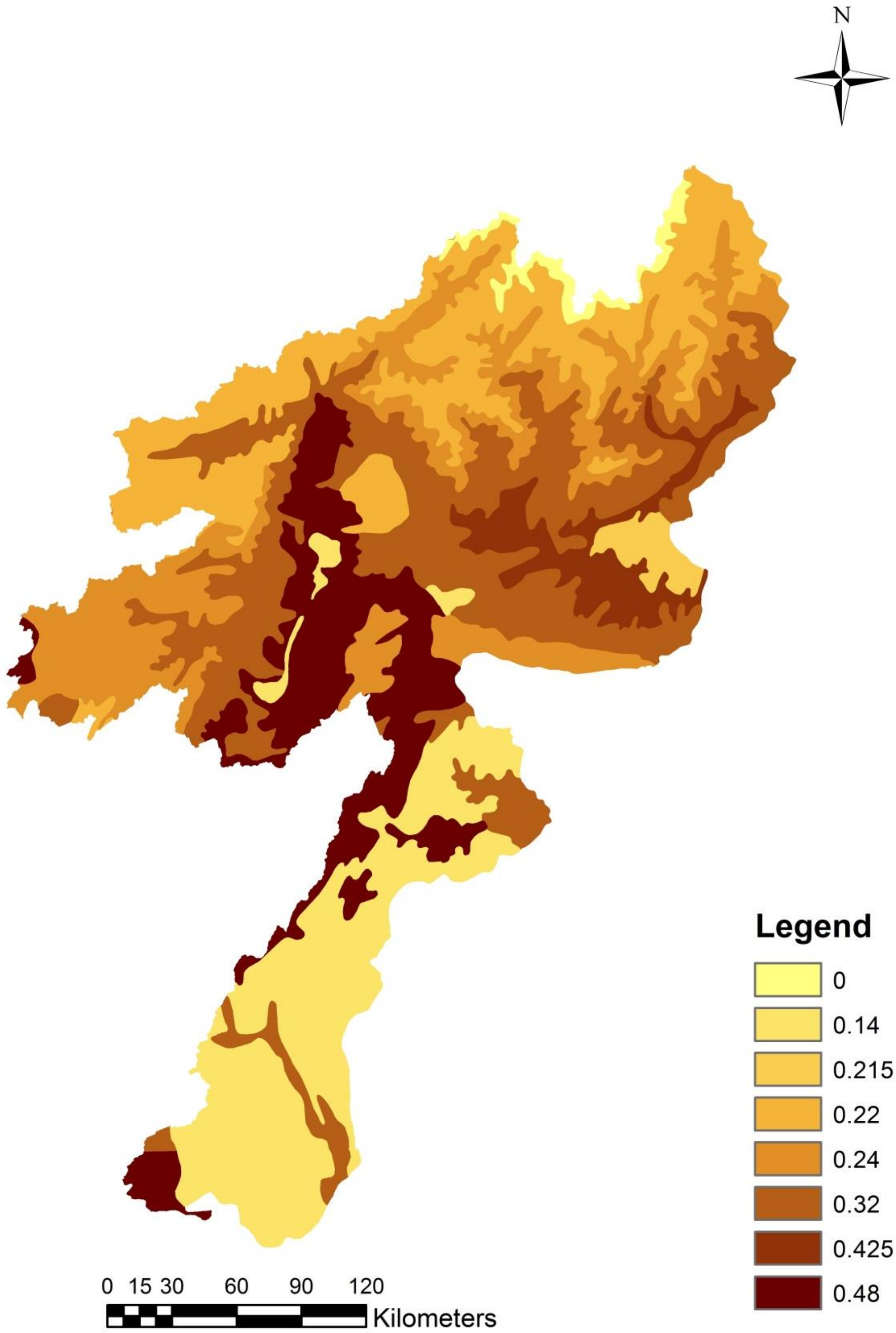


Figure 4.5 – Soil erodibility (K) map of the Kabul River Basin

4.1.3 Slope Length and Slope Steepness Factor (LS)

The effect of topography on soil erosion is accounted for by the LS factor in RUSLE, which combines the effects of a slope length factor (L) and a slope steepness factor (S). It is know that an increase in the slope length (L) will results in increase in soil erosion per unit area due to the progressive accumulation of surface runoff on downslope direction. As the slope steepness (S) increases, the velocity and soil erosion of surface runoff also increases.

Slope length (L) 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). Slope length (L) is also quantified as the ratio of soil loss from the field slope length to soil loss from a 72.6-ft long plot under identical conditions. Schematic profile of the slope length is shown in Figure 4.6. Slope length factor (L) is derived from unit plot data (Renard et al. 1997; McCool et al. 1987) and varies with slope length λ (in ft) as given in the equation:

$$L = \left(\frac{\lambda}{72.6}\right)^{m} \quad \text{(Eq 4.4)}$$

Where:

$\lambda =$ the horizontal slope length in ft

$m =$ a variable slope length exponent.

The slope length λ is the horizontal projection, not distance parallel to the soil surface. The slope length exponent m is related to the ratio β of rill erosion (caused by flow) to interrill erosion (principally caused by raindrop impact) by the following equation (Foster et al. 1977):

$$m = \frac{\beta}{(1+\beta)} \quad \text{(Eq. 4.5)}$$

β for conditions where the soil is moderately susceptible to both rill and interrill erosion is computed from (McCool et al. 1989)

$$\beta = \left(\sin\theta / 0.0896\right) / \left[3.0(\sin\theta)^{0.8} + 0.56\right] \quad \text{(Eq 4.6)}$$

Where $\theta =$ the slope angle in degrees

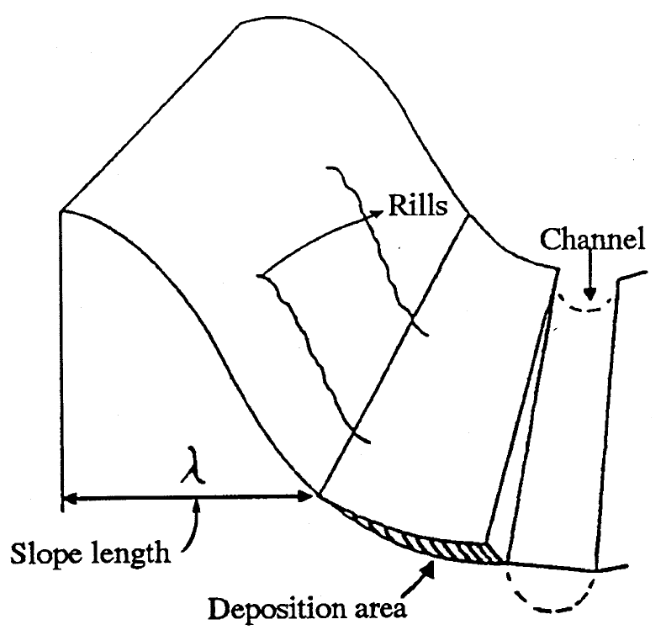


Figure 4.6- Schematic slope profile for RUSLE applications (Renard et al. 1997)

Slope steepness factor is defined as the ratio of soil loss from the field slope gradient to soil loss from a 9% slope under otherwise identical conditions (Renard et al. 1997). Soil loss increases rapidly with slope steepness than it does with slope length. For typical slope conditions, a 10% error in slope length results in a 5% error in computed soil loss. In contrast, a 10% error in slope steepness will usually result in about 20% error in computed soil loss (Morgan 2011). The slope steepness factor (S) is evaluated from (McCool et al. 1987)

$$S = 10.8 \sin\theta + 0.03 \qquad \sigma < 9\% \qquad \text{(Eq 4.7)}$$

$$S = 16.8 \sin\theta - 0.50 \qquad \sigma \geq 9\% \qquad \text{(Eq 4.8)}$$

Where:

$\theta =$ the slope angle in degrees;

$\sigma =$ the slope gradient in percentage.

A program is available which automatically processes the DEM input to calculate the LS-Factor (Van Remortel et al. 2004) using equations 4.4 to 4.8. The program was originally written in Arc Macro Language (AML) (Hickey 2000) and was upgraded in 2004 to C++ programming language in order to be more efficient in processing.

4.1.3.1 Description of C++ program's operation for application of RUSLE model

A brief description of the C++ program's operation is given. The program begins with a fill function on any depressions or sinks found in DEM input. The highest elevations on the DEM are identified by program and then the flow direction is determined. Theoretically, if rainfall lands on a high point, the direction of flow can be in either one of the cardinal direction (ie. N, S, E, W) or the diagonal directions (ie. NE, SE, SW, NW). In situation of converging flow, the flow direction of steepest decent takes precedence. Then, the distance between the centers of one grid cell to the next grid cell is calculated by the C++ program as the non-cumulative slope length (NCSL). The logic of the program to calculate L factor is based on the following concepts (Hickey 2000):

- if the cell being calculated is at high point
  - then NCSL = 0.5 (cell resolution size)
- if the input cell's flow direction is in a cardinal (N,S,E, W) direction
  - then NCSL = (cell resolution size)
- otherwise (if flow is in diagonal direction: NE, NW, SE, SW)
  - then NCSL = 1.4142 (cell resolution size)

A cumulative slope length is then computed by summing the NCSL from each grid cell, beginning at a high point and moving down along the direction of steepest descent. One important part of the C++ program is that it recognizes the areas where deposition is the dominant process instead of erosion. The assumption is that the deposition will begin in areas where the slope angle decrease enough that surface flow can no longer transport sediment. The program use a function called the cutoff slope angle defined as the ratio of change in slope angle from one grade to the next along the flow direction. The default values for the slope cutoff angle are 0.5 for slope gradients greater than 5% and 0.7 for slope gradients less than 5%. These values are based on observations that depositions are easier to start on slopes with low gradients (Van Remortel et al. 2004). When the slope angle decrease enough, the cumulative slope length calculation process stops and when the land surface extend further downhill, the calculation restarts. The methodology for calculating the L and S factors using C++ programming is illustrated in Figure 4.7.

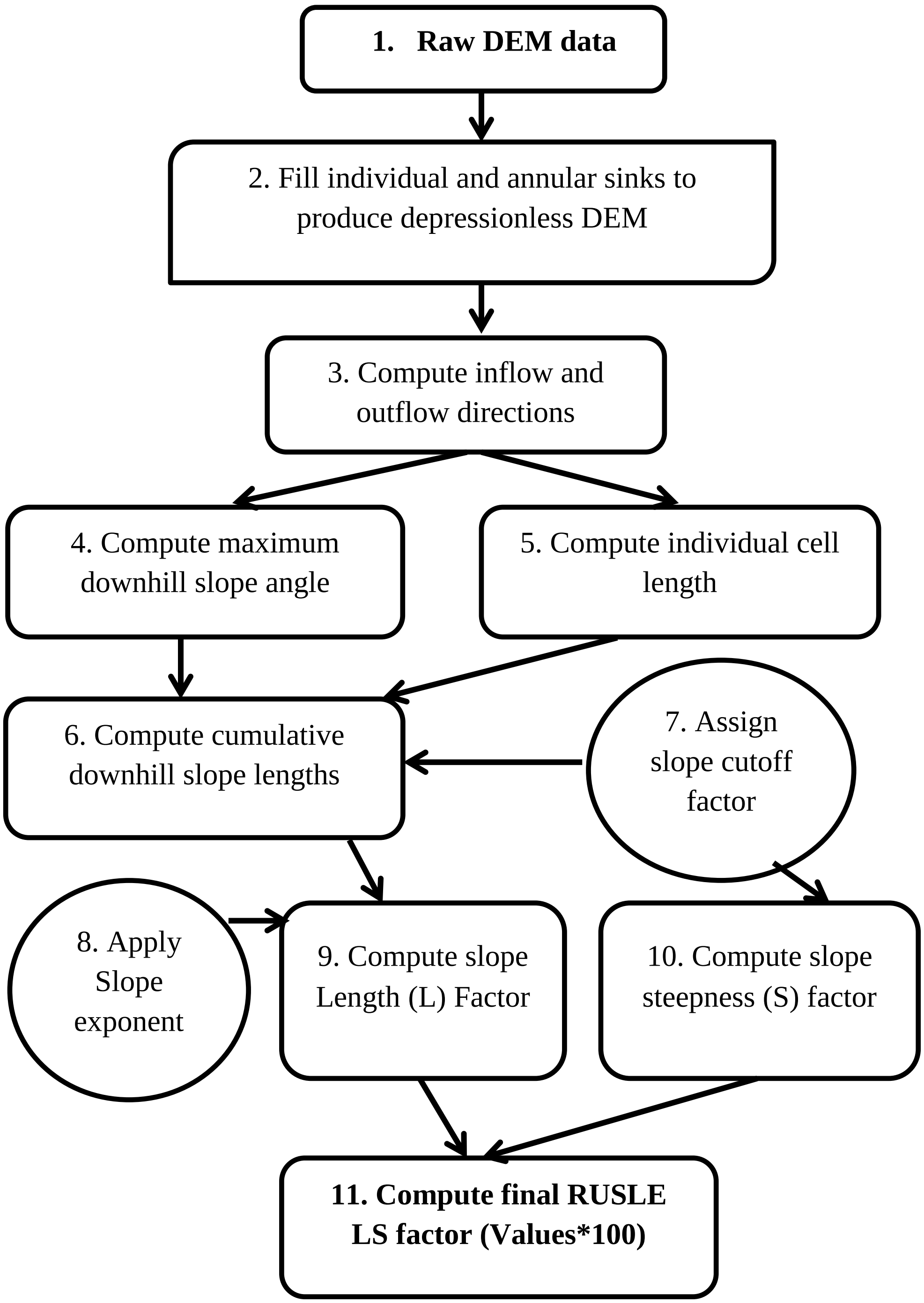


Figure 4.7- Flowchart illustrating process of calculating cumulative downhill slope length, slope steepness and final LS factor values using C++ executable program, for application of RUSLE erosion model (Van Remortel et al. 2004).

In this study, DEM for the Kabul River Basin is available in 85 meter resolution and extracted from USGS produced DEM file of Afghanistan. Figure 4.8 shows the results of slope length (L) and slope steepness (S) factor obtained from C++ program. The topographic LS factor is shown in Figure 4.9.

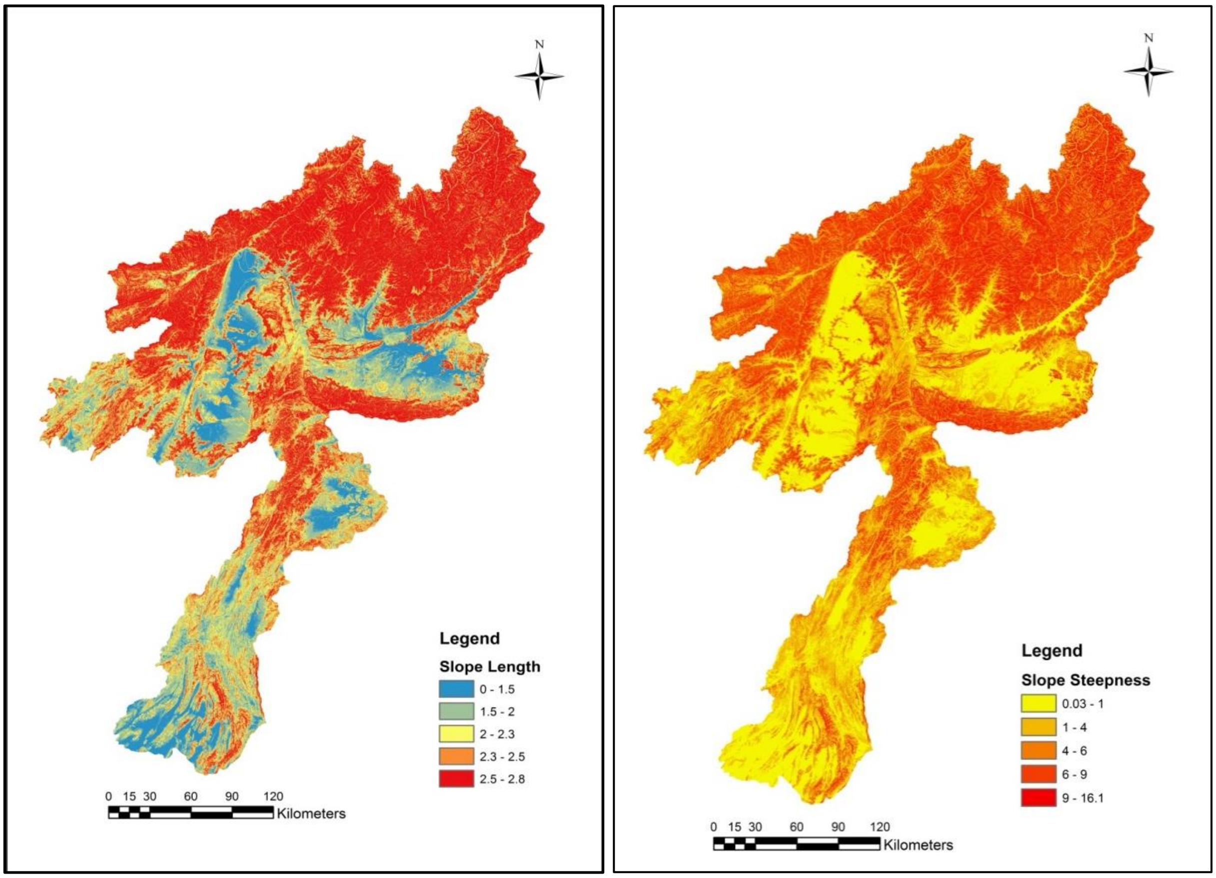


Figure 4.8 – C++ executable program a) Slope length Factor (L) map b) Slope steepness factor map

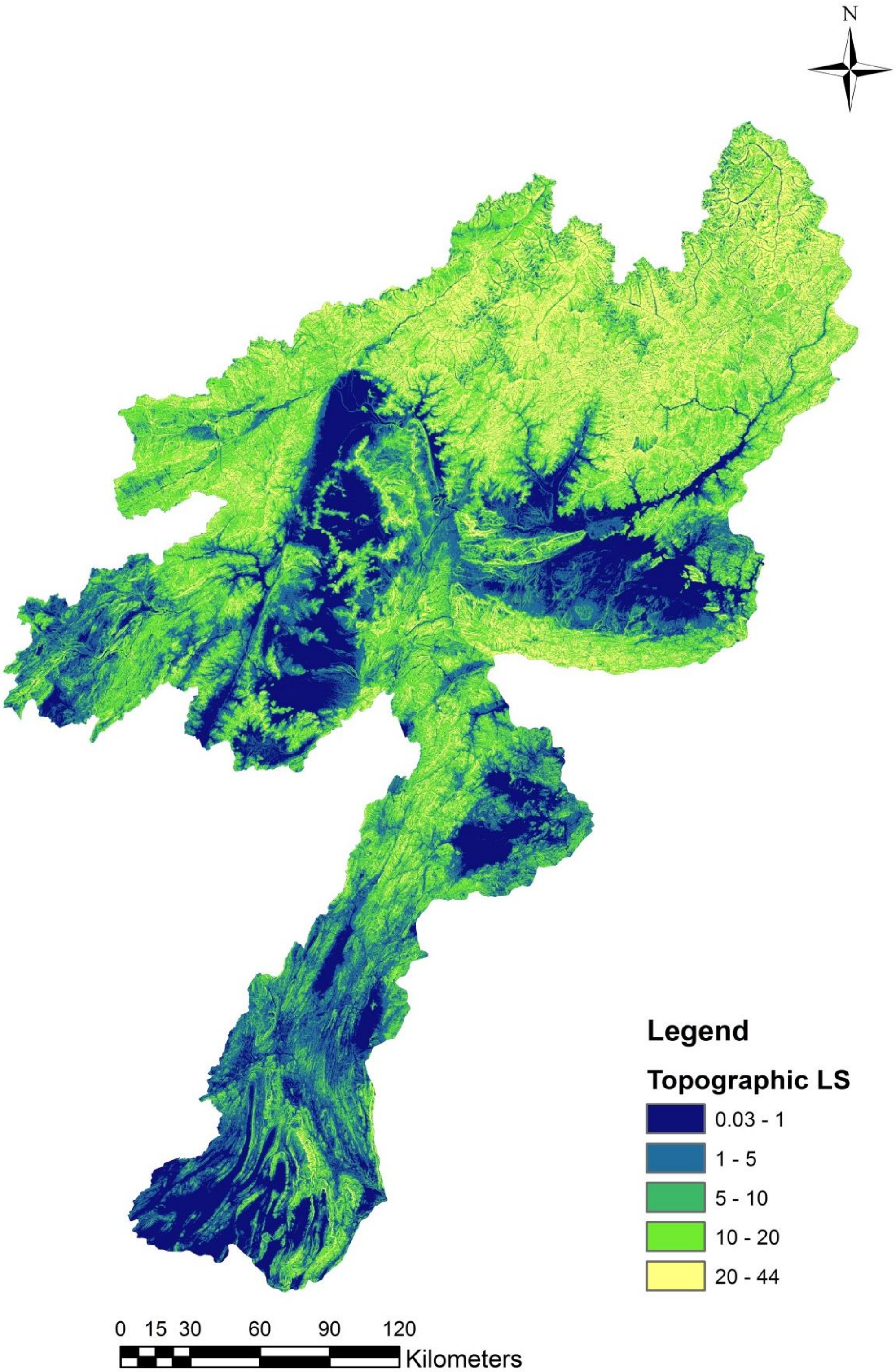


Figure 4.9 –Topographic LS factor map

4.1.4 Cover Management Factor (C)

The Cover Management Factor (C) shows the effect of vegetation cover, cropping and management practices on soil erosion rates. The C factor is the ratio of soil loss from a particular site with a specified cover and management to soil loss from the standard unit plot mentioned in early chapters.

The C factor is dimensionless since it is the ratio of soil loss occurring on field plots with the variables in place over field plots with no vegetation cover or techniques in place. C factor estimates for various vegetation types and soil prevention techniques are important because they can be used to predict the extent of soil loss that can be reduced by proper management practices and all possible mitigation measures and the estimated costs of implementation can be considered without actually carrying out the action.

The amount of protective cover of crops or vegetation for the land surface influences the soil erosion rates. The cover management factor (C) value is 1 when the land has continuous bare fallow with no vegetation coverage (standard plot condition) and it is lower when there is more vegetation or crop cover resulting in lower amount of soil erosion. For dense and mature forests, where the trees canopy and undergrowth vegetation covers between 75 to 100% of the surface area, the C value is almost 0.001 and there is no need for soil conservationists to take any erosion prevention actions.

RUSLE uses soil loss ratio (SLR) to present cover management factor (C). SLR is an estimate of the ratio of soil loss at any given time under actual conditions to losses experienced under the referenced conditions. In 1975, Wischmeier and Mutchler indicated that the general impact of cropping and management on soil series can be divided into a series of subfactors. The subfactors used to estimate a SLR value are prior land use, canopy cover, surface cover, surface roughness, and soil moisture.

