Erosion Assessment and Soil Conservation Strategy in Degraded Soil Conditions of Paktya Province, Afghanistan

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Doctoral Dissertation

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Summary

1. Background and objectives

Afghanistan remains very poor, and the living standards are among the lowest in the world. Almost 80% of the population depends on agricultural activities and 90% of the population lives in rural areas. Agriculture plays an indispensable role in their livelihoods. Although total arable land is 12%, only 6% is cultivated. The climate of the country is arid and semi-arid with cold and relatively rainy in winter and hot summer. Rainfall is infrequent with very low precipitation around 300 mm yr^{-1} annually but having high rainfall intensity. Afghanistan is suffering from lack of data, information, particularly soil and water conservation plans. Therefore, soil erosion is one of serious problems throughout the country due to the topography of the landscape, arid and semi-arid climates, barren nature of the land and desertification. However, little attention has been paid to address soil erosion problem in the country, particularly in Paktya Province. Hence, this study was conducted to estimate soil erosion through the application of the Universal Soil Loss Equation (USLE) on GIS and to discuss the effective conservation practices. As effective conservation practices, crop management and gypsum mineral ($CaSO_4.2H_2O$) application in agricultural lands were evaluated to reduce sediment concentration in runoff as well as soil erosion in agricultural lands.

2. Current agricultural conditions and constraints

Paktya Province is based on agricultural economic with 61% of the population depending on agricultural activities. About 96% of the population lives in the rural areas. Most of these agriculture-related activities fall within small-scale production systems with only a few farmers being self-sufficient. To identify the current

agricultural conditions and constraints, a questionnaire survey was conducted in Dawlatzai Village of Gardez District, Paktya Province. The main problems that Paktya Province is facing are; soil degradation, deforestation, inadequate of irrigation water, poor extension services and inadequate of agricultural inputs. In addition, based on the survey conducted in the study area, 32% of the farmers responded that soil erosion happens very severely and 50% responded as severely. It means that more than 80% of farmers require proper conservation strategies for holding soil fertility and reducing soil erosion.

3. Estimation of soil erosion based on USLE and GIS

Soil erosion risk mapping was done using empirical model, the Universal Soil Loss Equation (USLE) on ArcGIS platform. The USLE model can be used as predictive tools for assessing soil loss, conservation planning and project planning. Different components of the USLE model were used with mathematical equations. This study identified that the rainfall erosivity factor (R-factor) observed with an installed rainfall gauge for a year at 217.5 MJ mm ha^{-1} h^{-1} yr^{-1} made a good agreement with that calculated at 207.7 MJ mm ha^{-1} h^{-1} yr^{-1} based on the annual amount of rainfall for the Gardez Basin. Also, soil erodibility factor (K-factor) was obtained from the soil classification map of the country. And the K factor ranged from 0.038 to 0.063 t ha h ha^{-1} MJ^{-1} mm^{-1}. The LS factor was calculated from Digital Elevation Model (DEM), LS factor values were in the range from 0 to 176. Crop management factor was calculated based on the national land cover map. Additionally, there are no conservation practices for the study area; hence a conservation practice factor P-factor was assigned 1 in the calculation. The data layers extracted for R, K, LS, C and P factors were multiplied within the raster calculator of ArcGIS spatial analyst tool to generate the soil loss map. Also, the land use map of the study area was prepared and the average annual soil losses from different land uses were determined for recognizing priority areas for application of soil conservation practice.

On the other hand, the USLE model was calibrated by the erosion pin method. The results of the calibration indicated that the observed soil losses with the erosion pin method in the field showed certain agreements with the calculated soil losses based on the USLE model in this study.

