# ESTIMATION OF SPATIAL AND SEASONAL VARIABILITY OF SOIL EROSION IN A COLD ARID RIVER BASIN IN HINDU KUSH MOUNTAINOUS REGION USING REMOTE SENSING

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## DEDICATION

This dissertation dedicated to my parents who have always been an incredible source of support and encouragement through my entire study life, and my beloved wife and daughter who eased this journey to be happened with their genuine love and encouragement. And to my brother and sisters whom I am proudly grateful for having them in my life. Also, this work is dedicated to all my friends and each individual who contributed towards my Master study. Safari couldn't have been a success without your genuine support and prayers.

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# ABSTRACT

An approach is proposed in the present study to estimate the soil erosion in data-scarce Kokcha subbasin in Afghanistan. The Revised Universal Soil Loss Equation (RUSLE) model is used to estimate soil erosion. The satellite-based data are used to obtain the RUSLE factors. The results show that the slight (71.34%) and moderate (25.46%) erosion are dominated in the basin. In contrast, the high erosion (0.01%) is insignificant in the study area. The highest amount of erosion is observed in Rangeland (52.2%) followed by rainfed agriculture (15.1%) and barren land (9.8%) while a little or no erosion is found in areas with fruit trees, forest and shrubs, and irrigated agriculture land. The highest soil erosion was observed in summer (June–August) due to snow melting from high mountains. The spatial distribution of soil erosion revealed higher risk in foothills and degraded lands. It is expected that the methodology presented in this study for estimation of spatial and seasonal variability soil erosion in a remote mountainous river basin can be replicated in other similar regions for management of soil, agriculture, and water resources.

## TABLE OF CONTENTS

## LIST OF TABLES

## LIST OF FIGURES

## LIST OF ABBREVIATIONS

| | | |
|---|---|---|
| RUSLE | - | Revised Universal Soil Loss Equation |
| USLE | - | Universal Soil Loss Equation |
| DEM | - | Digital Elevation Model |
| AGNPS | - | Agricultural Non-Point Source |
| WEPP | - | Watershed Erosion Prediction Project |
| GIS | - | Geographic Information System |
| RS | - | Remote Sensing |
| MFI | - | Modified Fournier Index |
| MODIS | - | Moderate Resolution Imaging Spectroradiometer |
| FAO | - | Food and Agriculture Organization |
| ASTER | - | Advanced Space Thermal Emission Radiometer |
| GPM | - | Global Precipitation Measurement |
| NASA | - | National Aeronautics and Space Administration |
| NDVI | - | Normalized Difference Vegetation Index |
| GLASOD | - | Global Assessment of Human-induced Soil Degradation |
| NDVI | - | Normalized Difference Vegetation Index |
| JOCA | - | Jenk's Optimum Classification Algorithm |
| BMP | - | Best Management Practice |
| UTM | - | Universiti Teknologi Malaysia |
| MEW | - | Ministry of Energy and Water |
| EPIC | - | Erosion Productivity Impact Calculator |
| LULC | - | Land Use Land Cover |
| MAIL | - | Ministry of Agriculture Irrigation and Livestock |

# LIST OF SYMBOLS

| | | |
|---|---|---|
| A | - | Average annual soil loss (ton $Acre^{-1}$ yr) |
| C | - | Cover management factor (dimensionless) |
| E | - | Storm energy (ft. * tons * $acre^{-1}$) |
| EI Storm | - | Storm erosivity index (ft.tons $acre^{-1}$ $h^{-1}$, or hundreds of ft tons $acre^{-1}$ $h^{-1}$ ) |
| I | - | Precipitation intensity (in $h^{-1}$) |
| I30 | - | 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) |

# LIST OF APPENDICES

# CHAPTER 1

# INTRODUCTION

## 1.1 Overview

Soil erosion harms agriculture productivity due to the reduction of soil fertility(Balasubramani et al. 2015; Bashagaluke et al. 2018; Domínguez-Castillo et al. 2020; Issaka and Ashraf 2017) Besides, it affects water quality by reducing the level of dissolved oxygen (Lal 2015; Nyawade et al. 2019; Pimentel and Burgess 2013; Sthiannopkao, Takizawa, and Wirojanagud 2006). Soil erosion is caused by different drivers including water and air (Sharafati et al. 2020). A large portion of global land (1094 Mha) is altered by soil erosion due to hydrological processes, of which a significant portion (224Mha) cannot be restored (Lal 2003). The global average of soil erosion by either precipitation or floods is 20–30 Gtyr-1 (FAO and ITPS 2015).