There are two options to estimate C factor in RUSLE, a time variant option and a time invariant option. In time variant option, RUSLE calculations are based on a 15-day time step period; it means that SLR values are calculated every 15 days throughout the year. In time invariant option, RUSLE calculations are based on a single average SLR representing the entire year. Furthermore; for areas such as pasture or rangeland that have reached equilibrium, the parameters used in computing SLR values may change very slowly with time, so calculated SLR values will change little. In the case of the Kabul River Basin, about two third of annual precipitation is concentrated in first three months of the year, between February and April and also more than two third of the basin is covered by rangeland and barren soil with rocky outcrops. Therefore, due to precipitation and land cover of the Kabul River Basin, a time invariant option is selected.

Based on 1993's national land cover map published by UN-FAO, the land cover classification of the Kabul River Basin has 18 classes as follow: Degenerate Forest/High Shrubs ">1.5m in height", Fruit Trees, Gardens, Irrigated- Intensively Cultivated "1 Crop/year", Intensively Cultivated "2 Crops/year", and Intermittently Cultivated, Marshland Permanently inundated, Seasonal Marshland, Natural Forest "Closed cover (>60% cover)", Natural Forest "Open Cover (20%-60% cover)", Permanent Snow, Rainfed Crops "flat laying areas", Rainfed Crops "sloping areas", Rangeland "grassland/forbs/low shrubs", Rock outcrop/Bare land, Settlements, Vineyards, and Water Bodies.

Kabul River Basin does not have a locally-developed C factor table to be readily used in RUSLE calculation. Therefore, a crop management factor (C) was assigned for each land use type from the literature reviews. Table 4.4 presents long-term average crop management factor (C) values for land-cover type available in the Kabul River Basin.

To produce C factor map, the land-use shape file was added in ArcGIS. C factors were assigned to each land-use type with its valid field ID in excel sheet and inserted to the ArcGIS for join and related process. After joining the assigned C factors with land-use shape file, the land use shape file was converted from shape file to raster with 85m cell size. Figure 4.10 shows the land cover management factor (C) map of the Kabul River Basin.

Figure 4.10 implies that most of the barren lands with rocky outcrops are prone to severe erosion. Northeastern region of Kabul River Basin is covered by dense natural forest cover; it produces the lowest amount of sediment in the basin however recent reports shows that the natural forests are going under extensive deforestation in the Basin. Modified land use classification of the Kabul River Basin can be found in Appendix D.

Table 4.4 – Cover Management Factor (C)

No	Land cover type	Cover Management Factor (C)	Source	Land use
1	Settlements	0.2	Literature[a]	Urban
2	Gardens	0.12	Literature[a]	
3	Fruit Trees	0.05	Literature[a]	Agriculture
4	Vineyards	0.5	Literature[c]	
5	Irrigated Intensively Cultivated(2Crop/Year)	0.31	Literature[d]	
6	Irrigated Intensively Cultivated(1Crop/Year)	0.2	Literature[d]	
7	Irrigated (Intermittently Cultivated)	0.25	Literature[d]	
8	Rainfed Crops (Flat lying areas)	0.2	Literature[e]	
9	Rainfed Crops (slope areas)	0.3	Literature[e]	
10	Natural Forest (Closed Cover)	0.001	Literature[a,d,e]	Forest
11	Natural Forest (Open Cover)	0.01	Literature[e]	
12	Degenerated (Forest / High Shrubs)	0.05	Literature[a]	
13	Rangeland (Grassland/forbs/low shrubs)	0.15	Literature[a]	Rangeland
14	Bare Soil with Rock Outcrops	0.5	Literature[e,a]	Barren
15	Marshland (Permanently Inundated)	0	Literature[c]	Wetland
16	Marshland (Seasonal)	0	Literature[c]	
17	Water Bodies	0	Literature[a,b,c,e]	Water
18	Permanent Snow	0	Literature[c]	

Sources:

a) UN-FAO,Strategic Environmental Assessment. Vol. 5 (2001), pp.34

b) Cox, C., Madramootoo, C. Computers and Electronics in Agriculture. Vol. 20 (1998), pp.241

c) Jordan et al. Agriculture, Ecosystems and Environment 108 (2005), pp.126

d) Wischmeir, W.H. Soil Science Society Proceedings (1960), pp.324

e) Bakker et al. Geomorphology 98 (2008), pp. 218

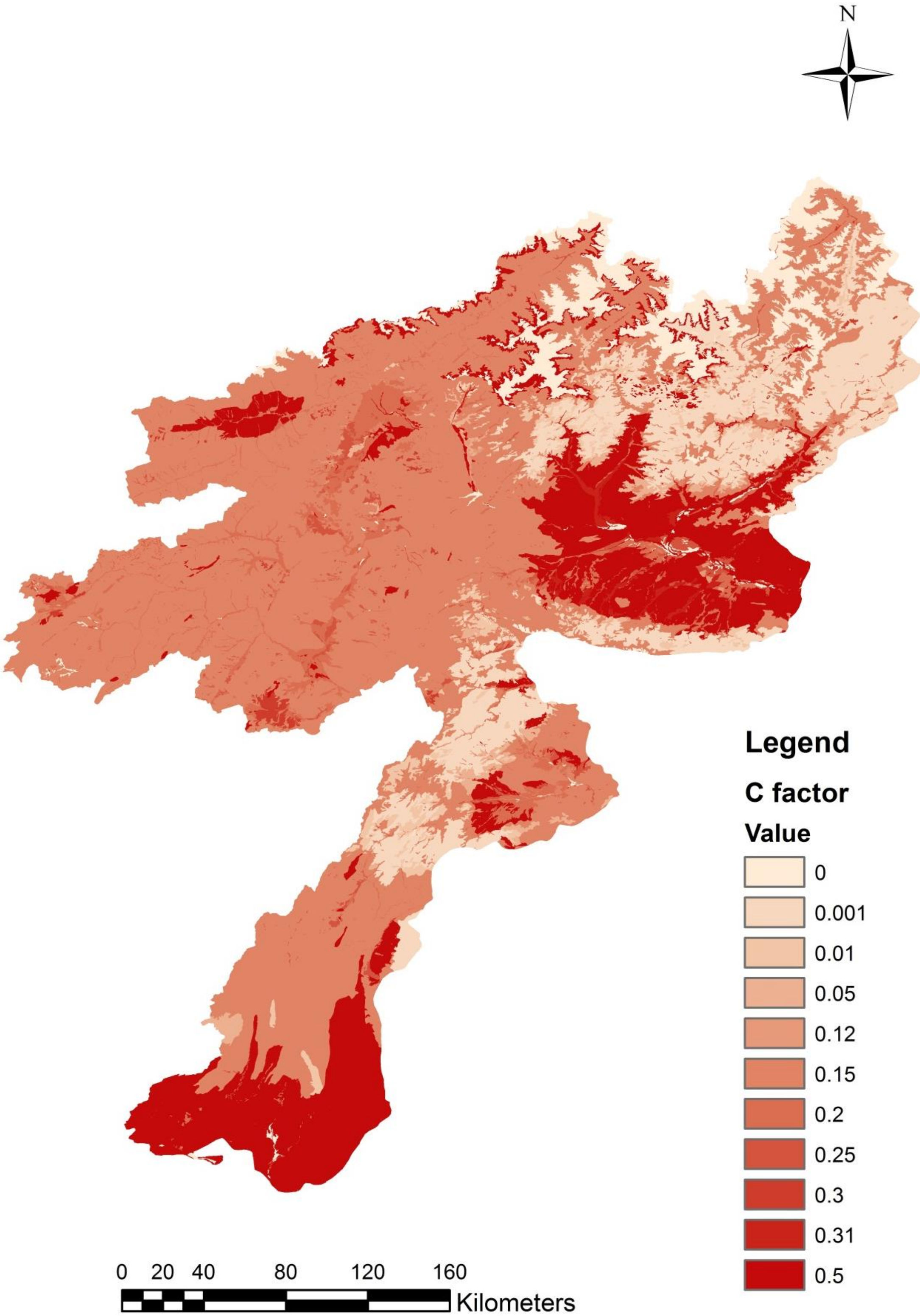


Figure 4.10 – Cover Management Factor (C) map of the Kabul River Basin

4.1.5 Support Practice Factor

Support Practice Factor (P) in RUSLE model is account for the ratio of soil loss with a specific support practice to corresponding soil loss with upslope and downslope tillage. These practices essentially effect erosion by adjusting the flow pattern, steepness, or direction of surface runoff and by reducing the amount and rate of runoff (Reynard and Foster 1983). The support practices for cultivable lands are including contouring, strip-cropping, terracing, and subsurface drainage. While on dryland or rangeland area, soil disturbing practices to result storage of moisture and reduction of runoff considered to be as support practices mechanisms.

Support Practice Factor (P) is ranged from 0 to 1. It is equal to 1 when the land is directly plowed on the slope and less than 1 when the adopted conservation practice reduces soil erosion., Terracing and contouring are common and effective support practices on the field level. The effects of terracing are reflected in the hillslope length and gradient, because it reduces the length of the hillslope. Contouring changes the flow direction and cause runoff to flow around the hillslope rather than directly downslope.

Currently there are no support practices in place within the study site. The common practice is to assign a value of 1 for the P factor. For future use, after calculating the estimated soil loss by RUSLE, the P factor values can be adjusted to forecast various prevention measures.

4.2 Summary

Chapter 4 presents the methodology used to estimate the RUSLE parameters. RUSLE has six parameters, which are rainfall-runoff erosivity (R), soil erodibility (K), slope length and slope steepness(LS), cover management (C), and support practice factor (P).

In the Kabul River Basin, based on the location of rainfall stations, the annual average R value ranges from 11.6 – 150.2 ($\text{hundreds of ft tons inch acre}^{-1}\ \text{h}^{-1}\ \text{year}^{-1}$). The maximum rainfall-runoff erosivity (R) factor is estimated in the eastern region of the basin with the value of 150.2.Based on the soil classification of the basin, soil erodibility (K) factor ranges from 0 to 0.48 where the maximum value of 0.48 were assigned to the regions with high silt loam. Slope length and steepness (LS) factor, also known as topographic LS factor, is estimated using the DEM and C ++ model developed by Van Remortel et al. (2001). LS values range from 0 to 44. The cover management factor (C) is calculated based on 1993's national land cover map published by the UN-FAO. The C factor range from 0 to 0.5. Based on the C factor map, the barren land with the maximum value of 0.5 is prone to severe erosion. Currently there are no support practices in place within the Kabul River Basin; therefore, the support practice factor (P) is assigned a value of 1 and is not used as a layer in calculating annual average soil loss rate (A) in ArcGIS.

CHAPTER FIVE

RESULTS AND APPLICATIONS

Introduction

In this chapter**,** annual average soil loss rate distribution of the Kabul River Basin and effect of deforestation on the watersheds will be discussed in section 5.1.The basic concept of the sediment yield with its comparative analysis will be covered in Section 5.2 and the sediment delivery ratio estimation based on area and topographic factor will be analyzed in section 5.3

5.1 The Annual Average Soil Loss Rate (A)

The RUSLE model uses six parameters including rainfall runoff erosivity (R), soil erodibility (K), slope length and steepness (LS), cover management (C), and support practice factor (P) to estimate annual average soil loss rate. Ranges of values for six parameters in the Kabul River are obtained from chapter four and are as follow:

1) Rainfall runoff erosivity factor (R) : 11.6 ~ 150.2 (100ft×tons×acre-1×yr-1)
2) Soil erodibility factor (K) : 0 ~ 0.48
3) Slope length factor (L) : 0 ~ 2.8
4) Slope steepness factor (S) : 0 ~ 16.1
5) Cover management factor (C) : 0 ~ 0.5
6) Support practice factor (P) : 1.0

In order to estimate the annual average soil loss rate for the basin, the above six parameters were multiplied using the raster calculator tool. Figure 5.1, 5.2 and 5.3 present the annual average soil loss rate map and histogram for the basin, respectively. The annual average soil loss is estimated to be 19.22 tons/acre/year (4748 tons/km^2/year).

In an agricultural context, ‘tolerable’ soil erosion rate is the maximum level of soil erosion that will permit a high level of agricultural productivity to be sustained economically and indefinitely. Based on the erosion maps, up to sixty percent of the annual average soil loss rate is in the range of tolerable soil erosion rate (0 - 5 tons/acre/year).

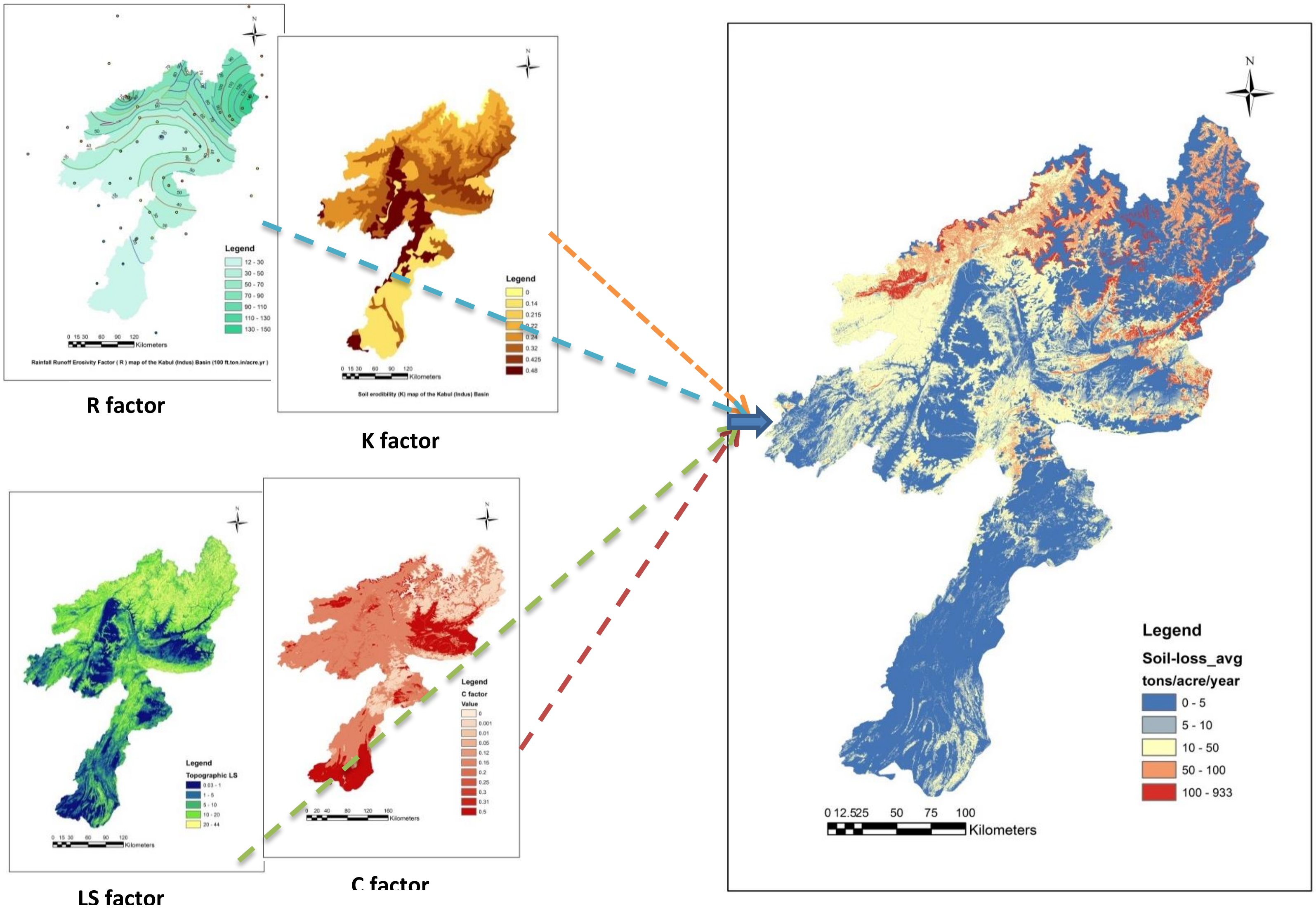


Figure 5.1 – Annual Average Soil loss rate map of the Kabul River Basin

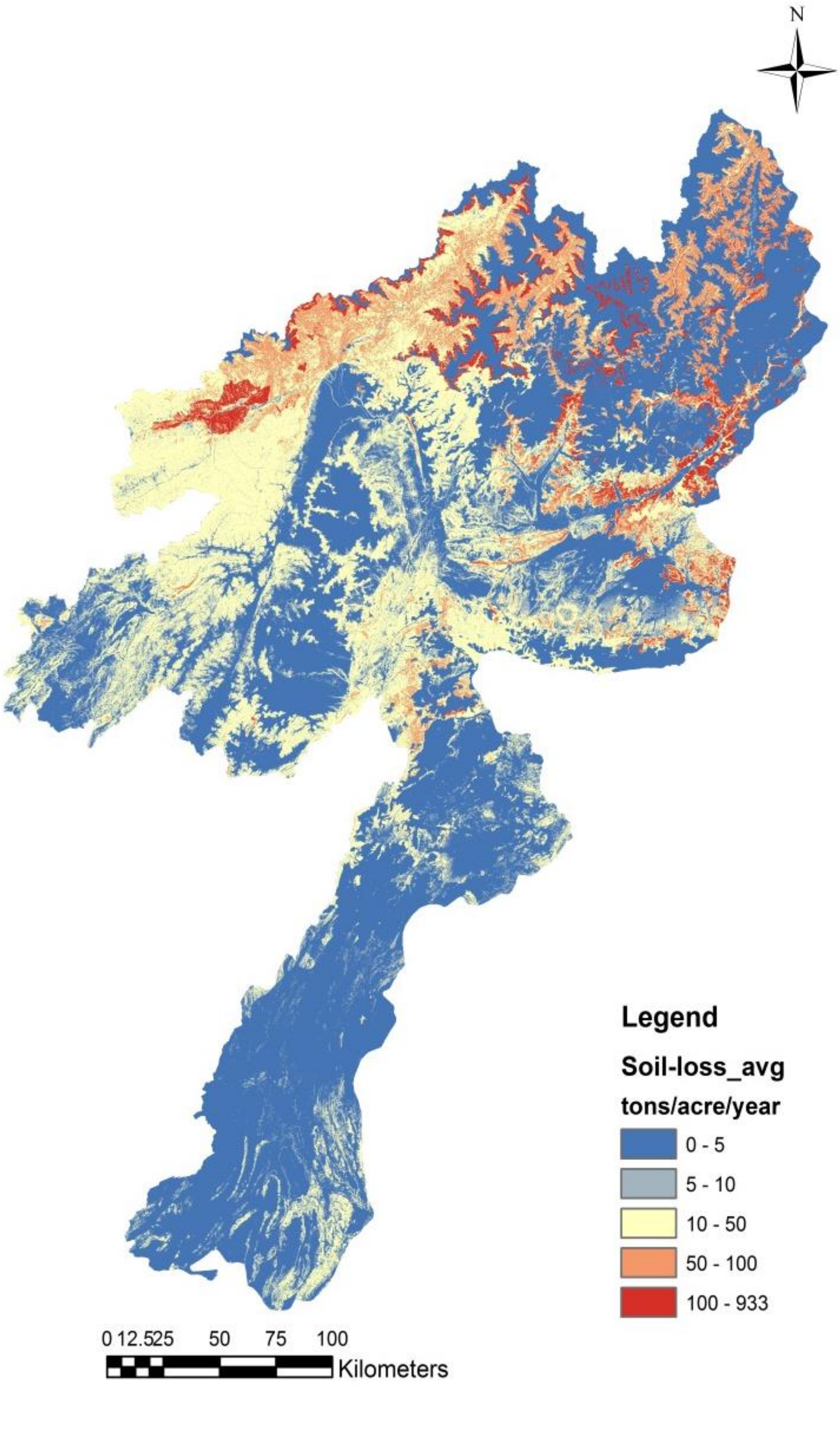
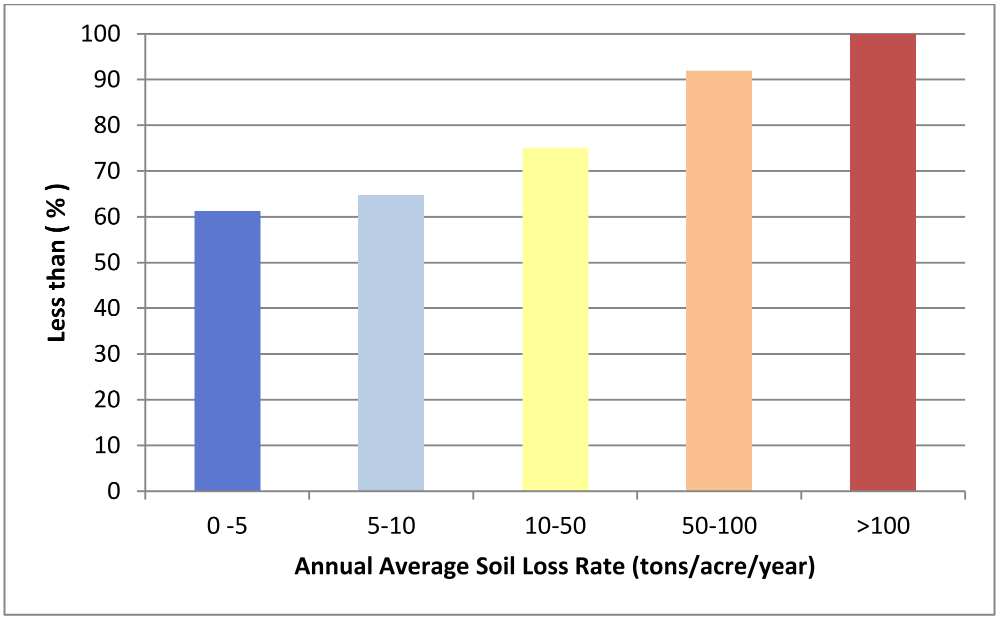


Figure 5.2 – Annual Average Soil loss rate map of the Kabul River Basin



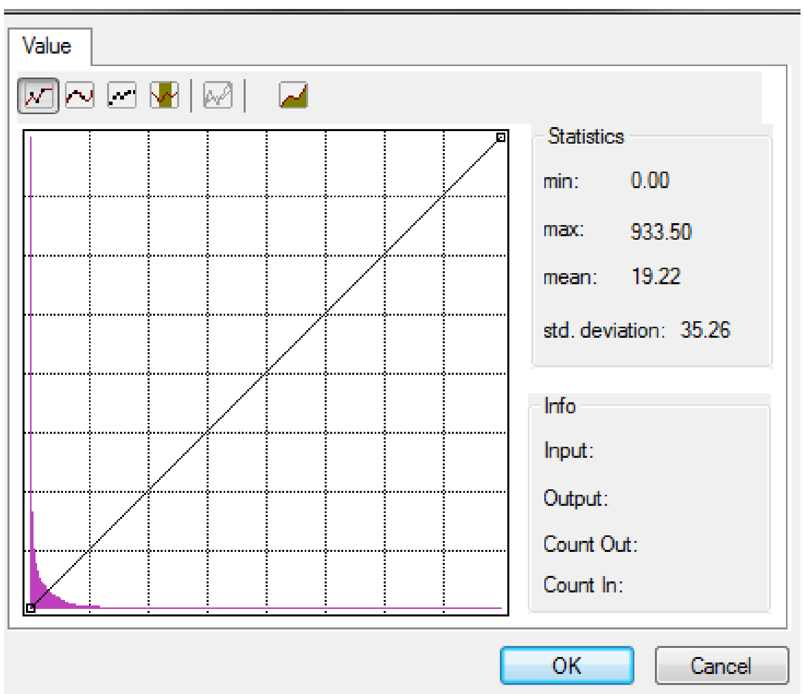


Figure 5.3 - a) spatial variability of annual average soil loss rate (tons/acre/year) b) Average annual soil loss rate histogram

Table 5.1 provides the annual average soil loss rate based on the land cover types of the basin. The total annual average soil loss rate of the Kabul River Basin is approx. 47million tons/year. Rangeland area comprises about 57% of total annual average soil loss rate and is followed by bare soil with rock outcrop

Table 5.1 – The annual average soil loss rate based on the land cover

No	LANDCOVER	AREA (Km^2)	Portion of Area (%)	Soil loss rate ($tons/km^2/year$)	Soil loss rate Million (tons/year)	Portion of Soil loss rate
1	Rangeland (grassland/forbs/low shrubs)	36267	50.98	746	27.04	57.24
2	Rock Outcrop / Bare Soil	13339	18.75	1350	18.01	38.13
3	Irrigated: Intermittently Cultivated	1265	1.78	344	0.43	0.92
4	Rainfed Crops (flat lying areas)	633	0.89	98	0.06	0.13
5	Marshland Permanently inundated	165	0.23	0	0	0
6	Irrigated: Intensively Cultivated (1 Crop/Year)	2615	3.68	261	0.68	1.45
7	Rainfed Crops (sloping areas)	344	0.48	1168	0.40	0.85
8	Permanent Snow	3896	5.48	0	0	0
9	Natural Forest (closed cover)	8986	12.63	13	0.12	0.24
10	Natural Forest (open cover)	1947	2.74	91	0.18	0.38
11	Degenerate Forest/High Shrubs	795	1.12	241	0.19	0.41
12	Settlements	162	0.23	26	0	0.01
13	Water Bodies	24	0.03	0	0	0
14	Marshland Seasonal	40	0.06	0	0	0
15	Irrigated: Intensively Cultivated (2 Crops/year)	440	0.62	245	0.11	0.23
16	Gardens	25	0.04	30	0	0
17	Fruit Trees	90	0.13	102	0.01	0.02
18	Vineyards	106	0.15	34	0	0.01
	Total	**71,139**	**100**	**4,748**	**47**	**100**

Based on UN-FAO and UNEP reports, Afghanistan has about 867,000 hectares of forest land which accounts for less than 2 percent of total land area. Between 1990 and 2000, Afghanistan lost an average of 29,400 hectares of forest per year which accounts for an average annual deforestation rate of 2.25 percent. But this rate has dramatically increased between 2000 and 2005, during this period the rate of deforestation increased to 2.92 percent per year. Considering the total deforestation rate from 1990 to 2005, Afghanistan has already lost 33.8% of its forest land and woodland habitat (U.N-FAO 2005).