4. Conservation strategy by crop management and amending soil with gypsum mineral

Although there are many soil conservation practices, crop management and gypsum application have been focused in this study. Preventing soil erosion with cultivating crops is a common farming practice in agricultural lands. Also, gypsum mineral is an amendment widely accepted in the recent days because of its availability in most regions and relatively low-cost. To evaluate the effectiveness of crop management and gypsum application in reducing sediment concentration in runoff with eliminating soil erosion in agricultural lands, a field experiment was conducted in Dawlatzai Village using a portable rainfall simulator. Four erosion plots, as gypsum-treated plot, clover cultivated plot, maize cultivated plot and control plot were designed. For the gypsum-treated plot, gypsum at the rate of 5 t ha^{-1} was applied. The experimental results indicated that total soil losses from gypsum-treated, clover and maize cultivated plots were reduced to 67.3%, 92.0% and 54.3% of that from the control, bared plot. Gypsum mineral, slightly increased EC of surface runoff because it is sparingly soluble salt but did not change largely the pH values of surface runoff. So, it was considered that gypsum is not a liming agent and does not neutralize the hydrogen ion in the soil solution. As crop cultivation is not available during the period of insufficient irrigation water in Dawlatzai Village of Gardez District, research interest was focused on gypsum application as an alternative conservation strategy. So, an additional experiment was conducted for discussing more detail about the effects of gypsum application in the laboratory using two different soil textures; one is sandy loam and the other loamy soils. The results showed that reduction in surface runoff by 38.8% was observed for sandy loam soil and 37.0% for loamy soil texture compared to the control. Likewise, infiltration into the soils was increased at 2.3 times for sandy loam and loamy soil textures compared to the control. Consequently, total soil losses from gypsum-treated plots were significantly reduced to 63.3 and 81.9% of the losses from the control for sandy loam and loam soils, respectively. Soil particles were well flocculated in gypsum-treated plot compared to the control. This flocculation phenomenon could have contributed towards the increased infiltration into the soil and the reduced sediment concentration and soil erosion in the gypsum-treated plot.

Accordingly, it was concluded that the conservation practice factor P-factor with gypsum application at 5 t ha^{-1} was in the range from 0.19 to 0.39 based on the field and laboratory experiments.

5. Evaluation of gypsum application as conservation practice factor using USLE with GIS

To determine the effectiveness of gypsum application as a conservation practice in Dawlatzai Village, P-factor was assumed as 0.33 based on the results of the field experiments. The maximum soil losses at 79 t ha^{-1} yr^{-1} from the agricultural lands without any conservation practices decreased to 20 t ha^{-1} yr^{-1} when gypsum application is done as a conservation practice. Accordingly, it was concluded that conservation practice with applying gypsum mineral in agricultural lands in Dawlatzai Village is one of the effective ways for reducing soil erosion.

6. Conclusions and recommendations

According to the results of the questionnaire survey conducted in the initial stage of this study, soil erosion is one of the main agricultural problems in Paktya Province. Therefore, this study dealt with the estimation of soil erosion through the application of the Universal Soil Loss Equation (USLE) on ArcGIS platform and to discuss the effective conservation practices. Although there are many soil conservation practices being applicable in Paktya Province, crop management and gypsum application have been focused in this study. Preventing soil erosion with cultivating crops is a common farming practice in agricultural lands. Also, gypsum mineral is an amendment widely accepted in the recent days because of its availability in most regions and relatively low-cost. To evaluate the effectiveness of crop management and gypsum application in reducing sediment concentration in runoff with eliminating soil erosion in agricultural lands, a field experiment was conducted in Dawlatzai Village using a portable rainfall simulator. The experimental results indicated that total soil losses from gypsum-treated, clover and maize plots were reduced to 63.3%, 92.0% and 54.3% of that from the control.

As crop cultivation is not available during the period of insufficient irrigation water in Dawlatzai Village of Gardez District, research interest was focused on gypsum application as an alternative conservation strategy. So, an additional experiment was conducted for discussing more about the effects of gypsum application in the laboratory using two different soil textures as sandy loam and loamy soils. The results showed that total soil losses from gypsum-treated were 60.3 and 81.9% of the losses from the control for sandy loam and loam soils, respectively. Soil particles were well flocculated in gypsum-treated plot compared to the control, and it was considered this flocculation contributed to reduce sediment concentration and soil erosion.