Soil erosion rates are higher in arid and semi-arid regions due to high sensitivity of such region to climate and land-use changes (Canora, D'Angella, and Aiello 2015; Lal 2012; Pour, Wahab, and Shahid 2020; Rodrigo Comino et al. 2016; Serpa et al. 2015; Tashayo et al. 2020). The soil erosion rates are also reported to be higher in Asian countries like China, India, and Afghanistan (Abdul malik Dawlatzi 2017; Ahmed et al. 2019; Thomas, Joseph, and Thrivikramji 2018a). Therefore, the arid region of Asia is considered as highly susceptible to soil erosion. Soil erosion is a slow natural geologic phenomenon, but it costs billions of dollars for agricultural losses (Crosson 1995; Pimentel et al. 1995; Wantzen and Mol 2013). Hence, soil erosion study is a vital concern for the regions with agricultural-based economies.

Afghanistan located between the south and central Asia has a predominantly arid and semi-arid climate. Soil erosion is a challenging issue for agricultural productivity in Afghanistan (Abdul malik Dawlatzi 2017; Saba 2001). Shrestha

(Shrestha 2018)reported that it is complicated to figure out the exact amount of soil erosion in Afghanistan due to a lack of data. The findings from the Global Assessment of Human-induced Soil Degradation (GLASOD) project indicated that a large portion (75%) of the topsoil of Afghanistan is removed due to water and wind. Furthermore, excessive erosions on riverbanks lead to notable social and economic losses. Despite the high importance of the soil erosion problem in Afghanistan, a few studies have been conducted to address the issue over the different regions in Afghanistan (Abdul malik Dawlatzi 2017; Sahaar 2013; Sharifi, Steinacker, and Saghafian 2016).

Sahaar (Sahaar 2013) integrated the Revised Universal Soil Loss Equation (RUSLE) with Geographic Information System (GIS) to estimate the annual soil loss of Kabul Rivers. They found that the river was significantly eroded in the rate of 19 ton·acre$^{-1}$·year$^{-1}$. (Sharifi, Steinacker, and Saghafian 2016) evaluated the annual soil loss of the Lower Harirud watershed in Heart province using RUSLE. The research findings indicated that soil erosion was varied in the range of 0.025 to 778 Mg ha$^{-1}$·y$^{-1}$. (Abdul malik Dawlatzi 2017) assessed the volume of eroded soil from Gardez basin in Paktya province, Afghanistan using the Universal Soil Loss Equation (USLE) integrated with GIS. Results showed that annual soil loss was found to be in the range of 0 to more than 100 ton.ha$^{-1}$.y$^{-1}$. The findings reported in the literature indicated that soil erosion rates are estimated to be significantly high. Thus, further studies should be conducted over the vulnerable basins to provide sustainability in agriculture and environment in the country.

Kokcha subbasin, which is located in Amu Darya River basin in Northeast of Afghanistan, is a data-scarce region with high soil erosion rate. People with agricultural income are dominated in the Kokcha subbasin. Hence, their properties are significantly dependent on the farming industry (Ahmad and Wasiq 2004; Asad Sarwar Qureshi 2002; Qutbudin et al. 2019). Rapid deforestation and highly frequent rainfall depth, which change the river flow pattern, provide an increasing trend in soil erosion over the Kokcha subbasin (Abdul malik Dawlatzi 2017; Aich et al. 2017; M Savage, B Dougherty 2009; Sediqi et al. 2019). Hence, it is essential to estimate the potential amount of soil erosion in the basin and provide the measures required for protecting the vulnerable lands.

A number of approaches have been developed to estimate the soil erosion such as USLE, RUSLE, Agricultural Non-Point Source (AGNPS) model, and Watershed Erosion Prediction Project (WEPP) (Lucà, Buttafuoco, and Terranova 2018). Several factors, including precipitation intensity, soil type, physiography, land use, and anthropogenic activities, have significant impacts on soil erosion (Obaid and Shahid 2017; Ostovari et al. 2017; Piacentini et al. 2018; Thomas, Joseph, and Thrivikramji 2018b; Wei et al. 2010; Zerihun et al. 2018). Hence, soil erosion modelling needs a large number of in situ measurements including hourly rainfall, land use, and digital elevation model data which are not available for the basin (Aich et al. 2017; M Savage, B Dougherty 2009; Shrestha 2018). Satellite-based remote sensing data are widely used to assess the susceptible zones of soil erosion in data-scare regions (Ghozat, Sharafati, and Hosseini 2021; Lucà, Buttafuoco, and Terranova 2018; Vågen and Winowiecki 2019). To estimate soil erosion with remote sensing data, the RUSLE method provided better performance (Benavidez et al. 2018b; Koirala et al. 2019; Mondal, Khare, and Kundu 2018). The parameters of the RUSLE method can be estimated using the remote sensing data collected from several sources and augmented in geographical information system (GIS). Bahrawi et al. (Bahrawi et al. 2016) reported that remote sensing data and GIS provided a flexible and powerful tool for assessing soil erosions in data-scarce regions.