Kabul River Basin contains 93 percent of the total forest lands in Afghanistan. Destruction of forest land will greatly impact the average annual soil loss rate of the basin. Kunar watershed is selected to observe the soil erosion rate of change with respect to forest cover change in the basin. Kunar watershed covers about 42 percent of total forest land in the basin.

Based on UN-FAO land cover classification map, three types of forest land cover are identified in the Kabul River Basin and they are as follow:

1. Degenerated Forest with high shrubs (more than1.5 m in height)
2. Natural forest with closed cover (more than 60 percent of area covered by canopy of trees and undergrowth)
3. Natural forest with open cover (20 to 60 percent of area covered by canopy of trees and undergrowth)

A number of different scenarios at the Kunar watershed are considered to determine the effect of deforestation on the annual average soil loss rate. The considered scenarios lead to the following research questions:

a) Considering UN-FAO1993's land cover map, what is the annual average soil loss rate in the watershed?
b) If the dense forest cover in scenario 1 is reduced to the open cover forest, what will be the new annual average soil loss rate in the watershed?
c) If the open cover of the forest in scenario 2 is reduced to degenerated forest, what will be the new annual average soil loss rate in the watershed?
d) If the land cover in scenario 3 is reduced to rangelands, what will be the new annual average soil loss rate in the watershed?
e) If the land covers in scenario 4 is reduced to barren lands, what will be the new annual average soil loss rate in the watershed?

Figures 5.4 and 5.5 present the annual average soil loss rate change based on the scenarios in the basin. For the first scenario, the average annual soil loss rate of the basin is about 29.3 tons/acre/year but it increases dramatically when the close cover of the forest is lost through degradation process. As shown in Figure 5.4, if the forest region of the Kunar watershed is completely reduced to barren lands, the watershed will produce five times more sediment than the estimated soil loss rate in the first case.

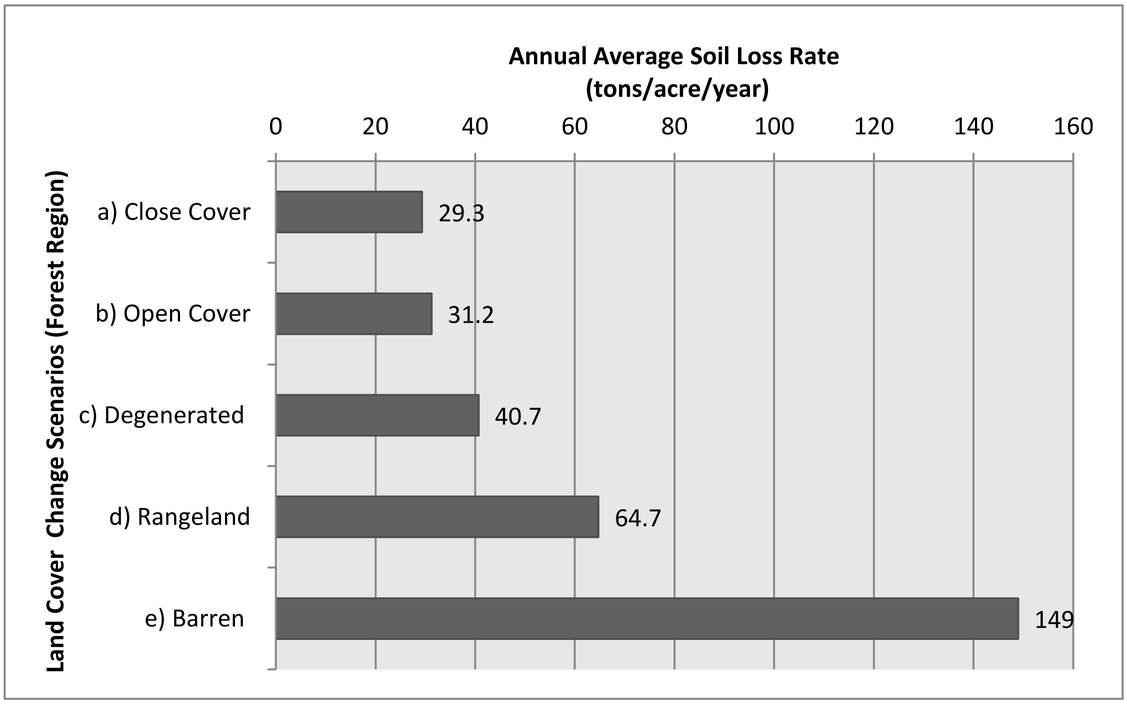
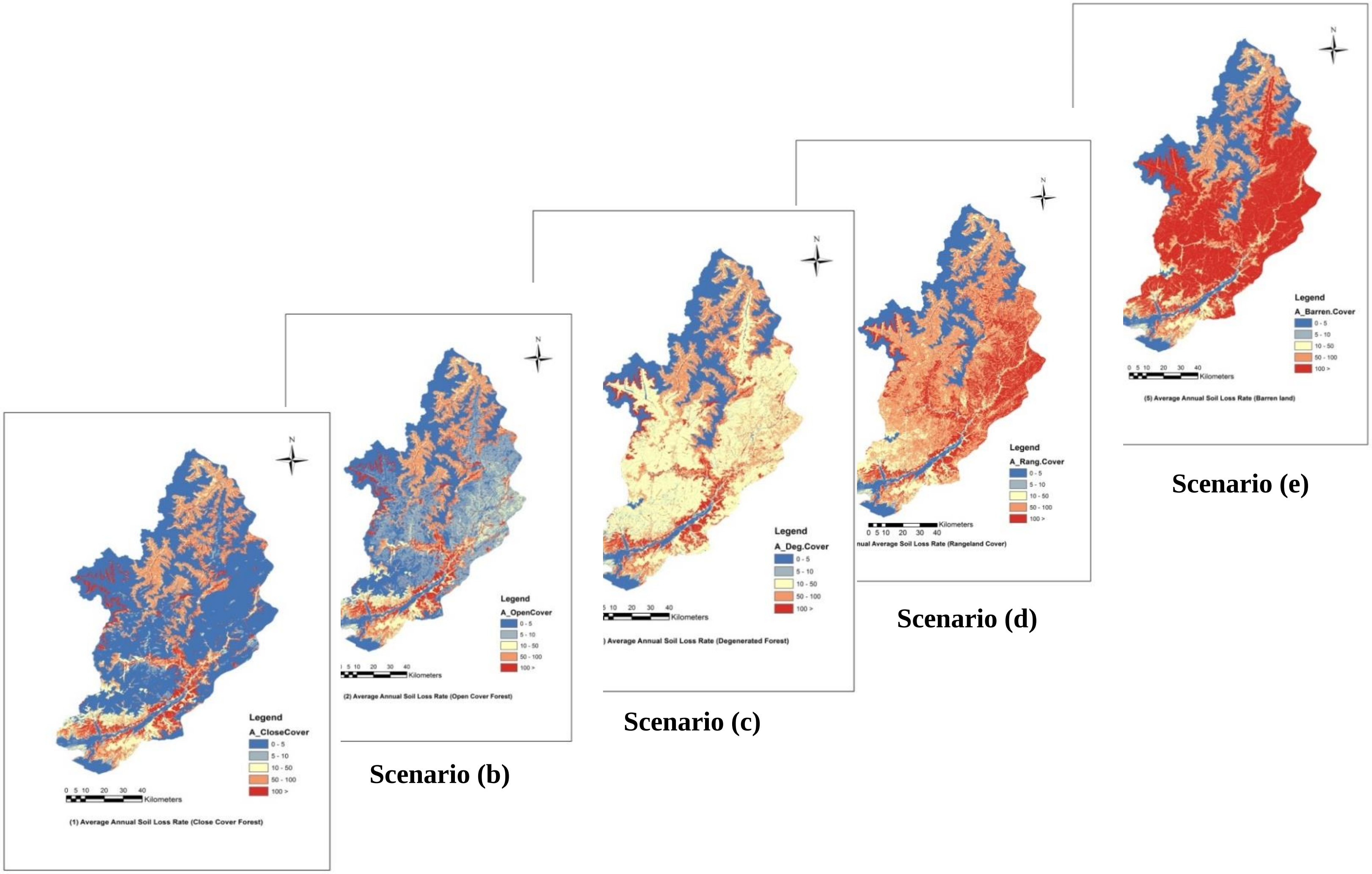


Figure 5.4- Annual average soil loss rate with land cover change at the Kunar watershed



Scenario (e)

Scenario (d)

Scenario (c)

Scenario (b)

Scenario (a)

Figure 5.5- Annual average soil loss rate change at the Kunar watershed

5.2 Sediment Yield

Sediment yield is dependent on gross erosion in the watershed and on the transport of eroded material out of the watershed. Only a part of eroded material from upland areas in a watershed is carried out of the watershed (Renfro 1975).The rate of sediment carried out by the natural streams is much less the gross erosion on its upstream watershed. The bulk of the sediment is deposited at intermediate locations whenever the transport capacity of runoff is insufficient to sustain transport. Between the source and the outlet, varying proportions of the eroded materials are deposited, for example particles eroded from bare upland areas trapped in vegetated areas. Some material trapped in floodplain and some are deposited in channels, but a large portion of eroded material is trapped in lakes or reservoirs. The total amount of sediment that is delivered to the outlet of the watershed is known as the sediment yield (Julien, 2010).

As defined, sediment yield Y is the total sediment outflow from a drainage basin over a specified period of time and it is generally measured in tons per year. For a given watershed or basin, the specific degradation SD is obtained by dividing yield Y by the drainage area A of the watershed. Therefore:

$$SD = \frac{Y}{A} \qquad \text{(Eq 5.1)}$$

Where, SD = specific degradation in metric tons/km^2. year, A = drainage area in km^2.

Kane and Julien (2007) compiled an extensive database of reservoir sedimentation surveys throughout conterminous U.S. to determine specific degradation SD relationship as a function of mean annual rainfall R and drainage area A. The mean annual rainfall for these individual basins ranges from 167mm to 2243mm and the drainage area extends from 0.017 km^2

to 89,852 km^2. Most of specific degradation values lie between 100 to 1000 ton/km^2 year. The analysis showed that there is a decrease of specific degradation with drainage area.

Table 5.2 presents the specific degradation, drainage area and average annual rainfall for the sediment gauge stations located in the basin.

Table 5.2- Sediment degradation for the stations located in the Kabul River Basin

No	River	Sediment Gauge Station	Specific Degradation ($ton/Km^2/year$)	Drainage Area (km^2)	Annual Rainfall (mm)
1	Panjshir	Panjshir I	275	1280	539
2	Panjshir	Baghdara	455	10850	464
3	Maidan	Hajian	250	1520	329
4	Logar	Gat	150	3780	298
5	Kabul	Tangi Gharu	148	12850	299
6	Kunar River	Dahana	780	11664	628
7	Ghorband	Pul-i-Ashawa	420	4020	452
8	Kabul	Naghlu	410	26046	371
9	Pajshir	Gulbahar	750	3565	516

To compare and validate the sediment yield data of the Kabul River Basin, the values of specific degradation of the sediment gauge stations with respect to its average annual rainfall and area were plotted on the log normal specific degradation plots (Figure 5.6) analyzed by Kane and Julien (2007)

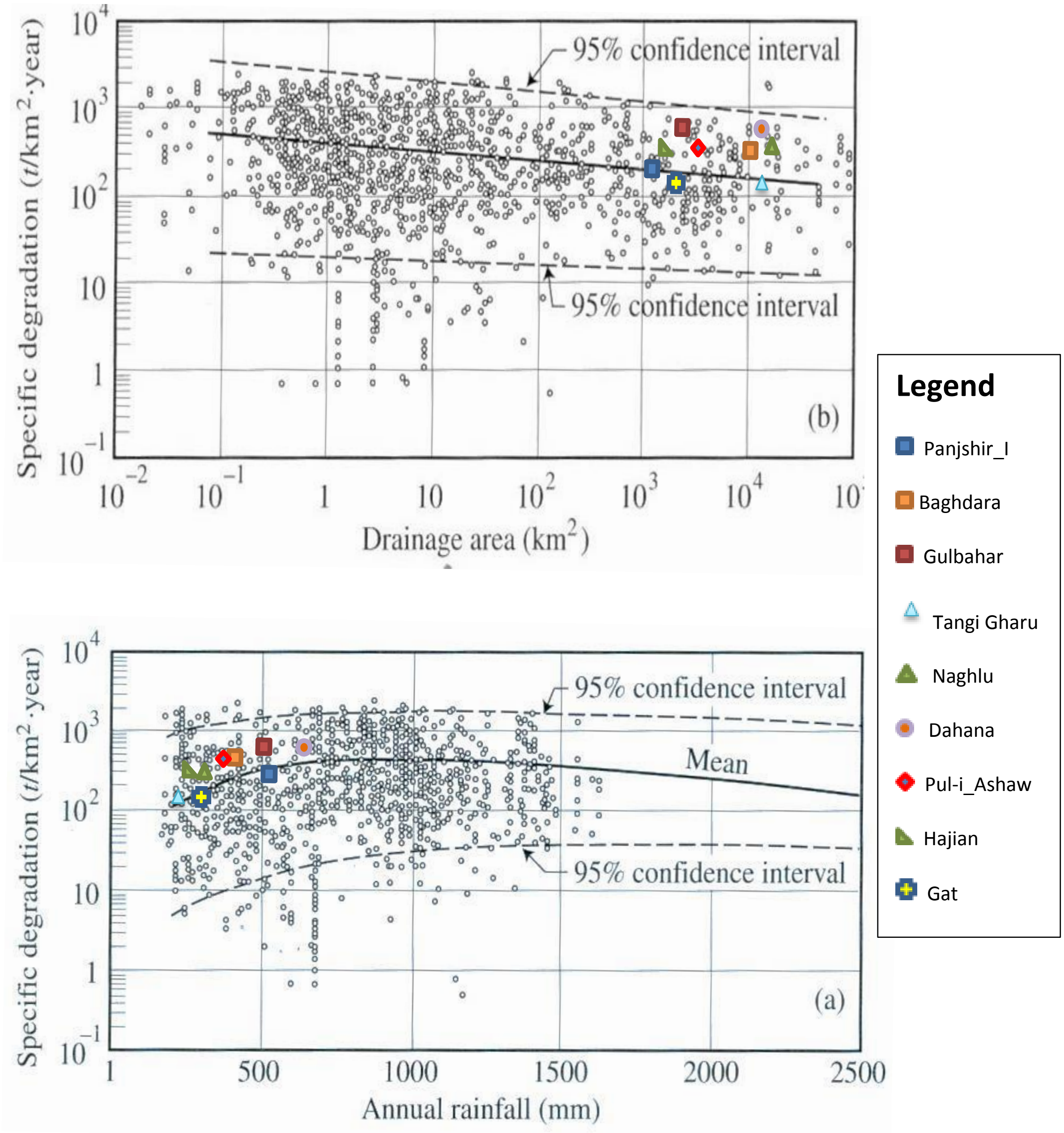


Figure 5.6- Specific Degradation (after Kane and Julien, 2007) versus a) drainage area; and b) annual rainfall (Julien, 2010)

Figure 5.6 shows that the specific degradation of the sediment gauge stations located in the Kabul River basin are within 95% confidence intervals specified by Kane and Julien (2007).

5.3 Sediment Delivery Ratio

The sediment delivery ratio (S_{DR}) defined as the ratio of the sediment yield Y at given stream cross section to the gross erosion A_T from the watershed upstream of the measuring point (Julien, 2010). The sediment delivery ratio can therefore be expresses as:

$$S_{DR} = \frac{Y}{A_T} \qquad \text{(Eq 5.2)}$$

Where S_{DR} is the sediment delivery ratio, Y is sediment yield, and A_T is gross erosion per unit area above a measuring point.

Factors influencing S_{DR} include hydrological inputs (mainly rainfall), landscape properties (e.g., vegetation, topography, and soil properties) and their complex interactions (Richards 1993). For example, a watershed with steep slope has a higher sediment delivery ratio than a watershed with mild to low slope. A watershed with bare soil land cover has a higher sediment ratio compared to the same watershed with a forest cover. Therefore, there is no generalized delivery relationship available that can be applied to every situation. However; several researchers show trends in the sediment delivery ratio for specific areas. The most common trend for sediment delivery ratio is the S_{DR} curve and relationship established for sediment delivery ratio and basin area is known as the S_{DR} curve. In order to establish the S_{DR} curve, the size of the area of interest should be defined.

5.3.1 Drainage Area and Sediment Delivery Ratio

Since late 1950's, number of researchers established the relationships between sediment delivery ratio and area. The similar trend observed in these relationships, watersheds with larger drainage area have lower sediment delivery ratio. This is because large areas have more chance to trap sediment; therefore the chances of sediment reaching the streams are low.

Renfro (1975) developed an equation based on Maner's (1962) equation relating S_{DR} with drainage area. The model was based on the sediment yield observation of 14 watersheds in the Blackland Prairie, Texas. The model showed correlation between S_{DR} and drainage area (R^2= 0.92).

$$\log(S_{DR}) = 1.7935 - 0.14191 \log(A) \qquad \text{(Eq 5.3)}$$

Where A is drainage area in km^2, and S_{DR} is sediment delivery ratio in percentage (%).

Boyce (1975) established relationship between sediment delivery ratio and drainage area by compiling and analyzing sediment yield observation from five areas in continental U.S. The following power function is derived from:

$$S_{DR} = 0.41\, A_T^{-0.3} \qquad \text{(Eq 5.4)}$$

Where A_T is drainage area in km^2, and S_{DR} is sediment delivery ratio

5.3.2 Topographic Factors and Sediment Delivery Ratio

Sediment delivery ratio is affected by the topographic features of the watersheds. Williams and Berndt's (1972) used slope of the main stream channel to predict sediment delivery ratio. The slope function is written as follow:

$$\mathrm{Log}(S_{DR}) = 0.627\, SLP^{0.403} \qquad \text{(Eq 5.5)}$$

Where SLP is slope of the main stream in percentage (%)

Maner (1958) suggested that sediment delivery ratio was better correlated with relief and maximum length of a watershed - relief-length ratio (*R/L*) - than with other factors. Renfro 1975 modified the model (R^2) as follow:

$$\log(S_{DR}) = 2.94259 + 0.82362 \log(R/L) \qquad \text{(Eq 5.6)}$$

where *R* is the relief of a watershed, and defined as the difference in elevation between the maximum elevation of the watershed and the watershed outlet. *L* is the maximum length of the watershed, measured approximately parallel to mainstream drainage.

5.3.3 Sediment Delivery Ratio Estimation

In 1980, Canadian engineering company with support of Afghan ministries prepared the first master plan for the Kabul River Basin. The sedimentology section of the master plan discusses about the rate of the sediment yield from stream gauge stations on the major rivers of the basin.

By using the ArcHydro toolbox in ArcGIS, the sub-watersheds for each sediment gauge stations were delineated and then annual average soil erosion for each sub-watershed is extracted from the erosion map predicted by the RUSLE model. Sediment degradation and average soil loss rate at sub-watersheds of the Kabul River Basin can be found in Appendix E. Table 5.3 presents the sediment delivery ratio predicted from the relationship between the annual soil erosion estimated by RUSLE model and the observed sediment yield data from master plan report, and compared with sediment delivery ratio estimated by Boyce(1975) and Renfro (1975) established relationships.