Accordingly, the estimated P-factor with gypsum treated at 0.33 was substituted into the Universal Soil Loss Equation (USLE) for re-calculating the maximum soil losses in Dawlatzai Village. The calculated results indicated that the soil losses at 79 t ha^{-1} yr^{-1} from the agricultural lands without any conservation practices changed to 20 t ha^{-1} yr^{-1} when gypsum application is done as a conservation practice.

Consequently, it was concluded that conservation practice with applying gypsum mineral in agricultural lands in Dawlatzai Village is one of the effective ways for reducing soil erosion, especially during the period of insufficient irrigation water. It is suggested and recommended that farmers in Paktya Province apply gypsum mineral on their farmlands for reducing surface runoff and soil loss. Therefore, gypsum mineral application should be adopted as a policy and be provided through agricultural extension services to farmers to enhance their knowledge and skill regarding its benefits and proper application in their agricultural lands for reducing soil erosion.

和文要旨

本研究は、アフガニスタン国パクティア州の土壌劣化地域を対象として、汎用土壌流亡量予測式 Universal Soil Loss Equation (USLE) に基づき GIS を適用して面的な土壌流亡量の把握と現地で適用できる土壌保全対策について論議したものである。研究初期の段階で、パクティア州ダウラザイ村の現地農家を対象として、農業の現状と課題に関するアンケート調査を実施した結果、土壌侵食に起因した土壌劣化、森林伐採、灌漑水不足、農業普及の未整備、劣悪な農業資材等の問題が明らかとなった。特に土壌侵食に関しては、32%の現地農家が「非常に厳しい」と、50%が「厳しい」と回答し、合わせて 80%以上の現地農家が土壌侵食による土壌劣化を問題視していることから、本研究では土壌侵食の把握と現地で適用できる土壌保全対策について論議を進めることとした。現地で適用できる土壌保全対策には様々な手立てが考えられたが、本研究では現地で容易に入手できる石膏（硫酸カルシウム・2 水和物）の施用に焦点を当てて研究を進めた。ダウラザイ村に設置した畑地圃場試験枠および大学研究室内のモデル試験枠を適用して、石膏添加による土壌侵食の抑制効果を評価した結果、現地圃場では 32%にまで流亡土壌を削減でき、研究室モデル試験枠では 19%から 39%までに削減することに成功した。これは土壌粒子に吸着した Na イオンが Ca イオンに置換して、表面流去水中の懸濁粒子が分散から凝集に変化することに起因したものであると、土壌懸濁水の分散凝集実験からも考察できた。この石膏添加による土壌侵食の抑制効果に関する結果から、汎用土壌流亡量予測式中の保全因子（P 因子）を 0.33 とし汎用土壌流亡量予測式に代入して、パクティア州ダウラザイ村を対象として保全対策前後における土壌流亡量の比較を行った。その結果、保全対策前には 0 t/ha/y から 79 t/ha/y の範囲内に分布していた土壌流亡量は、石膏添加の保全対策後には 0 t/ha/y から 20 t/ha/y に顕著に減少することが明らかとなった。本研究を通して、現地で容易に入手できる石膏を施用することで、効果的に圃場で発生する土壌侵食とともに流亡土量を削減できることが定量的に明らかになった。

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Chapter 1---

Background and objectives

1.1 Background

1.1.1 General information of Afghanistan

Afghanistan is a landlocked country located in South-central Asia between 29° 35’ 38° 40’ latitude and 60° 31’ 74° 55’ longitude. It is bordered by Pakistan to the south and the east, Iran to the west, Turkmenistan, Uzbekistan and Tajikistan to the north and China to the far northeast (Fig. 1.1). The total area of Afghanistan is 653,032 km^2. Afghanistan population is 34,180,017 based on the latest estimates (WPR, 2017) and large numbers of the population have been displaced temporarily live in Pakistan and Iran.