This study aims to estimate the soil erosion using the satellite-based remote sensing data in the Kokcha subbasin. In this way, the RUSLE method is employed for estimating soil erosion. The satellite-based products are used to obtain the data required for computing the RUSLE factors due to scarcity of in-situ data in Afghanistan. Cold agricultural regions share a significant portion of global food production (Liu et al. 2019). Soil erosion poses a major threat to soil degradation and crop productivity in cold regions. Wu et al. (Wu et al. 2018) found soil erosion in cold climate is often much higher than that in other climatic regions. Snow melting at the end of winter or early spring causes high overland flow which often exceed the runoff in rainy season of other climatic zones. Reduction of soil infiltration capacity due to freezing enhance surface runoff and thus erosion (Kurylyk, MacQuarrie, and McKenzie 2014; Starkloff n.d.). However, studies related to soil erosion in cold climate, particularly cold mountainous climate region is very limited. Analysis of seasonal variability and spatial distribution of soil erosion in Kokcha subbasin can contribute valuable knowledge to soil erosion in cold climatic region. The soil erosion maps generated in this study would help to understand the spatial patterns of soil erosion within the Kokcha subbasin to assist stakeholders in taking suitable mitigation measures.

## 1.2 Problem Statement

Rapid deforestation and change in the river flow pattern caused an increasing in soil erosion over the Kokcha subbasin of northeast Afghanistan. This in turn has caused a large increase in erosion and river sedimentation. Many of the hydraulic structures in the basin become inoperative due to high sedimentation (Figure 1.1). It is very important to understand the potential sources of sedimentation in the basin and take necessary measures for protection of land susceptible to erosion for reduction of river sedimentation. However, there is no study to assess the spatiotemporal vulnerability of soil erosion to take necessary adaptation measure. Modelling of river sedimentation and assessment of susceptible zones of soil erosion needs a large volume of in-situ measurements including high resolution hourly rainfall, landuse and digital elevation model data which are not available for the basin. Lake of data required for soil erosion vulnerability mapping is the major obstacle of development of erosion potential map of Afghanistan. Satellite-based remote sensing can be used to assess the susceptible zones of soil erosion in data-scare regions and assist the stakeholders in taking the suitable mitigation measures.

Figure 1.1 Soil erosion and flash floods caused non-operational irrigation structures (Source: MEW)

### 1.3 Research Goal

#### 1.3.1 Research Objectives

The major objective of the study is to model soil erosion and river sedimentation in data scare Kokcha sub basin using satellite-based remote sensing data. The specific objectives are:

(a) Calculating the annual average soil loss rate using the Precipitation, Digital Elevation Model (DEM), Soil Type Map, and Land Cover Map data.

(b) To process satellite-based remote sensing data for extraction of hourly rainfall, topography and landuse data.

(c) Analyzing the spatial distribution of soil erosion rates at the Kokcha subbasin and to develop a model for the mapping susceptible zones.

(d) Predicting the effect of deforestation on sediment losses under different land cover scenarios.

(e) To propose engineering measures for the mitigation of soil erosion and river sedimentation in Kokcha basin.

#### 1.3.2 Scope of the study

The scope of the study is outlined below:

(a) The proposed study will be conducted within the geographical boundary of Kokcha sub basin using RUSLE model combined with Geographic Information System (GIS) and Remote Sensing (RS) techniques.

#### 1.3.3 Significant of the study

A number of maps will be prepared in the present study to show the spatial distribution of soil erosion within the basin. Afghanistan is located in the south and central Asia which is under high soil erosion effect mostly due to deforestation, arid and semi-arid climates and characterized by steep slopes and deep valleys, irregular annual rainfall patterns over the country which sweep away the spongy, silty, fragile loess soil that is common in most parts of the country, and careless land use practices, e.g. Areas of open land for growing crops on the cost of deforestation, resuscitation on steep slopes, and over-utilization of bushes and grasses as fuelwood, the likely soil erosion in the country due to the action of water is significant and irreclaimable. Therefore, the maps of soil erosion severity and intensity developed in this study can be used to assist decision makers in providing suitable mitigation measures.

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