Table 5.3 – Results of S_{DR} in sub-watersheds of the Kabul River Basin

Sub-Watershed	Drainage Area	Sediment Degradation at Station	Avg. Annual Soil loss rate GIS extracted map	SDR (%)		
	km^2	tons/Km^2/year	tons/Km^2/year	Renfro	Boyce	Observed
Panjshir I	1280	275	11201	22.5	6.4	2.5
Baghdara	10850	455	9785	16.6	3.4	4.6
Hajian	1520	250	3973	22.0	6.1	6.3
Gat	3780	150	1890	19.3	4.6	7.9
Tangi Gharu	12850	148	2360	16.2	3.2	6.3
Dahana	11664	780	7248	16.5	3.3	10.8
Pul-i-Ashawa	4020	420	10843	19.1	4.5	3.9
Naghlu	26046	410	5575	14.7	2.6	7.4
Gulbahar	3565	750	11792	19.5	4.7	6.4

Table 5.4 shows results of sediment delivery ratio predicted from relief-length ratio, and slope of the main stream using the Williams and Brendt's (1972), and Maner (1958) model.

Table 5.4 – Results of Sediment delivery ratio using watershed features

Sub-Watershed	Max Elev.	Min Elev.	Length	SLP	S_{DR} (%)		
	El.m	El. m	km	%	Maner	Williams	Observed
Panjshir I	3480	2032	88	1.65	29.8	5.8	2.5
Baghdara	3490	1373	145	1.46	27.0	5.4	4.6
Hajian	3192	2037	83	1.39	25.9	5.2	6.3
Gat	3610	2409	113	1.06	20.7	4.4	7.9
Tangi Gharu	3109	1765	266	0.51	11.3	3.0	6.3
Dahana	5385	585	243	1.98	34.6	6.7	10.8
Pul-i-Ashawa	2915	1604	110	1.19	22.8	4.7	3.9
Naghlu	3638	1036	433	0.60	13.0	3.2	7.4
Gulbahar	3691	1650	124	1.65	29.8	5.8	6.4

Figure 5.7 shows the results of sediment delivery ratio of the sub –watersheds in the Kabul River basin plotted on the Boyce (1975) graph. The results shows that out of nine

observatory sediment gauge stations, two stations– Dahana on Kunar and Naghlu on Kabul river– has higher S_{DR} in the basin. The following reasons can be identified in these sub-watersheds.

1. Sediment discharge measurement at Naghlu station was conducted before the construction of the Naghlu Dam. The purpose of the survey was to estimate the life expectancy of the dam based on the annual average sediment yield. The Kabul River joins the Panjshir river at upstream of Naghlu sediment gauge station. Therefore, higher sediment yields were recorded in Naghlu sediment gauge station at the time.
2. Sediment yield data on the Kunar River was based on sediment discharge measurement recorded by Electrowatt Engineering Services Ltd. This estimate was based on data from 1965, the wettest year on record. Therefore, it may indicate considerably higher sediment yield than the long term average.

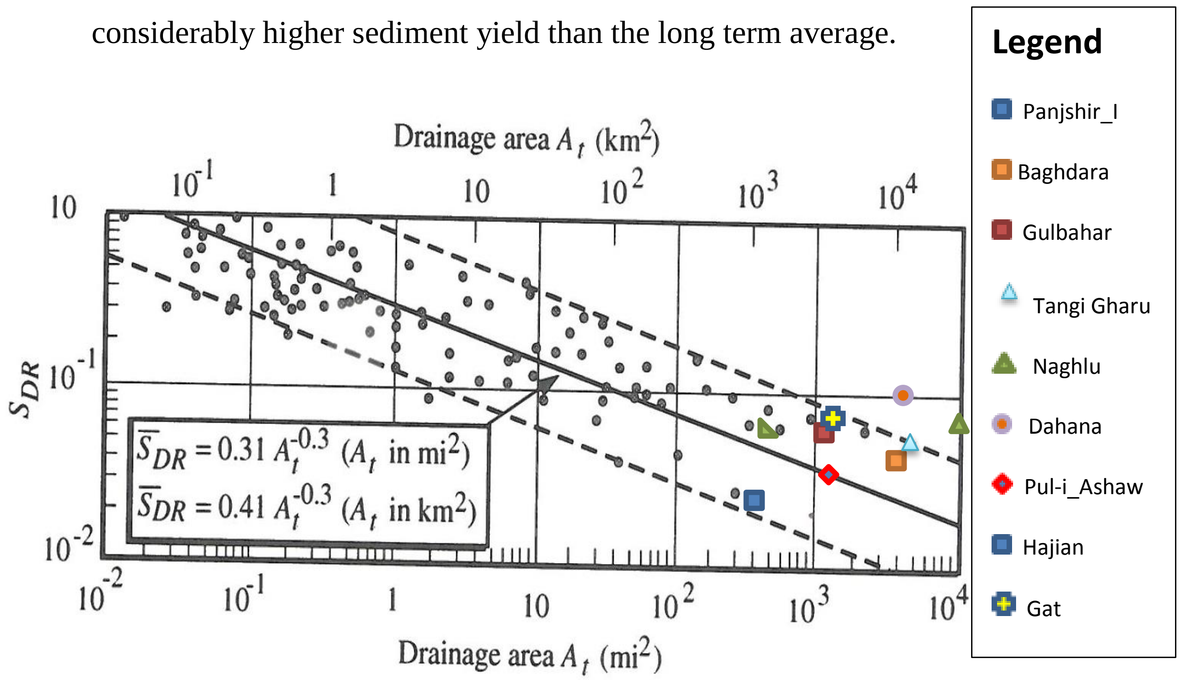


Figure 5.7 – Sediment Delivery Ratio of the sub-watersheds in the Kabul River Basin

5.4 Limitations

RUSLE method is known to have some problems. If one of the input factors is not accurately estimated then the multiplication of erroneous factors will lead to a larger error as a result. There are some limitations based on the available data in the Kabul River Basin.

1. Rainfall-runoff erosivity factor(R):

   Lack of continues precipitation data at the gauging station limit the use of Renard and Freimund equation. Wischmeier and Smith (1978) recommended that at least 20 years of rainfall data is required to capture the natural climatic variation. Poor economic conditions, as well as the topographic nature of the study area, present a situation where climatic stations measuring precipitation are extremely sparse .The 51 rainfall gauge stations in this area are randomly distributed along the basin. This causes uncertainty in interpolating rainfall data for the ungauged areas. The prediction standard error incorporated with precipitation uncertainty map of the Kabul River Basin can be found in Appendix F. It should be noted that most of precipitation occur during February to April so the effect of snow is not considered in this study.

2. Soil Erodibility Factor (K):

   Soil classification of the basin is based on the 1:1,000,000 World Soil Map Series developed by the U.S. Department of Agriculture-Soil Conservation Services (USDA-SCS). The scale of the soil map cannot cover the local variability of soil type in the basin, the K factor is limited based on the current data available and it may change if new soil cover map with larger scale will produced for the basin.

3. Slope Length and Slope Steepness Factor (LS):

Slope length and slope steepness factors in RUSLE model are well predicted when is applied to the agricultural land, but it is limited when applying to the steep mountainous region. Renard et al. 1997 introduced new algorithms to reflect rill to interrill erosion in slope length and steepness factors. Data tables on slope length and slope steepness factors reported in Agricultural Handbook 703 (Renard et al. 1997) are based on slope steepness up to 60%. Since the DEM describing the Kabul River Basin study area was determined to have 12% of its slope angles in excess of 60%, these locations with very steep slopes and may produce lots of erosion per cell so caution should be used while using erosion data from these regions. It should also be noted that the majority of the values having greater than 60% slope were located in the northeastern part of the basin where come under forested categories. Forested land cover within Kabul River Basin has almost negligible C-values due to the soil stabilizing and rainfall interception properties of this vegetation type. Consequently, appears that the low C-values for these locations act to minimize potential error associated with the derivation of S factor under slope angles in excess of 60%. There are some physical and conceptual models such as WEPP (Water Erosion Prediction Project), SWAT (Soil and Water Assessment Tool), and AGNPS (Agricultural Non-point Source Pollution) which are quite reliable and accurate in estimating soil loss rates on steep mountainous regions but they require extensive amount of hydrological and geophysical data which is currently not available for the study area. The slope steepness map of the Kabul River Basin with the RUSLE slope length exponent (m) graph can be found in Appendix G.

4. Cover Management Factor (C):

The Cover Management Factor (C) shows the effect of vegetation cover, cropping and management practices on soil erosion rates. Kabul River Basin does not have a locally-developed C factor table to be used in RUSLE calculation. Therefore, an average crop management factor (C) was assigned for each land use type from the literature reviews but it may vary if locally developed data were available or lower or upper range of C factors from literature reviews were considered to each land use type. It should be noted that land use type of the basin is based on 1993's national land cover map published by UN-FAO so the soil erosion rates calculated in this study does not project the current erosion problem in the basin. New land cover map of Afghanistan is needed to reflect the latest erosion rates in the basin.

5.5 Summary:

Annual average soil loss rate of the Kabul River Basin is estimated to be 19 tons/acre/year (4748 tons/km^2/year). Rangelands are the main contributor of the soil loss rate in the basin since they cover the largest portion of the basin area and produce about 57% of the total annual soil loss rate.

The annual average soil loss rate variations caused by the forest cover changes were considered in Kunar watershed. Based on 1993's UN-FAO land cover map, the watershed produces about 29 tons/acre/year but this value dramatically increases when the close cover of the forest is reduced through degradation process.

The estimate of sediment yield in the Kabul River Basin is based on sediment report "Kabul River Valley Development Project" published by Montreal Engineering Company in year 1980; the report indicated that the sediment yields vary widely across the Kabul River Basin. It is almost148 tons/km^2/year in Tangi-Gharu but it reaches to 780 tons/km^2/year in

Dahana_Kunar sediment gauge station. The estimates also indicate that the Panjshir, Kunar, and Ghorband Rivers contribute significantly higher sediment yields than the Logar, Maydan and Kubul Rivers.

The estimates of sediment delivery ratio shows that the values are in the range of S_{DR} established models by Maner (1958), Williams and Berndt's (1972), Renfro (1975), and Boyce (1975). The overall observed sediment delivery ratio in the Kabul River basin ranges from 2.5 ~ 10.8%, where $S_{DR} =$ 2.5 % is observed in Panjshir_I sediment gauge station located on the Panjshir River and the $S_{DR} =$ 10.8 % in Dahana_Kunar gauge station located on the Kunar River.

CHAPTER SIX

SUMMARY AND CONCLUSIONS

6.1 Summary and Conclusions

Soil erosion by water continues to be a serious global issue, particularly in Afghanistan where climatic and topographic conditions accelerate the process of erosion and sedimentation. The primary objective of this study was to generate mapping for use in prediction of soil erosion rates in the Kabul River Basin. A comprehensive approach was used to combine ArcGIS v.10.1 with RUSLE model to estimate the gross erosion rates and to evaluate the spatial distribution of soil loss rates under different landuses at the basin. Also, a prediction of mean annual soil erosion rate changes for the forested areas of the Kunar watershed was used to project the extent and severity of deforestation in the basin. Furthermore, nine sub-watersheds were selected to evaluate the range of sediment delivery ratios at the basin. The estimated sediment delivery ratios from the sub-watersheds were compared with other sediment delivery ratio models such as Boyce, Renfro, Williams and Maner.

Specific conclusions related to the results of the RUSLE model application and sediment delivery ratio at the Kabul River Basin are summarized below:

1. The annual average soil loss rate of the Kabul River Basin were estimated to be 19 tons/acre/year (4748 tons/km^2/year), and the gross mean annual soil loss rate was approximately 47 million tons/year. By producing 57% of the total annual average soil loss, rangelands were the primary contributor to the basin. Barren lands by producing about 38 % were the second largest contributor of the overall soil loss rate in the basin.
2. In case of the spatial distribution of erosion rates at the Kabul River Basin, the relationship between probability and annual average soil loss rates were analyzed. The

analysis indicated that up to sixty percent of the mean annual soil loss rates are in the range of tolerable soil loss rate (0 - 5 tons/acre/year). Moreover, northern part of the basin is prone to extensive erosion than the southern part.

3. The study predicted that if the forest region of the Kunar watershed is completely reduced to barren lands, the watershed will produce five times more sediment than the estimated soil loss rate from 1993's UN-FAO land cover map. The annual average soil loss rate in this watershed was about 29 tons/acre/year but it will increase to 149 tons/acre/year as deforestation continues to take place in the watershed (Figure 5.2).
4. To determine the sediment delivery ratio for contributing watersheds in the Kabul River Basin, the annual average soil loss rate was divided by the observed sediment yields at each sediment gauge stations (Table 5.3). The range of sediment delivery ratios for the basin's rivers is 2.5 -10.8 %. Based on this estimates, the sediment delivery ratio for the sediment gauging stations in the basin are in the similar range of predicted values by Boyce, Renfro, Williams and Maner (Table 5.4).

The methods and results described in this thesis are valuable to understand the relationship between soil erosion risk, dominant factors including land cover, land use, soil type and topography of the basin which are useful for managing and planning land use practices that will avoid land degradation. For the Kabul River Basin, such a study is very important due to current impact of increased deforestation and conversion to other land use patterns. A brief recommendation can be found in Appendix H.

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APPENDIX A: Rainfall Gauge Stations Dataset along the Kabul River Basin

NO	Station	AWS	Observatory Stations			Location		Precipitation mm/year
			Begin_Date	End_Date	Country	Longtitude	Latitude	
1	FOB_NAGHLU	695474	6/16/1999	4/28/2013	AFG	69.7000	34.6170	100
2	QUETTA	692844	1/25/1987	12/5/1998	PAK	66.9330	30.2500	154
3	JALALABAD_1	409540	1/8/1973	4/9/1992	AFG	70.4670	34.4330	158
4	GHAZNI_1	692804	2/1/1985	4/28/2013	AFG	68.4170	33.5000	176
5	COP_CURRY	694594	10/19/1982	7/23/1991	AFG	68.8670	32.5170	185
6	SUPER_FOB	692484	12/13/2007	4/28/2013	AFG	68.5000	32.9000	186
7	ZHOB	416200	1/14/1961	4/28/2013	PAK	69.4670	31.3500	192
8	WAZAKHWA	409810	3/2/1966	5/6/1979	AFG	68.3500	32.2000	192
9	MEHTARLAM_PRT	691226	3/1/2009	4/28/2013	AFG	70.2000	34.6800	212
10	SHARANA	692854	12/3/2007	4/28/2013	AFG	68.8400	33.1170	219
11	FOB_SHANK	692814	1/22/1985	4/28/2013	AFG	69.0600	33.9400	231
12	URGOON	409840	8/17/1977	2/4/1982	AFG	69.1330	32.9170	252
13	ORGUN_E	690654	8/9/2005	4/28/2013	AFG	69.1500	32.9330	256
14	PAN_JAO	409460	11/6/1975	7/13/1979	AFG	67.0330	34.3830	257
15	SUROBI	690336	5/1/2009	7/13/2012	AFG	69.7170	34.6170	260
16	FOB KUNDUZ	691984	1/16/1986	5/10/2013	AFG	68.9000	36.6600	263
17	MIRANSHAH_AIRPORT	415840	2/12/1973	4/13/1973	PAK	70.1170	32.9830	278
18	COP_CARWILE	691764	3/12/1985	7/2/2010	AFG	68.6500	33.8670	280
19	OKAK	409660	12/4/1976	4/23/1979	AFG	67.9500	33.8830	286
20	FOB_BAMYAN	691774	11/23/2009	4/2/2013	AFG	67.8330	34.8170	287
21	CAMP_AIRBORNE_HLZ	696714	2/16/2000	4/28/2013	AFG	68.8830	34.4000	287
22	KABUL_AIRPORT	409480	3/2/1966	4/28/2013	AFG	69.2170	34.5500	294
23	COP_WILDERNESS	690176	12/28/2007	4/28/2013	AFG	69.4170	33.3670	295
24	Khelegay	691534	1/18/1985	4/28/2013	AFG	68.7000	35.8700	300
25	BAGRAM	409450	5/30/1973	11/15/1987	AFG	69.2830	34.9500	305
26	PESHAWAR	415300	7/1/1957	5/10/2013	PAK	71.5830	34.0170	305
27	GARDEZ_1	696504	1/1/2005	4/24/2013	AFG	69.2500	33.5670	325

NO	Station	AWS	Observatory Stations			Location		Precipitation mm/year
			Begin_Date	End_Date	Country	Longtitude	Latitude	
28	KHOST	409710	9/27/1975	1/4/1988	AFG	69.9500	33.3500	330
29	FOB_KUTSCHBACH	690684	3/1/2009	4/28/2013	AFG	69.6330	34.8670	334
30	FOB_CONNOLLY	692544	12/7/1985	4/18/2013	AFG	70.2000	34.2670	340
31	FOB_TILLMAN	694604	10/30/2009	11/15/2012	AFG	69.4500	32.9330	352
32	JABUL_SARAJ	409320	3/19/1973	4/6/1990	AFG	69.2500	35.1330	368
33	KOHAT	415640	1/7/1973	10/15/2012	PAK	71.4330	33.5670	374
34	FOB_SHINWAR	696494	3/1/2009	7/28/2012	AFG	70.8170	34.1830	424
35	FAOZABAD	409040	3/4/1973	10/14/2012	AFG	70.5170	37.1170	452
36	HERRERA_HLZ	691324	10/11/2000	11/30/2012	AFG	69.7170	33.9330	455
37	HAJIGAK	409330	2/2/1979	7/9/1979	AFG	68.1000	34.5830	458
38	FOB_KALAGUSH	696704	2/15/2000	10/13/2012	AFG	70.3830	34.9670	485
39	COP_CHAMKANI	692514	4/27/1987	2/22/2013	AFG	69.8170	33.8000	495
40	PARACHINAR	415600	1/7/1973	4/26/2013	PAK	70.0833	33.8670	544
41	CHITRAL	415205	7/27/2005	10/10/2005	PAK	71.8000	35.8830	574
42	ISHKASHIM	389570	1/3/1960	2/23/2005	AFG	71.6000	36.7170	663
43	CAMP_BLESSING_NANGA	692246	12/3/2007	2/9/2011	AFG	70.9000	34.9830	664
44	COP_HONAKER_MIRACLE	692464	4/4/1984	4/8/2013	AFG	71.0830	34.9160	695
45	DROSH	415150	7/1/1957	4/28/2013	AFG	71.7830	35.5670	709
46	ASADABAD_FOB	692414	11/10/1987	4/28/2013	AFG	71.1400	34.8500	734
47	FOB_BOSTIC	647094	2/6/1991	7/31/2012	AFG	71.5170	35.2170	774
48	COP_MONTI	692644	9/23/2012	4/11/2013	AFG	71.3500	35.0330	843
49	NORT_SALANG	409300	1/13/1973	4/21/1992	AFG	69.0170	35.3170	849
50	SOUTH_SALANG	409310	1/6/1973	2/9/1980	AFG	69.0670	35.3000	849
51	DIR	415080	10/20/1980	4/28/2013	AFG	71.8500	35.2000	997

Station	Precipitation
ASADABAD_FOB	mm/Month
Jan	56.66
Feb	103.41
Mar	154.74
Apr	117.35
May	56.14
Jun	18.24
Jul	62.24
Aug	53.78
Sep	30.55
Oct	25.04
Nov	18.57
Dec	37.62
Mean_Annual (mm/year)	**734.34**

Station	Precipitation
BAGRAM	mm/Month
Jan	38.73
Feb	64.92
Mar	81.57
Apr	69.52
May	16.88
Jun	0.29
Jul	0.69
Aug	0.19
Sep	0.29
Oct	3.38
Nov	8.3
Dec	20.03
Mean_Annual (mm/year)	**304.79**

Station	Precipitation
CAMP_AIRBORNE_HLZ	mm/Month
Jan	33.33
Feb	57.15
Mar	71.98
Apr	62.78
May	23.87
Jun	0.67
Jul	1.09
Aug	0.29
Sep	0.14
Oct	2.87
Nov	8.72
Dec	24.01
Mean_Annual (mm/year)	**286.9**

Station	Precipitation
CHITRAL	mm/Month
Jan	45.06
Feb	80.51
Mar	121.45
Apr	98.97
May	54.84
Jun	15.04
Jul	30.43
Aug	28.37
Sep	17.57
Oct	21.33
Nov	19.67
Dec	41.1
Mean_Annual (mm/year)	**574.34**

Station	Precipitation
CAMP_BLESSING_NANGA	mm/Month
Jan	53.7
Feb	99.03
Mar	146.92
Apr	117.99
May	57.55
Jun	15.18
Jul	41.74
Aug	32.21
Sep	21.57
Oct	22.63
Nov	19.34
Dec	36.42
Mean_Annual (mm/year)	**664.28**

Station	Precipitation
COP_CARWILE	mm/Month
Jan	33.99
Feb	56.32
Mar	68.78
Apr	57.96
May	24.2
Jun	0.92
Jul	1.62
Aug	0.59
Sep	0.08
Oct	2.37
Nov	8.59
Dec	24.89
Mean_Annual (mm/year)	**280.31**

Station	Precipitation
COP_CHAMKANI	mm/Month
Jan	29.78
Feb	73.17
Mar	97.99
Apr	77.5
May	45.47
Jun	19.51
Jul	54.77
Aug	41.21
Sep	19.65
Oct	10.87
Nov	7.81
Dec	17.74
Mean_Annual (mm/year)	**495.47**

Station	Precipitation
COP_CURRY	mm/Month
Jan	21.61
Feb	36.15
Mar	46.04
Apr	29.56
May	10.22
Jun	1.98
Jul	13.59
Aug	11.94
Sep	0.74
Oct	0.67
Nov	1.73
Dec	11.23
Mean_Annual (mm/year)	**185.46**

Station	Precipitation
COP_HONAKER_MIRACLE	mm/Month
Jan	55.4
Feb	101.49
Mar	151.92
Apr	118.36
May	56.51
Jun	16.21
Jul	48.11
Aug	40.16
Sep	25.24
Oct	24.03
Nov	19.5
Dec	38.06
Mean_Annual (mm/year)	**694.99**

Station	Precipitation
COP_MONTI	mm/Month
Jan	64.17
Feb	117.46
Mar	171.2
Apr	127.38
May	63.04
Jun	22.61
Jul	73.95
Aug	69.47
Sep	36.36
Oct	28.46
Nov	22.34
Dec	46.87
Mean_Annual (mm/year)	**843.31**

Station	Precipitation
COP_WILDERNESS	mm/Month
Jan	27.76
Feb	58.18
Mar	68.1
Apr	51.64
May	23.04
Jun	5.67
Jul	18.66
Aug	12.71
Sep	2.43
Oct	3.05
Nov	5.1
Dec	18.91
Mean_Annual (mm/year)	**295.25**

Station	Precipitation
DIR	mm/Month
Jan	71.62
Feb	130.67
Mar	183.73
Apr	129.9
May	66.5
Jun	31.79
Jul	107.91
Aug	111.66
Sep	50.58
Oct	32.2
Nov	24.07
Dec	56.78
Mean_Annual (mm/year)	**997.41**

Station	Precipitation
DROSH	mm/Month
Jan	53.15
Feb	96.35
Mar	140.41
Apr	111.57
May	61.91
Jun	21.59
Jul	51.86
Aug	50.57
Sep	27.23
Oct	25.35
Nov	22.1
Dec	46.69
Mean_Annual (mm/year)	**708.78**