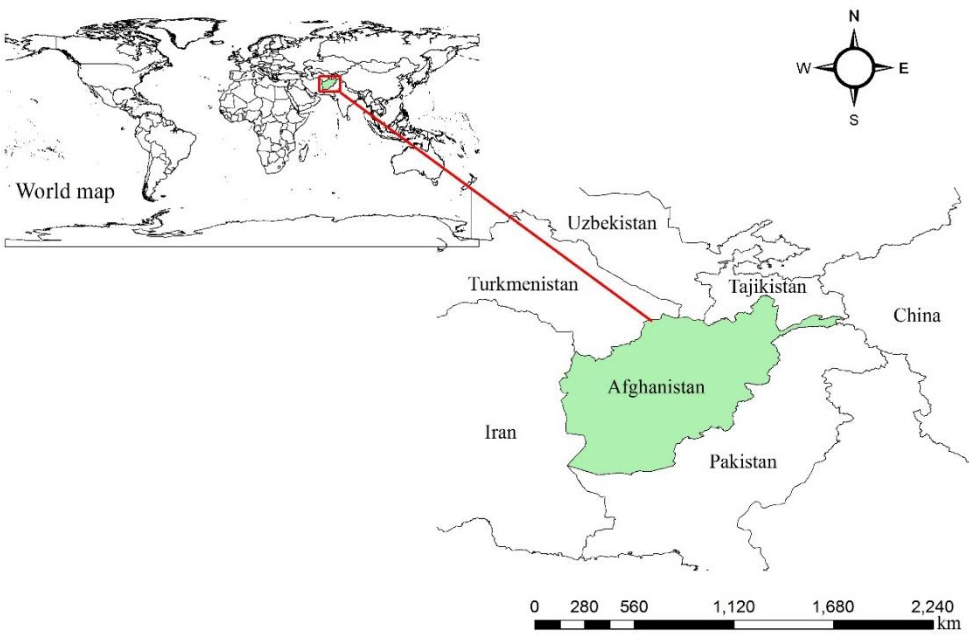

Fig. 1.1 Location of Afghanistan

Afghanistan remains very poor and the living standards are among the lowest in the world. Approximately 80% of the population depend on agriculture activities and 90% of the population live in rural areas. Agriculture plays an important role in their livelihoods (FAO, 2017). However, the agriculture sector was shared about 40% GDP in 2002. The sharing of agriculture sector GDP slightly dropped to 25%

(excluding the opium poppy economy) due to the revitalization of other sectors such as manufacturing and service industry (Ahmadzai, 2017).

Afghanistan arable land area is 7.9 million hectares. It covers 12% of the total and only 6% is cultivated. Out of the total arable land, only 23% (2.0 million hectares) are irrigated and 22% (1.7 million hectares) land is cultivated as rain-fed agriculture, while the remaining 55% (4.2 million hectares) land is uncultivated (USDA-Foreign Agricultural Service, 2011). Moreover, arable land is 12%, the forest is 3%, pastures is 46% and mountainous and building is 39% (Fig 1.2).

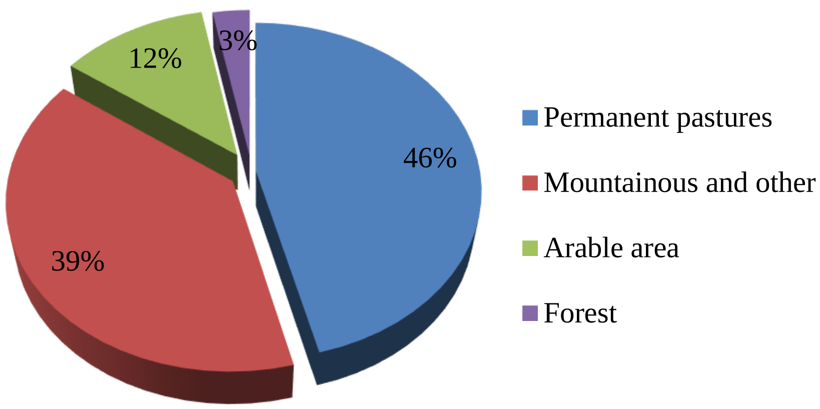

Fig. 1.2 Agricultural land distribution in Afghanistan

Source: Central Statistic Organization, 2015-16

Agriculture is dominated by small-scale farm households with an average farm size of about 1.5 hectares. Wheat is a staple food in Afghanistan and occupies the major portion of the agricultural land. Wheat has contributed approximately 60% of total calories to the diet and plays an important role in food security (NRVA, 2011-2012). Other important crops include maize, rice, barely, industrial crops, vegetable and fruits.