Station	Precipitation
FOB_CONNOLLY	mm/Month
Jan	22.82
Feb	48.76
Mar	74.45
Apr	64.26
May	31.67
Jun	9.48
Jul	29.28
Aug	18.7
Sep	14.16
Oct	8.9
Nov	6.53
Dec	11.41
Mean_Annual (mm/year)	**340.42**

Station	Precipitation
FOB_BAMYAN	mm/Month
Jan	30.52
Feb	46.1
Mar	64.98
Apr	67.44
May	36.17
Jun	0.15
Jul	0.02
Aug	0
Sep	0.01
Oct	2.28
Nov	13.91
Dec	24.99
Mean_Annual (mm/year)	**286.57**

Station	Precipitation
FOB_KALAGUSH	mm/Month
Jan	42.53
Feb	78.55
Mar	115.7
Apr	97.37
May	44.16
Jun	7.82
Jul	20.51
Aug	12.6
Sep	10.75
Oct	14.64
Nov	14.28
Dec	26.2
Mean_Annual (mm/year)	**485.11**

Station	Precipitation
FOB_BOSTIC	mm/Month
Jan	57.79
Feb	104.91
Mar	149.09
Apr	119.55
May	67.27
Jun	24
Jul	63.87
Aug	60.15
Sep	30.37
Oct	26.45
Nov	23.14
Dec	47.17
Mean_Annual (mm/year)	**773.76**

Station	Precipitation
FOB_KUTSCHBACH	mm/Month
Jan	36.07
Feb	65.85
Mar	87.51
Apr	74.29
May	24.79
Jun	1.8
Jul	5.71
Aug	2.26
Sep	1.81
Oct	5.4
Nov	8.65
Dec	20.08
Mean_Annual (mm/year)	**334.22**

Station	Precipitation
FOB_NAGHLU	mm/Month
Jan	19.08
Feb	15.92
Mar	18.14
Apr	12.47
May	3.52
Jun	0
Jul	0
Aug	0
Sep	0
Oct	3.32
Nov	10
Dec	17.99
Mean_Annual (mm/year)	**100.44**

Station	Precipitation
FOB_SHANK	mm/Month
Jan	26.23
Feb	50.33
Mar	60.33
Apr	47.08
May	16.12
Jun	1.09
Jul	3.88
Aug	1.32
Sep	0.38
Oct	2.33
Nov	5.13
Dec	17.02
Mean_Annual (mm/year)	**231.24**

Station	Precipitation
FOB_SHINWAR	mm/Month
Jan	28.25
Feb	53.22
Mar	92.63
Apr	80.72
May	38.64
Jun	10.94
Jul	38.09
Aug	24.95
Sep	19.08
Oct	15.15
Nov	8.01
Dec	14.03
Mean_Annual (mm/year)	**423.71**

Station	Precipitation
GARDEZ_1	mm/Month
Jan	34.01
Feb	64.61
Mar	76.47
Apr	61.91
May	27.98
Jun	4.39
Jul	11.2
Aug	7.35
Sep	1.03
Oct	3.35
Nov	7.89
Dec	25.09
Mean_Annual (mm/year)	**325.28**

Station	Precipitation
FOB_TILLMAN	mm/Month
Jan	42.06
Feb	72.04
Mar	92.49
Apr	80.06
May	23.43
Jun	0.76
Jul	1.7
Aug	0.56
Sep	0.66
Oct	4.83
Nov	10.12
Dec	23.68
Mean_Annual (mm/year)	**352.39**

Station	Precipitation
GHAZNI_1	mm/Month
Jan	26.9
Feb	37.81
Mar	47.84
Apr	32.65
May	10.29
Jun	0.15
Jul	0.9
Aug	0.29
Sep	0.01
Oct	1.07
Nov	4.26
Dec	13.75
Mean_Annual (mm/year)	**175.92**

Station	Precipitation
HAJIGAK	mm/Month
Jan	51.02
Feb	75.09
Mar	100.13
Apr	102.85
May	55.69
Jun	0.47
Jul	0.13
Aug	0.06
Sep	0.03
Oct	3.99
Nov	23.21
Dec	45.4
Mean_Annual (mm/year)	**458.07**

Station	Precipitation
PESHAWAR	mm/Month
Jan	37.27
Feb	79.06
Mar	100.81
Apr	83.37
May	42.83
Jun	11.42
Jul	27.16
Aug	18.05
Sep	8.31
Oct	8.91
Nov	11.11
Dec	26.31
Mean_Annual (mm/year)	**454.61**

Station	Precipitation
GARDEZ_1	mm/Month
Jan	47.55
Feb	77.77
Mar	95.6
Apr	83.66
May	21.26
Jun	0.32
Jul	0.45
Aug	0.12
Sep	0.26
Oct	4.54
Nov	11.21
Dec	25.32
Mean_Annual (mm/year)	**368.06**

Station	Precipitation
KHOST	mm/Month
Jan	14.11
Feb	24.25
Mar	39.64
Apr	35.66
May	13.84
Jun	1.39
Jul	6.23
Aug	4.1
Sep	5.24
Oct	3.36
Nov	4.22
Dec	5.95
Mean_Annual (mm/year)	**157.99**

Station	Precipitation
FOB_KUTSCHBACH	mm/Month
Jan	32.09
Feb	58.92
Mar	77.15
Apr	65.16
May	22.66
Jun	1.19
Jul	3.41
Aug	1.16
Sep	0.63
Oct	3.42
Nov	7.34
Dec	21.36
Mean_Annual (mm/year)	**294.49**

Station	Precipitation
FOB_CONNOLLY	mm/Month
Jan	96.5
Feb	134.55
Mar	175.71
Apr	184.48
May	102.21
Jun	1.8
Jul	0.69
Aug	0.24
Sep	0.4
Oct	13.88
Nov	48.94
Dec	89.66
Mean_Annual (mm/year)	**849.06**

Station	Precipitation
OKAK	mm/Month
Jan	35.69
Feb	52.55
Mar	67.89
Apr	60.77
May	29.2
Jun	0.35
Jul	0.26
Aug	0.14
Sep	0.01
Oct	1.43
Nov	11.14
Dec	26.94
Mean_Annual (mm/year)	**286.37**

Station	Precipitation
PAN_JAO	mm/Month
Jan	31.89
Feb	45.37
Mar	60.75
Apr	54.5
May	27.82
Jun	0.03
Jul	0.01
Aug	0
Sep	0
Oct	0.94
Nov	11.51
Dec	24.3
Mean_Annual (mm/year)	**257.12**

Station	Precipitation
PARACHINAR	mm/Month
Jan	26.53
Feb	69.68
Mar	98.17
Apr	78.73
May	50.41
Jun	25.02
Jul	73.81
Aug	58.58
Sep	29.14
Oct	13.05
Nov	7.28
Dec	14.05
Mean_Annual (mm/year)	**544.45**

Station	Precipitation
ORGUN_E	mm/Month
Jan	25.66
Feb	50.04
Mar	59.84
Apr	43.68
May	18.5
Jun	4.44
Jul	17.72
Aug	13.3
Sep	1.66
Oct	1.86
Nov	3.63
Dec	16.09
Mean_Annual (mm/year)	**256.42**

Station	Precipitation
SHARANA	mm/Month
Jan	26.73
Feb	46.86
Mar	55.2
Apr	39.49
May	14.76
Jun	1.61
Jul	7.31
Aug	4.41
Sep	0.3
Oct	1.42
Nov	3.95
Dec	16.48
Mean_Annual (mm/year)	**218.52**

Station	Precipitation
SOUTH_SALANG	mm/Month
Jan	96.5
Feb	134.55
Mar	175.71
Apr	184.48
May	102.21
Jun	1.8
Jul	0.69
Aug	0.24
Sep	0.4
Oct	13.88
Nov	48.94
Dec	89.66
Mean_Annual (mm/year)	**849.06**

Station	Precipitation
SUPER_FOB	mm/Month
Jan	26.02
Feb	40.13
Mar	49.07
Apr	32.14
May	10.83
Jun	0.83
Jul	5.36
Aug	3.78
Sep	0.13
Oct	0.74
Nov	2.9
Dec	14.2
Mean_Annual (mm/year)	**186.13**

Station	Precipitation
SUROBI	mm/Month
Jan	30.65
Feb	53.04
Mar	69.89
Apr	59.71
May	16.95
Jun	0.35
Jul	0.84
Aug	0.21
Sep	0.16
Oct	2.22
Nov	6.53
Dec	19.32
Mean_Annual (mm/year)	**259.87**

Station	Precipitation
URGOON	mm/Month
Jan	27.77
Feb	50.79
Mar	60.53
Apr	44.5
May	18.48
Jun	3.32
Jul	12.79
Aug	9.59
Sep	0.81
Oct	1.64
Nov	4.13
Dec	17.88
Mean_Annual (mm/year)	**252.23**

Station	Precipitation
ZHOB	mm/Month
Jan	13.11
Feb	21.74
Mar	37.52
Apr	21.38
May	7.64
Jun	5.07
Jul	35.74
Aug	40.26
Sep	3.28
Oct	0.21
Nov	0.37
Dec	5.87
Mean_Annual (mm/year)	**192.19**

Station	Precipitation
WAZAKHWA	mm/Month
Jan	27.36
Feb	38.92
Mar	49.26
Apr	31.15
May	10.67
Jun	1.23
Jul	8.26
Aug	8.09
Sep	0.14
Oct	0.36
Nov	2.06
Dec	14.84
Mean_Annual (mm/year)	**192.34**

Station	Precipitation
Khelegay	mm/Month
Jan	40.85
Feb	59.63
Mar	76.59
Apr	63.9
May	21.77
Jun	0.05
Jul	0.02
Aug	0
Sep	0.01
Oct	3.17
Nov	12.46
Dec	22.26
Mean_Annual (mm/year)	**300.71**

Station	Precipitation
KHOST	mm/Month
Jan	17.96
Feb	47.1
Mar	57.47
Apr	51.11
May	26.48
Jun	12.76
Jul	49.41
Aug	36.07
Sep	14.52
Oct	3.98
Nov	3.64
Dec	9.61
Mean_Annual (mm/year)	**330.11**

Station	Precipitation
ISHKASHIM	mm/Month
Jan	63.77
Feb	85.79
Mar	117.22
Apr	111.66
May	87.18
Jun	25.17
Jul	17.03
Aug	8.53
Sep	5.42
Oct	28.72
Nov	45.85
Dec	66.5
Mean_Annual (mm/year)	**662.84**

Station	Precipitation
MEHTARLAM_PRT	mm/Month
Jan	19.68
Feb	35.29
Mar	53.96
Apr	46.96
May	18.38
Jun	1.92
Jul	7.67
Aug	4.23
Sep	4.99
Oct	4.59
Nov	5.6
Dec	9.05
Mean_Annual (mm/year)	**212.32**

Station	Precipitation
FOB KUNDUZ	mm/Month
Jan	36.88
Feb	49.82
Mar	68.08
Apr	47.38
May	21.58
Jun	0.01
Jul	0.02
Aug	0
Sep	0
Oct	3.13
Nov	14.97
Dec	20.67
Mean_Annual (mm/year)	**262.54**

Station	Precipitation
MIRANSHAH_AIRPORT	mm/Month
Jan	14.09
Feb	35.75
Mar	47.05
Apr	39.61
May	19.89
Jun	10.61
Jul	47.07
Aug	38.63
Sep	13.39
Oct	2.8
Nov	2.18
Dec	7.28
Mean_Annual (mm/year)	**278.35**

Station	Precipitation
QUETTA	mm/Month
Jan	41.31
Feb	35.16
Mar	38.05
Apr	15.26
May	2.08
Jun	0.05
Jul	1.85
Aug	2.56
Sep	0
Oct	0.01
Nov	0.78
Dec	17.37
Mean_Annual (mm/year)	**154.48**

Station	Precipitation
KOHAT	**mm/Month**
Jan	15.43
Feb	31.79
Mar	54.13
Apr	35.13
May	23.05
Jun	12.96
Jul	65.92
Aug	79.18
Sep	34.37
Oct	10.26
Nov	4.87
Dec	7.05
Mean_Annual (mm/year)	**374.14**

Station	Precipitation
PESHAWAR	**mm/Month**
Jan	17.84
Feb	34.35
Mar	60.82
Apr	36.51
May	19.12
Jun	5.72
Jul	38.51
Aug	52.85
Sep	18.4
Oct	7.43
Nov	5.18
Dec	8.73
Mean_Annual (mm/year)	**305.46**

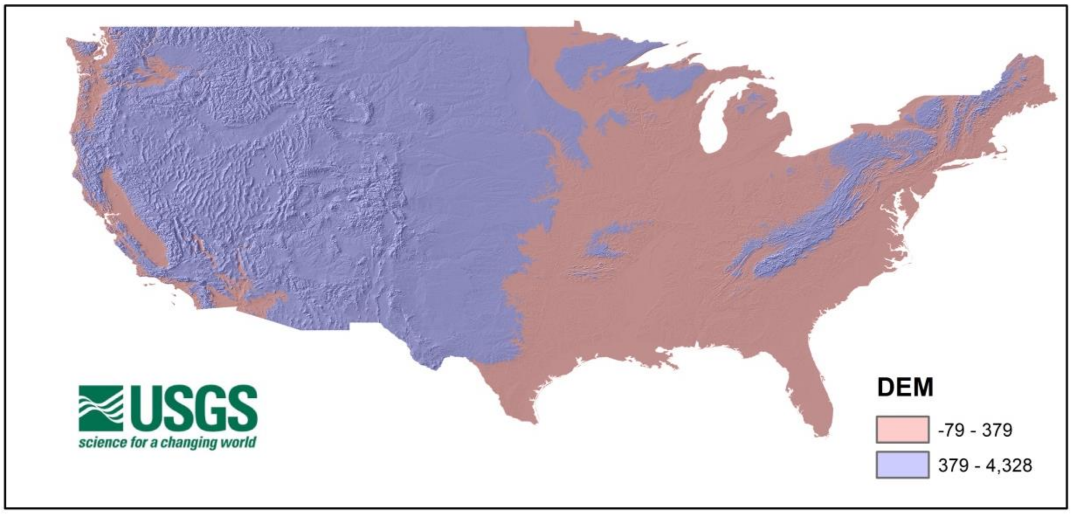
Station	Precipitation
FAOZABAD	**mm/Month**
Jan	47.28
Feb	66.11
Mar	94.72
Apr	94.25
May	66.69
Jun	5.55
Jul	1.62
Aug	1.07
Sep	0.28
Oct	15.41
Nov	24.98
Dec	33.9
Mean_Annual (mm/year)	**451.86**

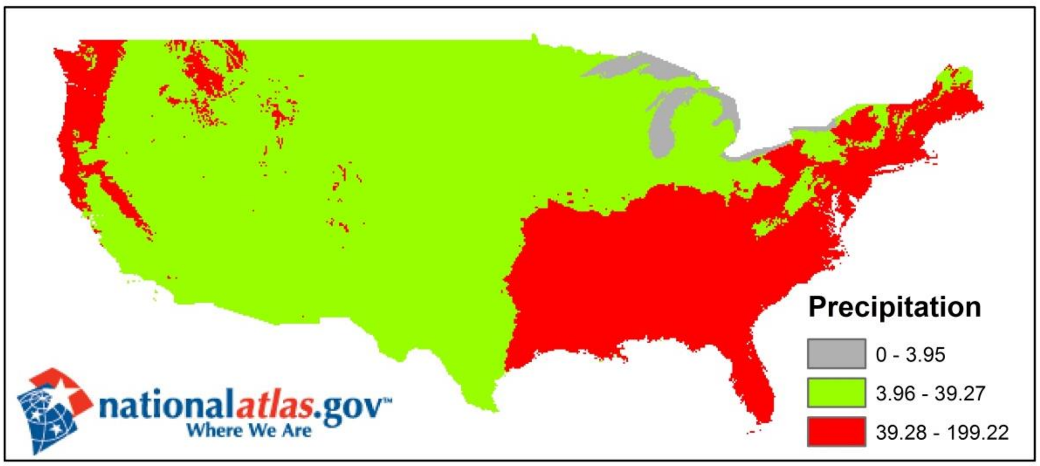
APPENDIX B: Erosivity Factor (R) of the Kabul River Basin

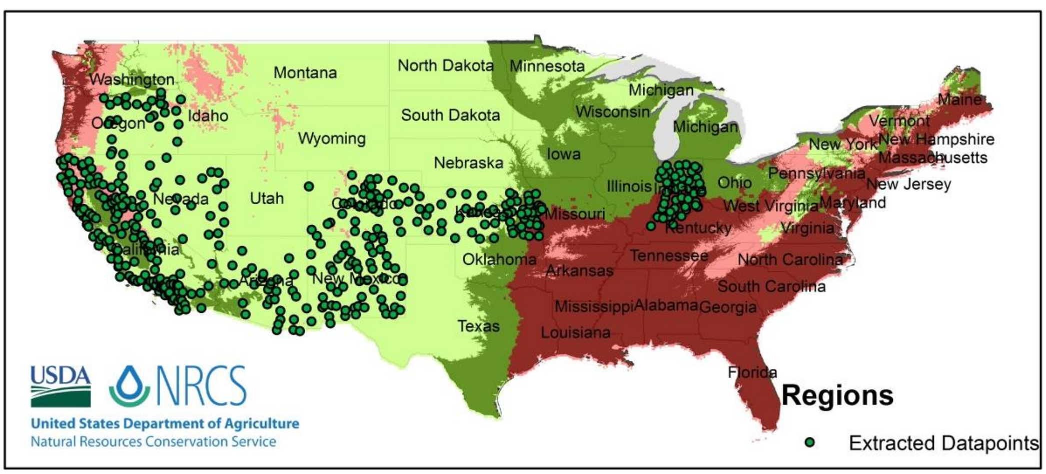
NO	Station	Code	Location		Precipitation mm/year	R-factor SI Units	R-factor U.S. Units
			Longitude	Latitude			
1	FOB_NAGHLU	695474	69.7000	34.6170	100	81	4.7
2	QUETTA	692844	66.9330	30.2500	154	161	9.5
3	JALALABAD_1	409540	70.4670	34.4330	158	167	9.8
4	GHAZNI_1	692804	68.4170	33.5000	176	199	11.7
5	COP_CURRY	694594	68.8670	32.5170	185	217	12.7
6	SUPER_FOB	692484	68.5000	32.9000	186	218	12.8
7	ZHOB	416200	69.4670	31.3500	192	229	13.5
8	WAZAKHWA	409810	68.3500	32.2000	192	230	13.5
9	MEHTARLAM_PRT	691226	70.2000	34.6800	212	269	15.8
10	SHARANA	692854	68.8400	33.1170	219	282	16.6
11	FOB_SHANK	692814	69.0600	33.9400	231	309	18.2
12	URGOON	409840	69.1330	32.9170	252	356	20.9
13	ORGUN_E	690654	69.1500	32.9330	256	365	21.4
14	PAN_JAO	409460	67.0330	34.3830	257	367	21.5
15	SUROBI	690336	69.7170	34.6170	260	373	21.9
16	FOB KUNDUZ	691984	68.9000	36.6600	263	379	22.3
17	MIRANSHAH_AIRPORT	415840	70.1170	32.9830	278	417	24.5
18	COP_CARWILE	691764	68.6500	33.8670	280	421	24.8
19	OKAK	409660	67.9500	33.8830	286	436	25.6
20	FOB_BAMYAN	691774	67.8330	34.8170	287	437	25.7
21	CAMP_AIRBORNE_HLZ	696714	68.8830	34.4000	287	437	25.7
22	KABUL_AIRPORT	409480	69.2170	34.5500	294	456	26.8
23	COP_WILDERNESS	690176	69.4170	33.3670	295	458	26.9
24	Khelegay	691534	68.7000	35.8700	300	470	27.6
25	BAGRAM	409450	69.2830	34.9500	305	482	28.3
26	PESHAWAR	415300	71.5830	34.0170	305	484	28.4
27	GARDEZ_1	696504	69.2500	33.5670	325	535	31.5
28	KHOST	409710	69.9500	33.3500	330	548	32.2
29	FOB_KUTSCHBACH	690684	69.6330	34.8670	334	559	32.9
30	FOB_CONNOLLY	692544	70.2000	34.2670	340	576	33.8
31	FOB_TILLMAN	694604	69.4500	32.9330	352	609	35.8
32	JABUL_SARAJ	409320	69.2500	35.1330	368	653	38.4
33	KOHAT	415640	71.4330	33.5670	374	671	39.4
34	FOB_SHINWAR	696494	70.8170	34.1830	424	819	48.1
35	FAOZABAD	409040	70.5170	37.1170	452	909	53.4
36	HERRERA_HLZ	691324	69.7170	33.9330	455	918	53.9
37	HAJIGAK	409330	68.1000	34.5830	458	929	54.6

NO	Station	Code	Location		Precip. mm/year	R-factor SI Units	R-factor U.S. Units
38	FOB_KALAGUSH	696704	70.3830	34.9670	485	1019	59.9
39	COP_CHAMKANI	692514	69.8170	33.8000	495	1054	61.9
40	PARACHINAR	415600	70.0833	33.8670	544	1227	72.1
41	CHITRAL	415205	71.8000	35.8830	574	1337	78.6
42	ISHKASHIM	389570	71.6000	36.7170	663	1684	99.0
43	CAMP_BLESSING_NANGA	692246	70.9000	34.9830	664	1690	99.3
44	COP_HONAKER_MIRACLE	692464	71.0830	34.9160	695	1818	106.8
45	DROSH	415150	71.7830	35.5670	709	1876	110.2
46	ASADABAD_FOB	692414	71.1400	34.8500	734	1986	116.7
47	FOB_BOSTIC	647094	71.5170	35.2170	774	2161	127.0
48	COP_MONTI	692644	71.3500	35.0330	843	2482	145.8
49	NORT_SALANG	409300	69.0170	35.3170	849	2509	147.4
50	SOUTH_SALANG	409310	69.0670	35.3000	849	2509	147.4
51	DIR	415080	71.8500	35.2000	997	3456	203.0

APPENDIX C: Location and R Value of the Climatic Stations on the U.S. Map, based on the Similar Range of Precipitation and Elevation of the Kabul River Basin


USGS
science for a changing world
DEM
-79 - 379
379 - 4,328


nationalatlas.gov
Where We Are
Precipitation
0 - 3.95
3.96 - 39.27
39.28 - 199.22


Washington
Oregon
Idaho
Montana
North Dakota
Minnesota
South Dakota
Wyoming
Nebraska
Iowa
Wisconsin
Michigan
Nevada
Utah
California
Arizona
New Mexico
Oklahoma
Texas
Missouri
Arkansas
Illinois
Ohio
Kentucky
Tennessee
Mississippi
Alabama
Georgia
Louisiana
Florida
West Virginia
Virginia
North Carolina
South Carolina
Pennsylvania
New York
Vermont
New Hampshire
Maine
Massachusetts
New Jersey
Maryland
USDA
NRCS
United States Department of Agriculture
Natural Resources Conservation Service
Regions
Extracted Datapoints

Colorado				
No	Station ID	Longitude	Latitude	R_Value
1	50109	-103.15	40.15	46.3
2	50183	-105.53	40.2	13.3
3	50263	-105.88	39	18.1
4	50304	-102.17	38.85	54.9
5	50372	-106.83	39.18	8.6
6	50834	-102.18	39.63	78.1
7	50843	-105.27	40.03	31.4
8	51179	-104.13	39.75	39.2
9	51539	-103.5	38.1	30.7
10	52220	-104.87	39.77	54.5
11	52286	-108.97	40.23	9.1
12	52354	-105.33	40.43	30.9
13	52535	-102.48	40.12	70.3
14	53007	-105.22	40.67	40.5
15	53063	-104.7	38.68	57
16	53386	-105.22	39.7	36
17	53477	-102.32	38.07	65
18	53579	-104.73	39.1	43.3
19	53584	-104.73	39.22	42.2
20	53662	-106.92	38.55	6.8
21	54172	-103.47	39.13	59.4
22	54538	-103.32	37.45	59.4
23	54742	-105.48	38.92	16.1
24	54877	-105.63	39.77	19.7
25	55121	-105.15	40.25	27.3
26	55352	-104.93	38.85	50.5
27	55531	-108.48	37.2	27.1
28	55711	-106.15	37.48	5.4
29	55765	-105.2	39.65	27.1
30	55922	-103.85	40.6	66.7
31	55982	-106.33	40.93	7.9
32	56023	-104.78	40.7	39.3
33	56203	-107.67	38.02	13.7
34	56326	-104.65	39.53	43.6
35	56591	-108.8	37.58	18.5
36	57337	-106.13	38.08	7
37	57428	-105.42	37.2	7.2

38	57519	-102.87	39.3	53
39	58064	-106.37	39.25	11.6
40	58204	-107.82	37.93	16.1
41	58220	-105.05	37.08	35.6
42	58429	-104.48	37.17	36.7
43	58781	-104.78	37.63	33.5
44	59096	-106.22	40.03	12.2
45	59210	-105.08	39.1	36.2
New Mexico				
No	**Station ID**	**Longitude**	**Latitude**	**R_Value**
46	299565	-108.85	36.07	17.9
47	299897	-108.83	35.07	23.4
48	290417	-108.82	31.95	33.8
49	293142	-108.25	36.7	8.1
50	290818	-108.12	33.42	39.5
51	293265	-108.15	32.8	41.7
52	295754	-108.02	32.93	46.1
53	297918	-107.65	35.33	14.6
54	292436	-107.73	32.25	44.4
55	292024	-107.65	31.83	33
56	290640	-107.62	34.08	35.7
57	292250	-107.52	35.08	22.6
58	294009	-107.57	32.93	48.8
59	297423	-107.22	33.75	25.8
60	299031	-107.18	35.8	18.1
61	292241	-106.97	36.03	25.5
62	291286	-107.3	32.9	36
63	298387	-106.88	34.08	31.4
64	298535	-106.75	32.28	26.1
65	294426	-106.73	32.62	42.7
66	292837	-106.73	36.6	20.7
67	294366	-106.53	35.38	68.5
68	290041	-106.43	36.23	13.3
69	291982	-106.32	35.63	41.9
70	299686	-106.18	32.78	37.3
71	296435	-106.1	32.38	54.6
72	299193	-106.07	35.5	30.7
73	298518	-105.97	35.17	39
74	290199	-105.95	32.88	37.4
75	291120	-105.73	33.45	29.3

76	297094	-105.88	34.42	41.4
77	292665	-105.4	34.47	46.9
78	297736	-105.57	32.8	53.9
79	292700	-105.27	36.55	21.2
80	294862	-105.2	35.53	63.9
81	292510	-105.07	35.18	51.4
82	296275	-105.05	36.18	52
83	291840	-105	33.9	62
84	298501	-104.58	36.37	66.1
85	297610	-104.53	33.3	93.5
86	297279	-104.43	36.92	46.7
87	290600	-104.38	32.77	77
88	298596	-104.38	34.6	95.4
89	291469	-104.23	32.42	69.8
90	297638	-104.2	35.95	68.8
91	292030	-104.18	35.4	61.4
92	295370	-103.7	32.82	89.5
93	299156	-103.68	35.2	74.7
94	299569	-103.8	32.38	80.8
95	292203	-103.33	33.52	85.5
96	291963	-103.22	34.6	94.6
97	291939	-103.2	34.42	84.5
98	296659	-103.38	32.65	131
		Nevada		
No	**Station ID**	**Longitude**	**Latitude**	**R_Value**
99	265441	-119.87	39.35	5.8
100	265191	-119.77	38.97	7.4
101	267612	-119.33	38.95	6.1
102	268822	-119.12	39.08	3.9
103	268838	-119.28	39.7	7.1
104	263515	-118.67	38.55	20.7
105	264527	-118.72	41.52	4.5
106	265362	-118.32	37.97	8.1
107	264698	-118.47	40.18	2.9
108	267192	-118.3	40.47	5.3
109	264935	-117.72	42	5.4
110	267620	-117.17	38.78	6
111	260507	-117.08	39.5	13
112	260691	-116.88	40.62	5.6
113	260718	-116.72	37	6.9

114	267640	-116.2	39.07	8
115	264394	-115.52	40.72	3.3
116	265880	-115.12	37.27	8.9
117	267908	-115.02	38.42	14.1
118	268988	-114.97	41.12	6
119	267369	-114.92	35.47	22.1
120	264651	-114.48	36.62	15.9
121	262557	-114.55	37.35	13.6
122	267750	-114.18	38.03	23
123	266148	-114.53	41.07	5.8
124	262820	-114.18	40.42	2.1
125	264341	-114.62	40.05	7.9
126	263340	-114.22	39	5.9
Oregon				
No	Station ID	Longitude	Latitude	R_Value
127	354147	-116.83	45.57	14.6
128	356294	-116.97	44.05	3.7
129	354321	-117.05	42.98	13.8
130	353604	-117.12	44.88	19.7
131	350409	-117.82	44.77	5.6
132	358746	-117.88	45.22	4.2
133	358000	-118.05	45.75	20.4
134	358985	-118.05	46	14.8
135	354622	-118.08	45.32	10.9
136	350723	-118.17	43.92	7.8
137	350356	-118.5	44.58	11.3
138	356636	-118.62	45.5	6.3
139	356845	-118.72	44.45	6.8
140	358726	-118.93	45.13	9.6
141	353830	-119.53	45.28	7.1
142	351765	-120.18	45.23	8.9
143	350265	-120.2	45.72	4.5
144	354670	-120.37	42.22	9.2
145	355734	-120.72	45.48	6.1
146	356238	-120.73	44.3	6.7
147	350853	-121.05	42.4	12.4
148	357817	-121.07	43.12	8.8
149	353232	-121.13	42.2	10.2
150	357056	-121.17	44.27	4.7
151	358717	-121.17	45.25	7

152	350694	-121.28	44.07	8.6
153	354008	-121.55	45.65	32.2
Arizona				
No	**Station ID**	**Longitude**	**Latitude**	**R_Value**
154	26194	-113.67	35.38	22
155	20100	-113.58	34.23	8.1
156	20080	-112.87	32.37	30.8
157	29158	-112.82	34.93	32
158	28895	-113.07	36.28	16.8
159	26194	-113.03	33.08	26.2
160	20487	-112.48	35.22	62.1
161	22329	-112.33	34.2	41.1
162	25635	-111.83	34.62	32.1
163	27708	-111.77	34.87	41.7
164	28273	-111.48	33.9	41.2
165	21314	-111.53	33	27.2
166	26323	-111.33	34.23	57.2
167	23035	-111.37	33.28	31.4
168	27876	-110.97	33.8	39.7
169	28349	-111.07	33.3	58.2
170	25924	-110.95	31.42	83.6
171	28995	-110.72	32.05	32.1
172	21574	-110.92	34.53	48.1
173	27593	-110.85	31.77	125.7
174	26119	-110.73	32.6	81.8
175	20768	-109.92	31.43	55.3
176	29271	-109.97	33.83	62.1
177	26468	-109.88	34.82	15.8
178	21870	-109.9	32.07	39.7
179	20808	-109.77	33.48	33
180	22659	-109.53	31.35	
181	24586	-110.2	35.82	19.7
182	27593	-109.12	32.75	29.8
California				
No	**Station ID**	**Longitude**	**Latitude**	**R_Value**
183	44089	-124.2	41.77	196.1
184	42910	-124.17	40.8	47.1
185	44577	-124.03	41.52	211.1
186	43357	-123.97	41.87	

187	41084	-123.88	40.48	168.5
188	45711	-123.78	40.18	189
189	44883	-123.72	39.87	240.8
190	42749	-123.72	42	149.8
191	44089	-123.67	41.05	139.8
192	43761	-123.37	41.8	116.2
193	49851	-123.23	38.9	117.8
194	42084	-123.08	39.83	85.2
195	44191	-123.45	40.62	74.9
196	44689	-123.18	39.23	81.5
197	43791	-122.97	40.37	66.2
198	47109	-123.13	39.37	106.3
199	41839	-123	38.8	114.3
200	42899	-122.9	41.47	46.6
201	48072	-122.82	38.4	129.2
202	49273	-123.02	38.62	128.4
203	43182	-122.85	41.6	34.2
204	41886	-122.7	41.08	25.5
205	46826	-122.63	38.23	56
206	45785	-122.47	41.78	21.8
207	45258	-122.78	38.85	50.2
208	45996	-122.6	37.9	109.6
209	43020	-122.45	40.35	227.5
210	47767	-122.5	37.77	0
211	40212	-122.43	38.57	109.6
212	48135	-122.42	40.72	227
213	45983	-122.32	41.32	73.5
214	40546	-122.13	40.4	69.7
215	40368	-122.25	38.43	82.4
216	41005	-122.2	37.15	189.8
217	42935	-122.03	38.28	51.5
218	47581	-121.93	40.8	201.9
219	42362	-121.87	36.6	42.8
220	47821	-121.9	37.35	22
221	49390	-121.87	40.47	66.9
222	41715	-121.82	39.7	51.8
223	42048	-121.8	36.98	58.3
224	46528	-121.57	39.53	136.9
225	45679	-121.6	40.35	145

226	45853	-121.65	37.13	42.2
227	49605	-121.38	39.03	30.6
228	44025	-121.4	36.85	27.9
229	47719	-121.08	36.52	31.7
230	41142	-121.1	35.8	21.1
231	41462	-121.05	39.45	252.6
232	41497	-121.08	40.17	74.4
233	44035	-121.23	36.92	13.7
234	43573	-121.07	39.22	138.9
235	46232	-120.9	39.37	144.2
236	45741	-121	37.63	20.7
237	48703	-120.67	40.43	75.2
238	41428	-120.85	38.25	46
239	42500	-120.83	39.57	163.5
240	46964	-120.85	38.73	96.5
241	40883	-120.67	38.92	157.9
242	43928	-120.7	36.3	43.6
243	43038	-120.7	38.53	94.9
244	46730	-120.68	35.63	29
245	47851	-120.67	35.3	83.9
246	41018	-120.65	39.45	192.3
247	47933	-120.63	35.37	129.3
248	47867	-120.68	35.75	25.9
249	40161	-120.55	41.5	8
250	45535	-120.48	37.32	14.5
251	44762	-120.22	35.37	62.6
252	47489	-120.37	38.9	120
253	48697	-120.57	34.68	42.5
254	48873	-120.43	40.87	8.3
255	48218	-120.37	39.58	52.5
256	49043	-120.18	39.33	54
257	43891	-120.42	39.07	64.3
258	43669	-120.23	37.83	100.4
259	45623	-120.35	40.13	14.2
260	43048	-120	34.73	77.9
261	47859	-119.82	34.52	118.1
262	43939	-119.78	37.95	69.9
263	47817	-119.72	37.08	16.2
264	43402	-119.68	34.52	131.8
265	49482	-119.65	37.55	108.4

266	49855	-119.58	37.75	81.3
267	41540	-119.48	34.4	130.6
268	44176	-119.22	37.23	94.5
269	45151	-119.68	35.62	3.7
270	45417	-119.3	34.48	83.8
271	48355	-119.45	38.35	10.6
272	40449	-119.08	36.92	75.9
273	48460	-118.8	36.13	15
274	40422	-119.02	36.63	140.5
275	44867	-118.88	34.08	83.3
276	41754	-119.02	34.8	28.1
277	48917	-118.87	36.47	57.7
278	48463	-118.65	36.2	60.3
279	46942	-118.7	34.4	61.8
280	45026	-118.73	36.6	148.5
281	49120	-118.65	35.88	35.2
282	48092	-118.47	34.17	50.4
283	48832	-118.43	35.13	17.6
284	49512	-118.3	35.67	20
285	46162	-118.53	34.38	67.3
286	41194	-118.35	34.18	61.5
287	40014	-118.27	34.5	31.8
288	44232	-118.2	36.8	6.4
289	48230	-118.17	33.8	52.1
290	45637	-118.08	34.38	16.2
291	46624	-118.1	34.58	8.8
292	49666	-118.08	34.02	32.8
293	45067	-118.05	36.45	9.8
294	47926	-117.97	34.12	76.8
295	46473	-117.88	33.93	43.6
296	47779	-117.87	34.2	230.9
297	40779	-117.68	34.38	160.1
298	48436	-117.82	34.05	100.7
299	44650	-117.8	33.55	
300	48992	-117.6	33.65	36.7
301	45218	-117.48	34.23	191.4
302	46379	-117.35	33.22	26.4
303	47993	-117.53	33.72	28.5
304	49325	-117.3	34.53	10.1
305	42164	-117.3	34.23	40.9

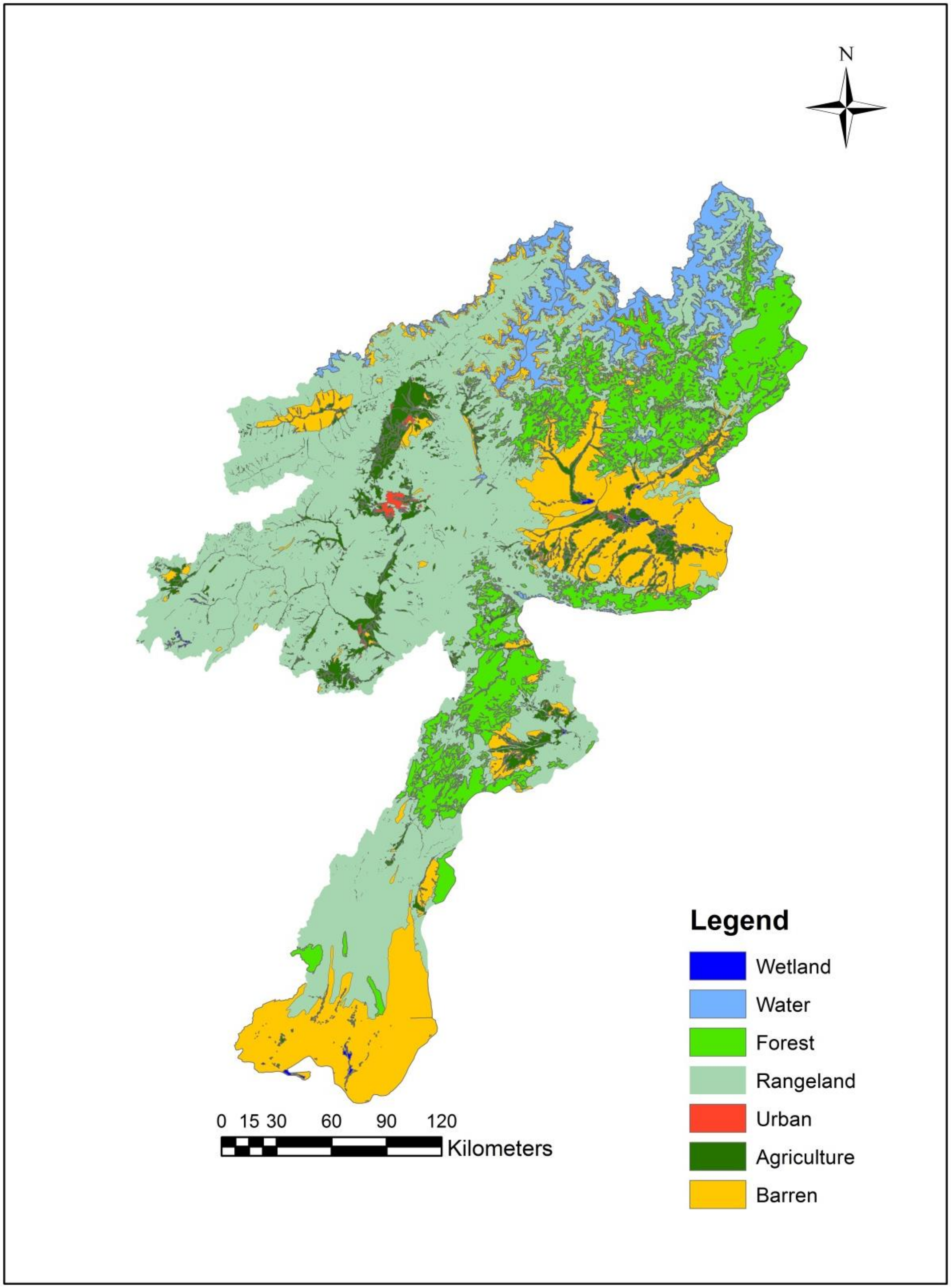
306	42958	-117.25	33.35	34.2
307	47600	-117.08	34.2	194.6
308	45162	-116.93	32.62	23
309	44726	-117	33.17	31
310	45632	-116.93	34.08	51.4
311	47813	-116.97	33.78	27
312	41369	-116.98	34.15	57.3
313	46657	-116.87	33.35	107.2
314	42709	-116.82	32.88	47.8
315	42255	-116.87	34.87	5.4
316	43914	-116.77	33.23	98.4
317	44211	-116.72	33.75	73.5
318	42239	-116.58	32.98	122.2
319	45840	-116.52	32.68	32.8
320	48893	-116.17	33.63	4.3
321	43855	-115.63	33.7	11.9
322	42713	-115.57	32.77	10
323	44297	-115.13	34.13	7
324	43855	-114.17	34.28	15
		Indiana		
No	Station ID	Longitude	Latitude	R_Value
325	43855	-85.68	40.1	141.2
326	120482	-85.22	39.28	153.7
327	120830	-85.17	40.75	151.3
328	120922	-87.12	39.52	192.3
329	121147	-86.4	40.48	160.8
330	121256	-86.63	37.9	212.8
331	121415	-86.88	40.67	164.8
332	121739	-85.48	41.15	134.3
333	121752	-85.93	39.18	138.8
334	121882	-86.9	40.05	146.7
335	121929	-85.83	38.8	172.4
336	122309	-86.7	38.45	204.2
337	122816	-85.1	38.97	176.9
338	122825	-85.15	40.25	142.4
339	123104	-87.3	38.87	205.1
340	123206	-85.12	41.33	125.3
341	123418	-85.83	41.57	127.3
342	123777	-85.4	40.38	149.6
343	124364	-87.18	39.17	191.4

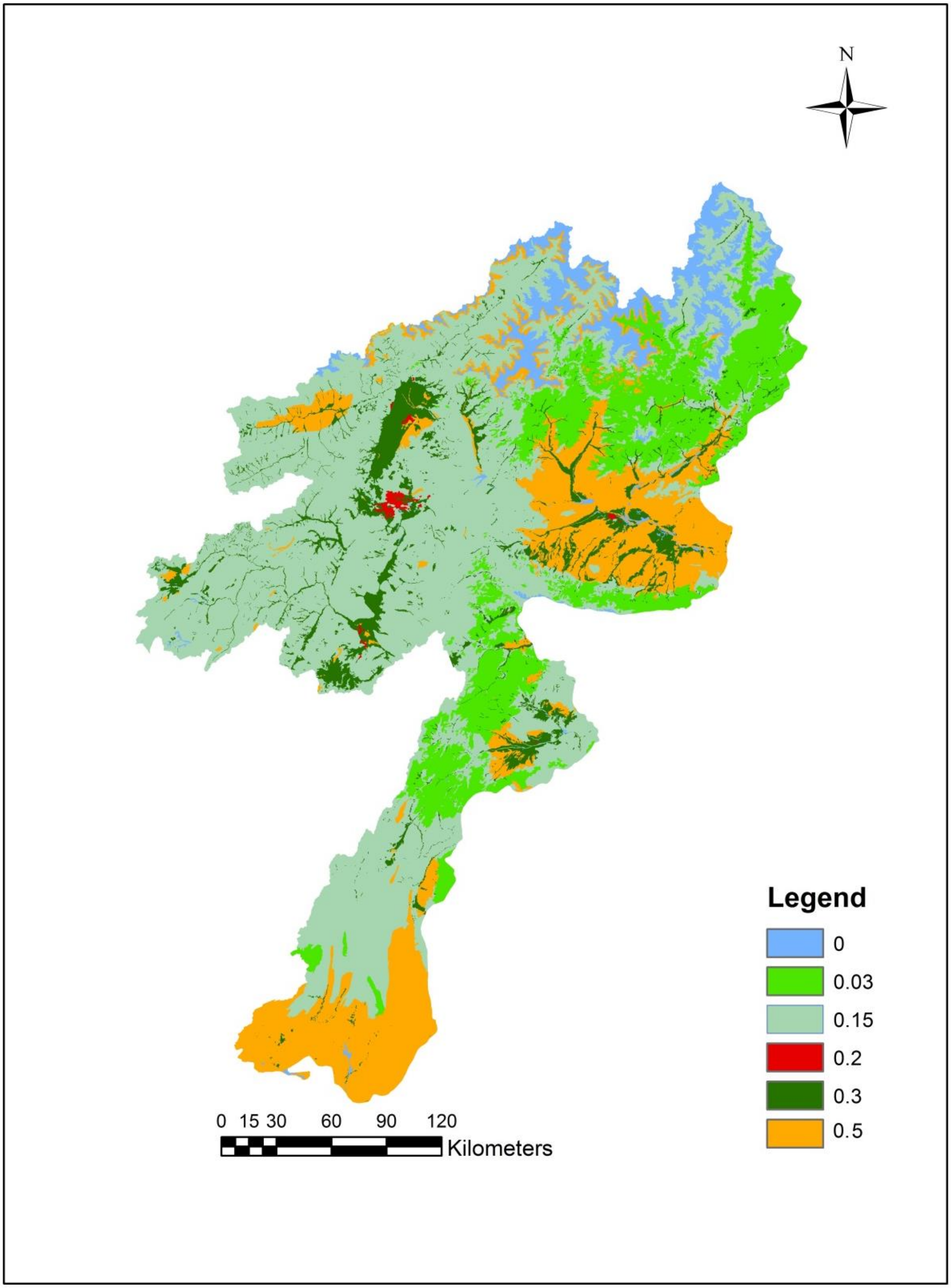
344	124372	-86.92	38.38	226.9
345	124497	-85.27	41.45	132.9
346	124527	-87.45	40.77	175.2
347	124782	-86.27	41.52	147.6
348	124908	-86.47	40.07	171.9
349	124973	-85.35	39.8	146.1
350	125337	-85.67	40.57	149.6
351	125407	-86.45	39.4	168.3
352	125535	-86.9	41.17	153.6
353	126304	-86.1	39.55	167.6
354	126580	-86.53	38.88	171.4
355	126697	-86.12	38.4	161.9
356	126864	-86.05	40.75	153.2
357	127069	-85	40.42	132.6
358	127125	-87.58	38.35	219.9
359	127298	-87.15	40.93	161.2
360	127370	-84.88	39.88	131.2
361	127482	-86.22	41.07	160.1
362	127601	-86.5	40.85	160.8
363	127930	-85.88	38.97	171.3
364	127991	-87.33	41.18	168.6
365	128036	-86.8	38.67	184.6
366	128352	-87.25	38.28	197.6
367	128784	-86.12	40.22	175.2
368	128967	-87.98	37.8	206
369	128999	-87.03	41.52	150.5
370	129069	-85.25	39.08	159.9
371	129174	-85.7	39.45	140
372	129300	-87.03	39.88	201.9
373	43855	-87	40.47	162.3
Kansas				
No	**Station ID**	**Longitude**	**Latitude**	**R_Value**
374	140645	-98.18	37.9	206.2
375	140620	-99.75	38.27	105.3
376	140637	-96.53	37.65	198.2
377	140645	-98.67	38.65	198.2
378	140802	-101.63	37.55	85
379	140906	-95.02	38.1	238.2
380	140957	-94.88	39.07	223.4
381	141162	-95.83	38.8	216.6

382	141233	-97.62	37.05	192.7
383	141351	-96.63	38.05	192.5
384	141608	-95.4	38.92	233.8
385	141612	-95.33	38.93	254.7
386	141740	-94.85	37.18	285.8
387	141867	-96.52	38.68	188.4
388	142135	-96.77	38.57	216.6
389	142430	-95.8	37.28	294.6
390	142560	-100	37.05	121
391	142686	-96.08	37.65	249.4
392	142845	-94.82	37.82	279.8
393	142872	-96.42	39.7	190.4
394	142938	-98.95	38.65	151.9
395	142980	-100.82	37.98	98.3
396	143248	-96.45	37.37	220.8
397	143366	-97.55	37.97	195.8
398	143441	-95.38	38.33	291.6
399	143527	-99.33	38.87	118.5
400	143686	-94.9	38.67	248.9
401	143810	-95.52	39.67	217.2
402	143984	-95.43	37.92	282.5
403	143997	-98.35	39.67	130.4
404	144104	-95.75	38.25	201.3
405	144178	-97.95	38.6	170.5
406	144341	-98.48	37.02	156.2
407	145039	-97.08	38.38	225.8
408	145063	-96.63	39.83	210.2
409	145210	-95.7	38.5	244.3
410	145306	-96.88	39.08	215.3
411	145536	-95.45	37.18	281.2
412	145787	-100.23	39.82	127.5
413	145888	-100.85	39.13	104
414	146024	-96.22	39.32	221.1
415	146128	-95.28	38.62	255.2
416	146333	-95.42	39.12	210.8
417	146374	-99.32	39.75	118.4
418	146498	-95.57	38.65	222
419	146725	-95.95	38.55	276.1
420	147160	-97.65	38.8	218.6
421	147420	-94.72	38.98	223

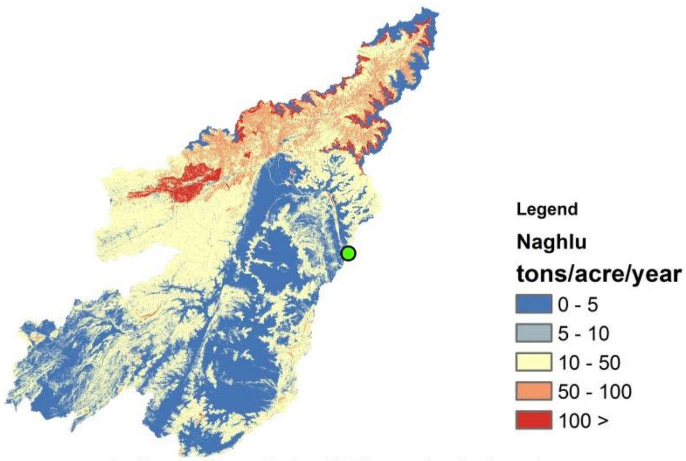
422	147756	-94.67	38.82	221.1
423	147922	-100.85	37.48	81.3
424	147965	-98.97	37.4	166.6
425	148191	-95.93	37.75	249.2
426	148235	-101.77	38.47	88.7
427	148250	-95.05	39.78	197.5
428	148259	-96.6	39.25	179.2
429	148293	-94.97	37.85	274.6
430	148341	-95.45	39.35	223.4
431	148535	-101.58	38.88	92.3
432	141612	-98.48	38.97	138.2

APPENDIX D: Modified Land Use Classification of the Kabul River Basin

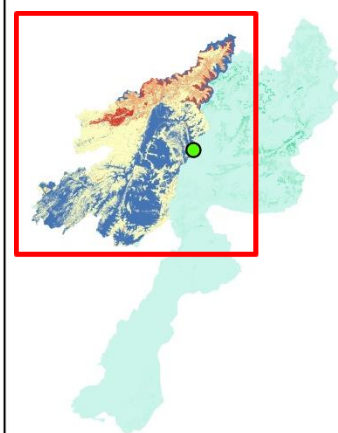

N
Legend
Wetland
Water
Forest
Rangeland
Urban
Agriculture
Barren
0 15 30 60 90 120
Kilometers


N
Legend
0
0.03
0.15
0.2
0.3
0.5
0 15 30 60 90 120
Kilometers

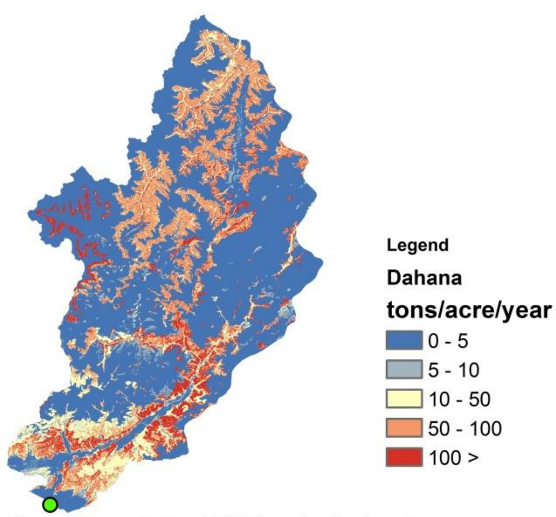
APPENDIX E: Sediment Degradation and Average soil loss RATE AT sub-watersheds of the Kabul River Basin



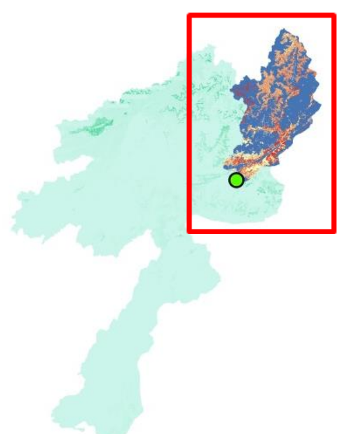
Sediment Degradation (410 tons/sq.km/year)
Average Soil Loss Rate (22.5 tons/acre/year or 5575 tons/sq.km/year)



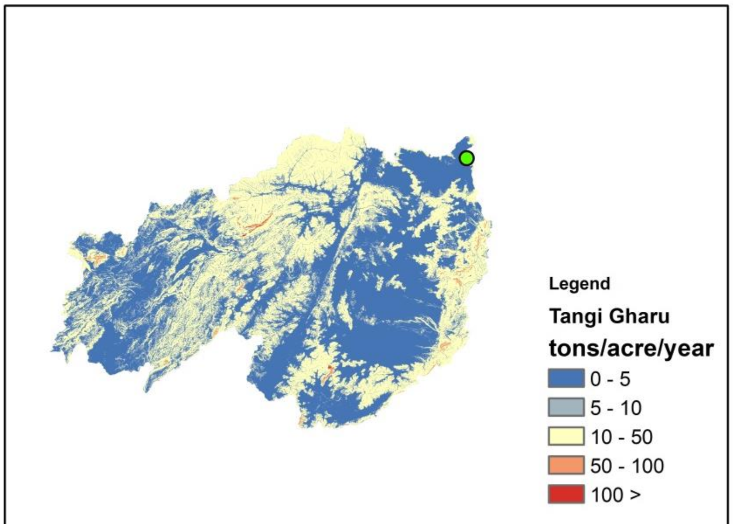
Naghlu sediment gauge station
and sub-watershed
location at the Kabul River Basin



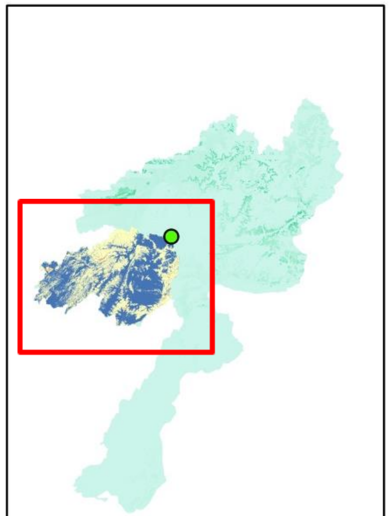
Sediment Degradation (780 tons/sq.km/year)
Average Soil Loss Rate (29 tons/acre/year or 7248 tons/sq.km/year)



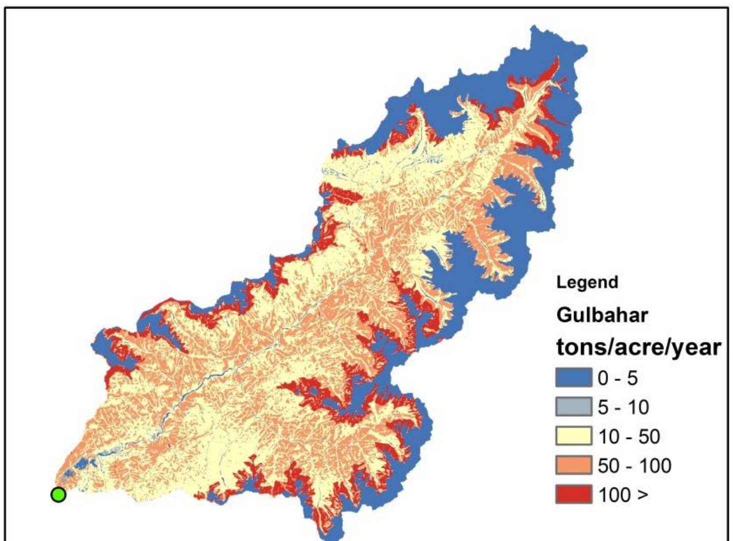
Dahana or Kunar sediment
gauge station and sub-watershed
location at the Kabul River Basin



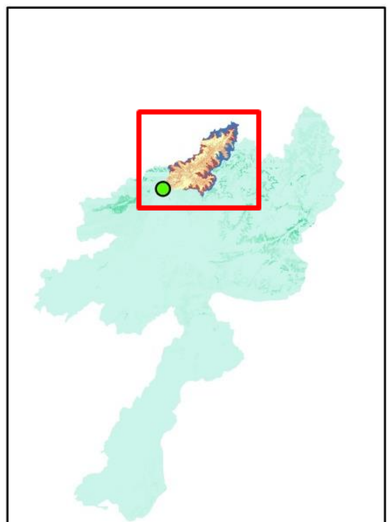
Sediment Degradation (148 tons/sq.km/year)
Average Soil Loss Rate (9.5 tons/acre/year or 2360 tons/sq.km/year)



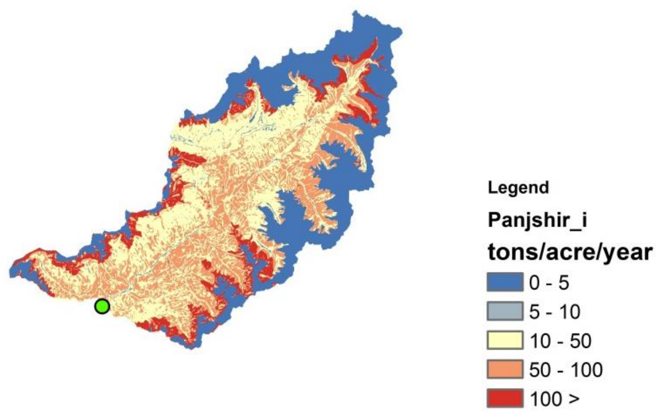
Tangi Gharu sediment gauge station
and sub-watershed
location at the Kabul River Basin



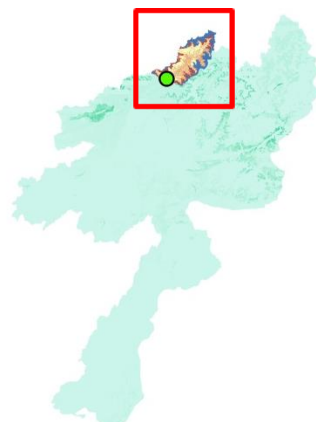
Sediment Degradation (750 tons/sq.km/year)
Average Soil Loss Rate (48 tons/acre/year or 11792 tons/sq.km/year)



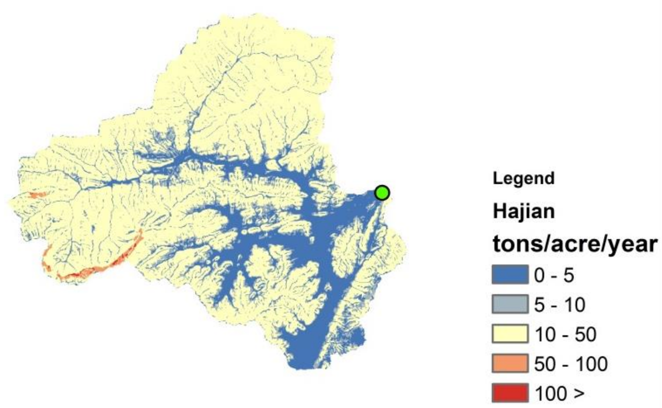
Gulbahar sediment gauge station
and sub-watershed
location at the Kabul River Basin



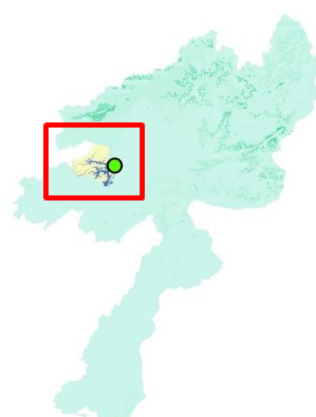
Sediment Degradation (275 tons/sq.km/year)
Average Soil Loss Rate (45 tons/acre/year or 11201 tons/sq.km/year)



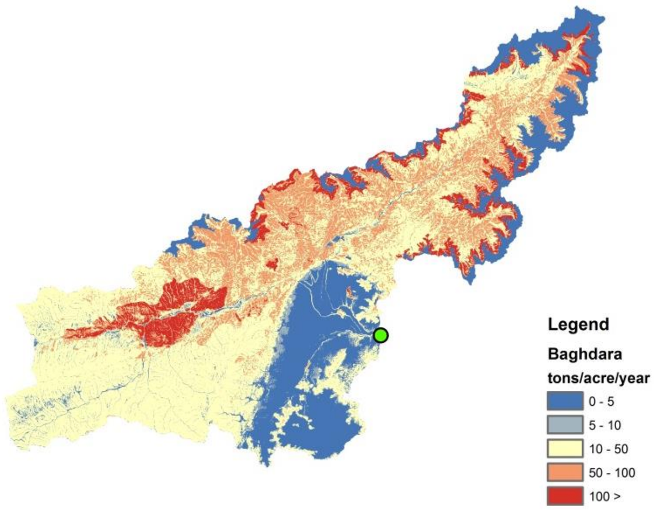
Panjshir_i sediment gauge station and sub-watershed location at the Kabul River Basin



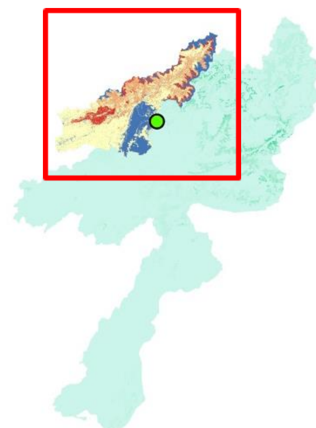
Sediment Degradation (250 tons/sq.km/year)
Average Soil Loss Rate (16 tons/acre/year or 3973 tons/sq.km/year)



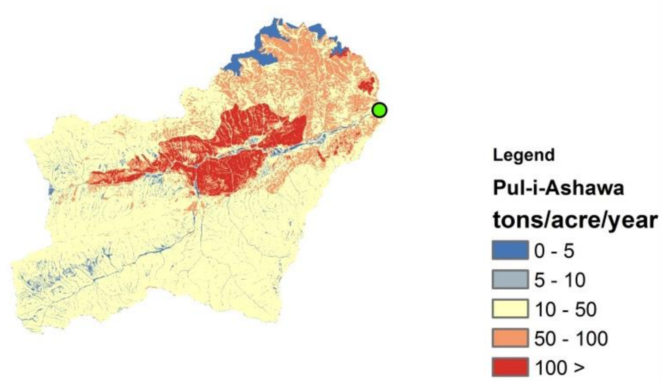
Hajian sediment gauge station and sub-watershed location at the Kabul River Basin



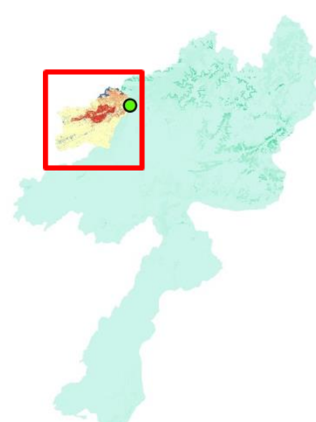
Sediment Degradation (455 tons/sq.km/year)
Average Soil Loss Rate (39 tons/acre/year or 9785 tons/sq.km/year)



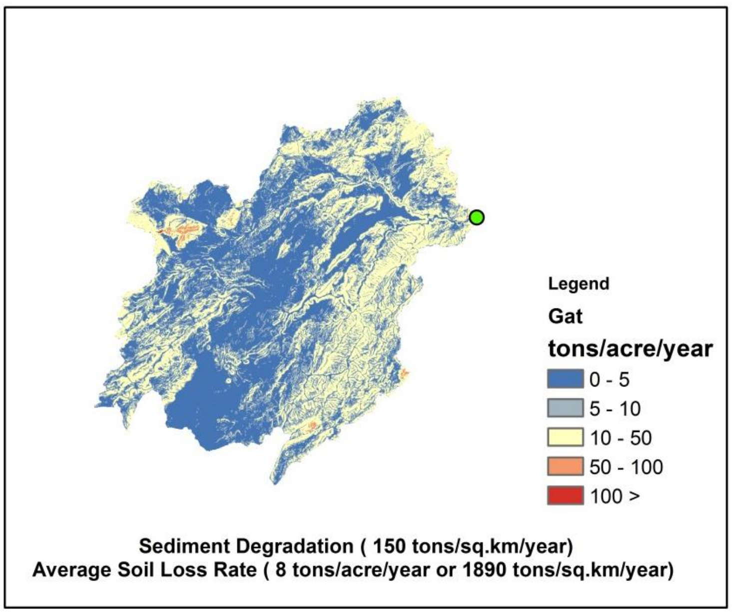
Baghdara sediment gauge station and sub-watershed location at the Kabul River Basin

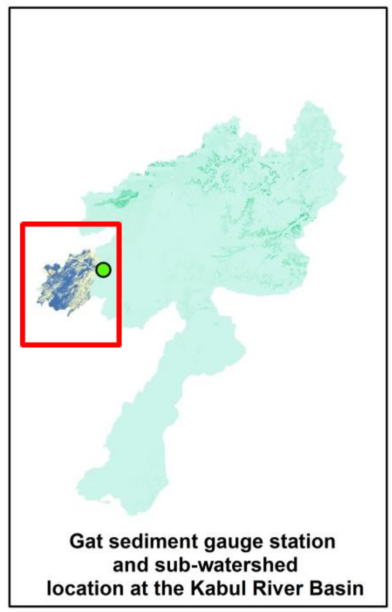


Sediment Degradation (420 tons/sq.km/year)
Average Soil Loss Rate (44 tons/acre/year or 10843 tons/sq.km/year)

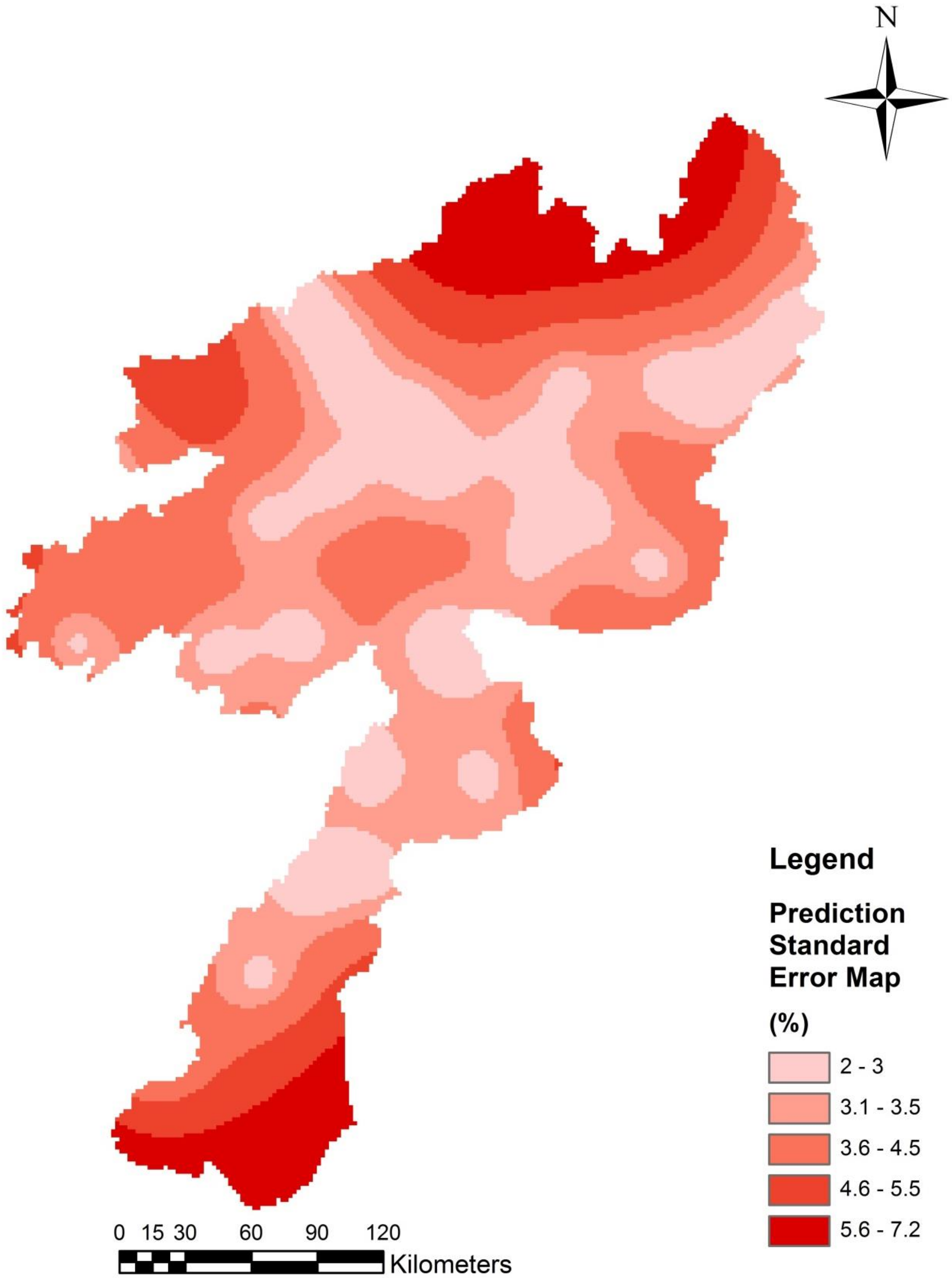


Pul-i-Ashawa sediment gauge station and sub-watershed location at the Kabul River Basin

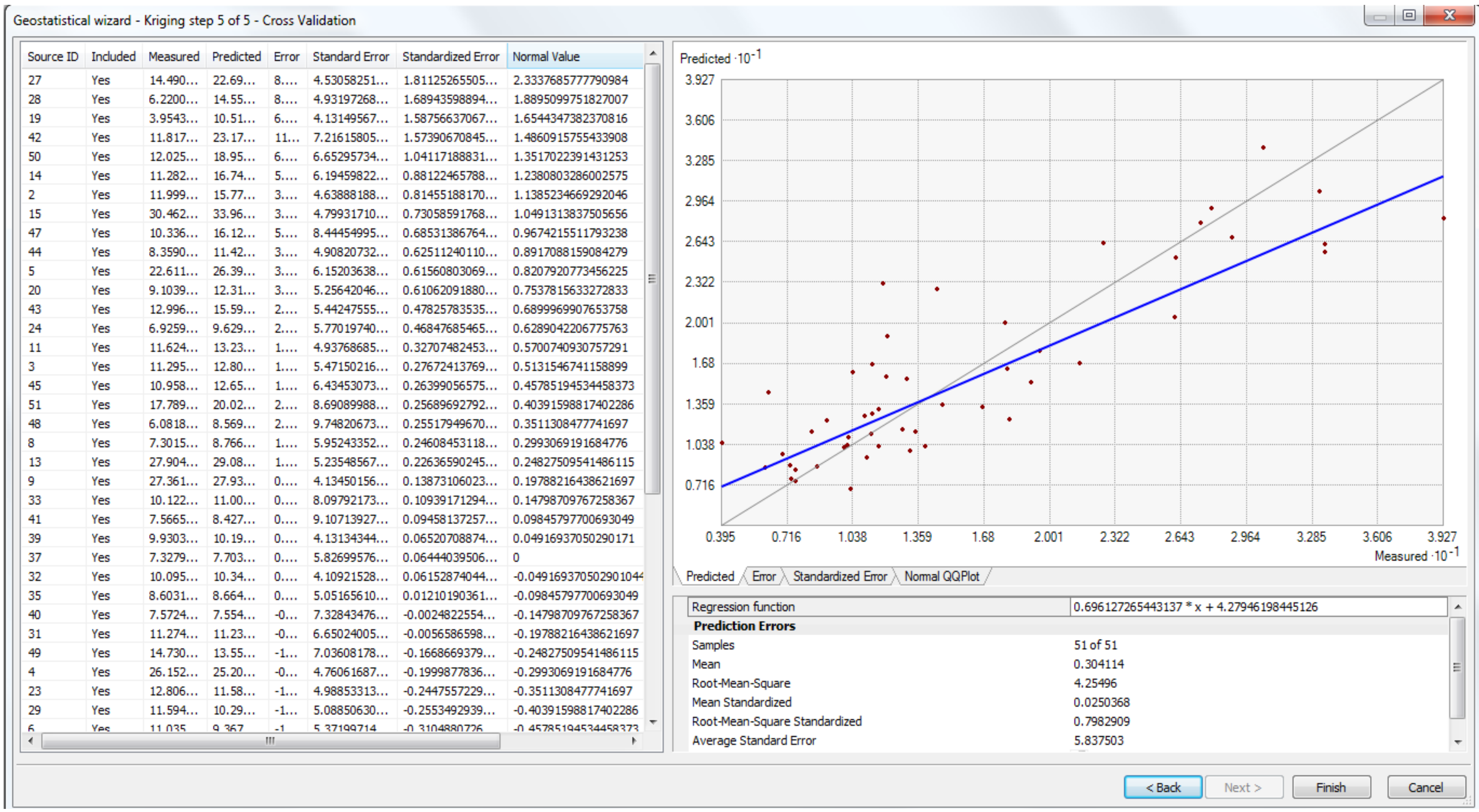

Legend
Gat
tons/acre/year
0 - 5
5 - 10
10 - 50
50 - 100
100 >
Sediment Degradation (150 tons/sq.km/year)
Average Soil Loss Rate (8 tons/acre/year or 1890 tons/sq.km/year)


Gat sediment gauge station
and sub-watershed
location at the Kabul River Basin

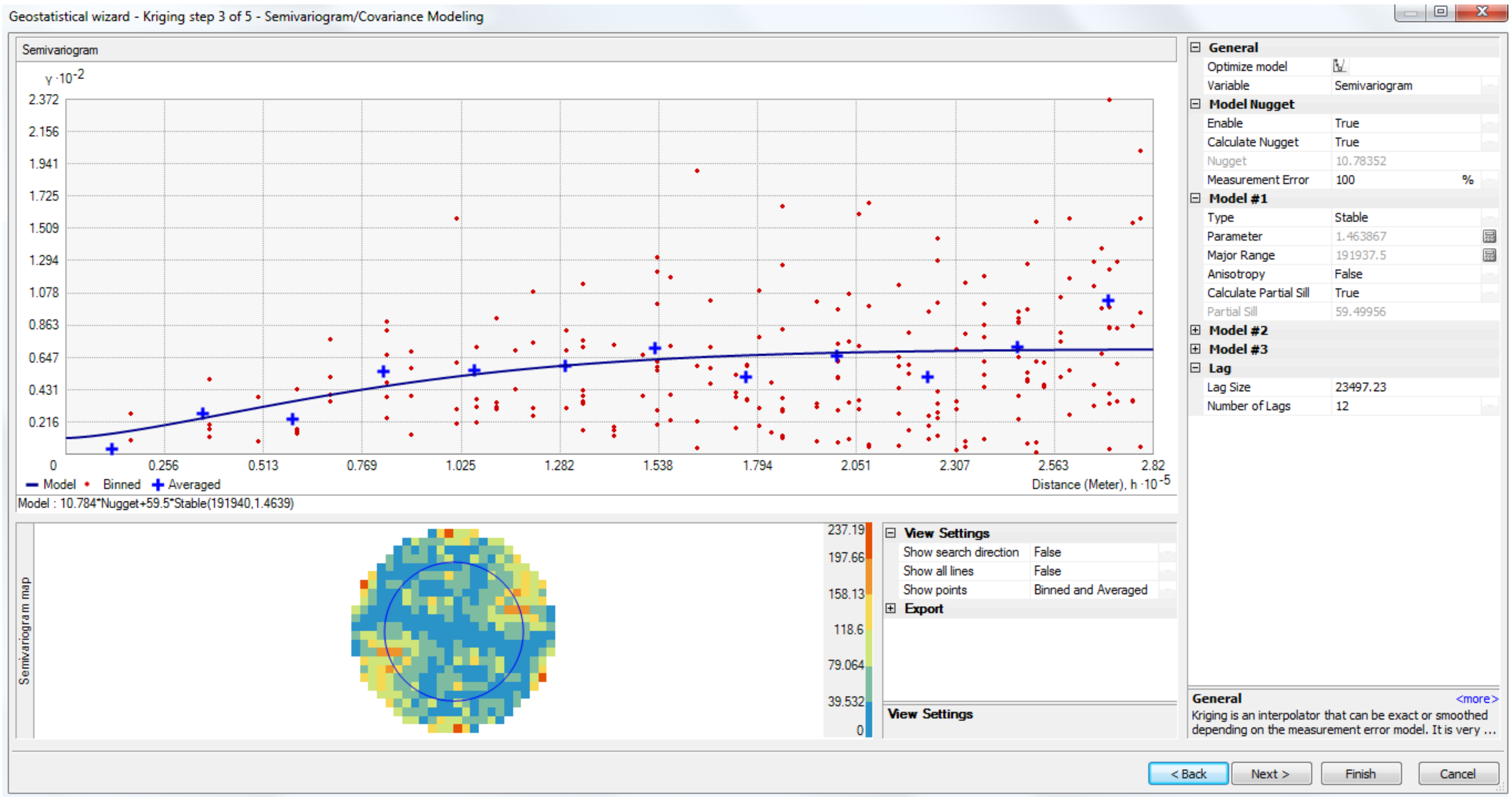
APPENDIX F: Uncertainty Map for Precipitation Data of the Kabul River Basin



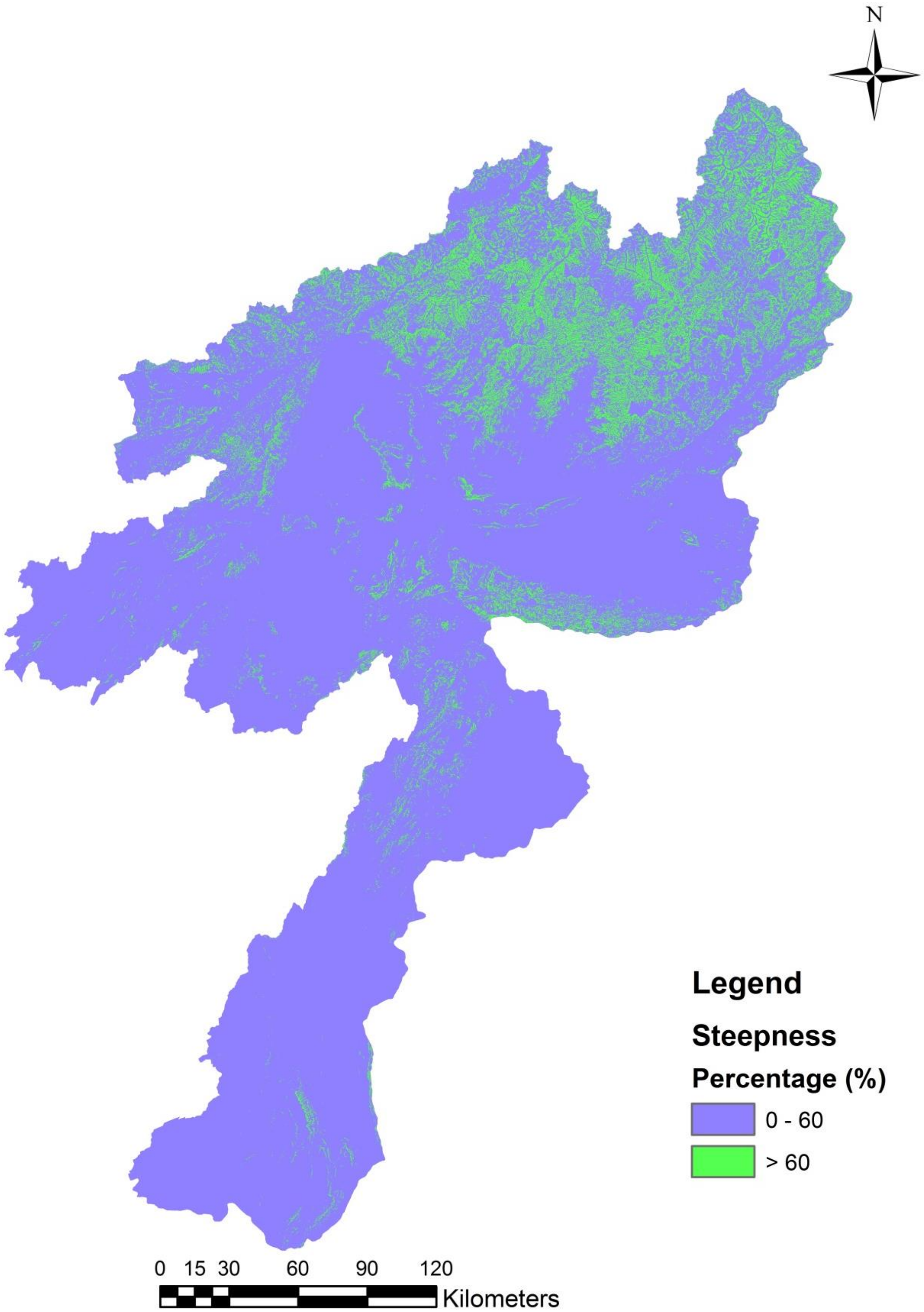
Uncertainty map of precipitation data (in/hr) based on Kriging prediction method for the gauge stations located at the Kabul River Basin



Source ID	Included	Measured	Predicted	Error	Standard Error	Standardized Error	Normal Value
27	Yes	14.490...	22.69...	8....	4.53058251...	1.81125265505...	2.3337685777790984
28	Yes	6.2200...	14.55...	8....	4.93197268...	1.68943598894...	1.8895099751827007
19	Yes	3.9543...	10.51...	6....	4.13149567...	1.58756637067...	1.6544347382370816
42	Yes	11.817...	23.17...	11...	7.21615805...	1.57390670845...	1.4860915755433908
50	Yes	12.025...	18.95...	6....	6.65295734...	1.04117188831...	1.3517022391431253
14	Yes	11.282...	16.74...	5....	6.19459822...	0.88122465788...	1.2380803286002575
2	Yes	11.999...	15.77...	3....	4.63888188...	0.81455188170...	1.1385234669292046
15	Yes	30.462...	33.96...	3....	4.79931710...	0.73058591768...	1.0491313837505656
47	Yes	10.336...	16.12...	5....	8.44454995...	0.68531386764...	0.9674215511793238
44	Yes	8.3590...	11.42...	3....	4.90820732...	0.62511240110...	0.8917088159084279
5	Yes	22.611...	26.39...	3....	6.15203638...	0.61560803069...	0.8207920773456225
20	Yes	9.1039...	12.31...	3....	5.25642046...	0.61062091880...	0.7537815633272833
43	Yes	12.996...	15.59...	2....	5.44247555...	0.47825783535...	0.6899969907653758
24	Yes	6.9259...	9.629...	2....	5.77019740...	0.46847685465...	0.6289042206775763
11	Yes	11.624...	13.23...	1....	4.93768685...	0.32707482453...	0.5700740930757291
3	Yes	11.295...	12.80...	1....	5.47150216...	0.27672413769...	0.5131546741158899
45	Yes	10.958...	12.65...	1....	6.43453073...	0.26399056575...	0.4578519453453373
51	Yes	17.789...	20.02...	2....	8.69089988...	0.25689692792...	0.40391598817402286
48	Yes	6.0818...	8.569...	2....	9.74820673...	0.25517949670...	0.3511308477741697
8	Yes	7.3015...	8.766...	1....	5.95243352...	0.24608453118...	0.2993069191684776
13	Yes	27.904...	29.08...	1....	5.23548567...	0.22636590245...	0.24827509541486115
9	Yes	27.361...	27.93...	0....	4.13450156...	0.13873106023...	0.19788216438621697
33	Yes	10.122...	11.00...	0....	8.09792173...	0.10939171294...	0.14798709767258367
41	Yes	7.5665...	8.427...	0....	9.10713927...	0.09458137257...	0.09845797700693049
39	Yes	9.9303...	10.19...	0....	4.13134344...	0.06520708874...	0.04916937050290171
37	Yes	7.3279...	7.703...	0....	5.82699576...	0.06444039506...	0
32	Yes	10.095...	10.34...	0....	4.10921528...	0.06152874044...	-0.049169370502901044
35	Yes	8.6031...	8.664...	0....	5.05165610...	0.01210190361...	-0.09845797700693049
40	Yes	7.5724...	7.554...	-0...	7.32843476...	-0.0024822554...	-0.14798709767258367
31	Yes	11.274...	11.23...	-0...	6.65024005...	-0.0056586598...	-0.19788216438621697
49	Yes	14.730...	13.55...	-1...	7.03608178...	-0.1668669379...	-0.24827509541486115
4	Yes	26.152...	25.20...	-0...	4.76061687...	-0.1999877836...	-0.2993069191684776
23	Yes	12.806...	11.58...	-1...	4.98853313...	-0.2447557229...	-0.3511308477741697
29	Yes	11.594...	10.29...	-1...	5.08850630...	-0.2553492939...	-0.40391598817402286
6	Yes	11.035	9.367	-1	5.37199714	-0.3104880726	-0.4578519453458373


Geostatistical wizard - Kriging step 3 of 5 - Semivariogram/Covariance Modeling
Semivariogram
γ ·10^-2
Distance (Meter), h ·10^-5
Model
Binned
Averaged
Model : 10.784*Nugget+59.5*Stable(191940,1.4639)
Semivariogram map
View Settings
Show search direction False
Show all lines False
Show points Binned and Averaged
Export
General
Optimize model
Variable Semivariogram
Model Nugget
Enable True
Calculate Nugget True
Nugget 10.78352
Measurement Error 100 %
Model #1
Type Stable
Parameter 1.463867
Major Range 191937.5
Anisotropy False
Calculate Partial Sill True
Partial Sill 59.49956
Model #2
Model #3
Lag
Lag Size 23497.23
Number of Lags 12
General <more>
Kriging is an interpolator that can be exact or smoothed depending on the measurement error model. It is very ...
< Back
Next >
Finish
Cancel

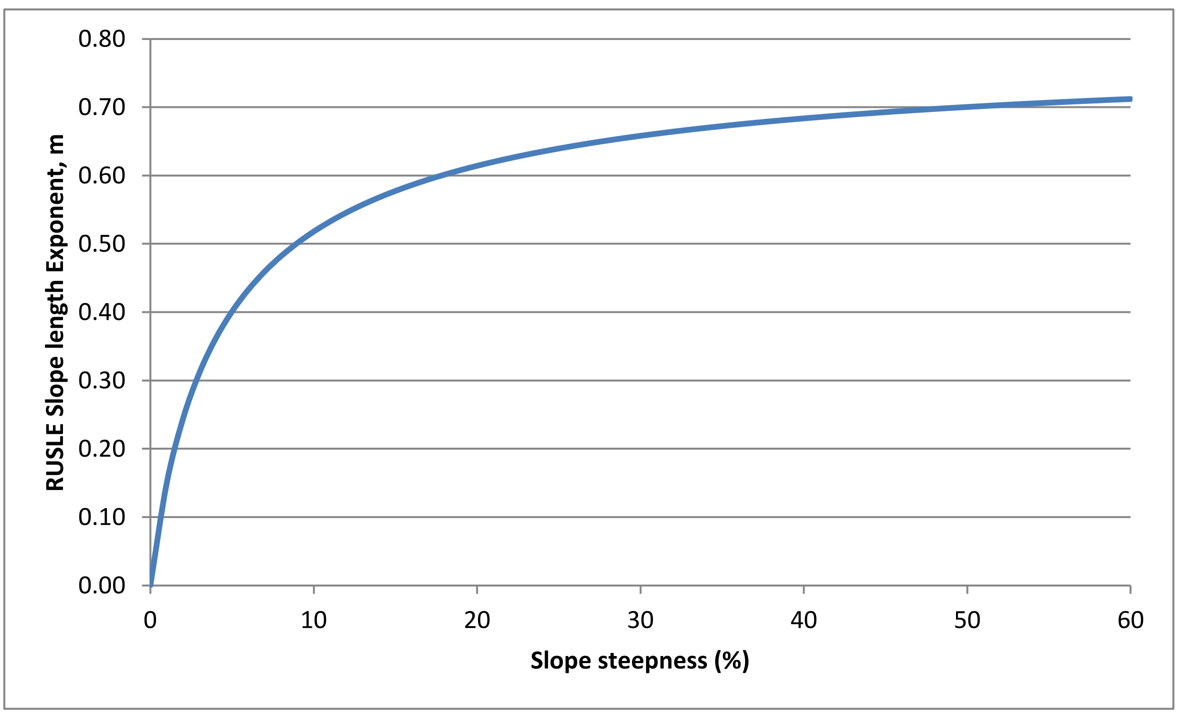
APPENDIX G: Slope Steepness map of the Kabul River Basin AND RUSLE slope length exponent (m) graph



Slope steepness of the Kabul River Basin in percent (%)

Slope Steepness (%)	Slope length Exponent (m)
0	0
3	0.31
6	0.43
9	0.50
12	0.55
15	0.58
18	0.60
21	0.62
24	0.64
27	0.65
30	0.66
33	0.67
36	0.67
39	0.68
42	0.69
45	0.69
48	0.70
51	0.70
54	0.71
57	0.71
60	0.71

No	Steepness (%)	CELL COUNT	PERCENTAGE
1	0-60	8814424	87.5
2	> 60	1267720	12.5



APPENDIX H: Recommendations

Recommendations

Additional research and data acquisition is required to estimate soil erosion rates in the basin, mainly in the following sections:

1. An institutional upgrade is required to facilitate expansion of the climatic database. Continuous record of hydrological parameters is lacking in the basin but they are crucial for efficient measurement of soil erosion rates in the basin. In RUSLE method, the rainfall-runoff erosivity factor R - one of the key inputs in erosion modeling; is solely dependent on 30 minute continuous rainfall intensity data; however, such datais not available for the entire basin. Therefore, existing stations should be rehabilitated, and new equipment should be installed to record long-term data.
2. A more accurate assessment of the land cover and soil type data is required. Current land cover map of the basin is based on 1993's UN-FAO published map but since then, extensive land cover changes have taken place in the basin. Deforestation, city expansions and growth in agricultural activities are good examples of these changes in the basin. Furthermore, areal and ground surveys are required to produce large scale soil map of the basin. Not only it is important to evaluate accurate amount of erosion rate but it is also useful in estimating surface runoff for irrigation purposes and ground water recharge for water supply purposes.
3. A rapid measurement of sediment deposition on existing reservoirs is required. The assessment would give details on long term sediment delivery rates, and can be useful tool for engineers to estimate designed life for the proposed dams.