Afghanistan occurs arid and semi-arid climates. Rainfall is greatly scarce the precipitation figures are truly low (Fig. 1.3). The mean annual precipitation is about 300 mm yr^{-1}, with very cold winter the average minimum temperature is -15 °C and hot summer, maximum average temperature 35 °C. Most of the, rain falls during the winter.

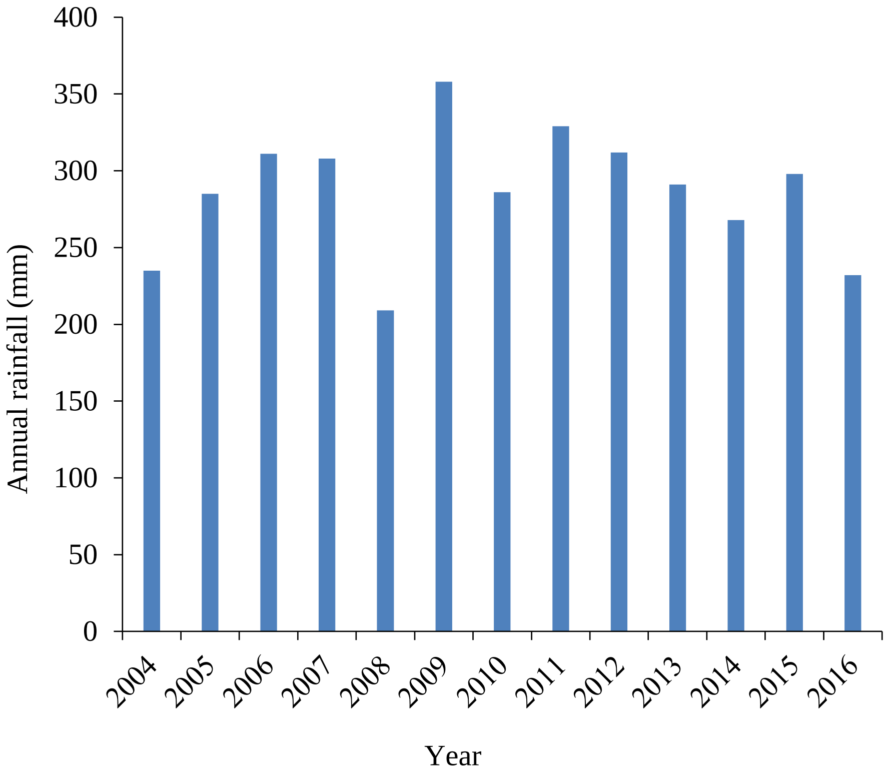

Fig. 1.3 Annual rainfall in Afghanistan

Source: Ministry of Agriculture, 2004 to 2016

Irrigation water is a severe problem throughout the country. Drought between the years of 1999 to 2003 degraded widespread natural resources; lower water tables, dried-up wetlands, eroded land, depleted wildlife population and removed forest, all these factors have the serious impact in livelihood and environment (Habib, 2014). Agriculture used almost 99% of water primarily from rivers and streams followed by springs, Karezes shallow and deep aquifers. Mountains operate as a natural storage facility source of irrigation water, snow accumulates during the winter season and slowly melting in the spring season.

Deforestation is one of the biggest challenges in Afghanistan. Reported by Asian Soil Problem, 2010 destruction of vegetation for fuel wood is the main factor for desertification, thus cut down countless trees and have destroyed countless forests about 70% forest has been destroyed within two decades throughout in the country (Fig. 1.4). During the year of 1990 to 2001, forest lost an average of 29,400 hectares per year (NEPA, 2008). Therefore, rangeland is converted to rain-fed agriculture and lead to increase soil erosion, loss of productivity and soil humus has created ever more arid conditions.

Fig. 1.4 Current condition of forest population in Afghanistan

1.2 Soil erosion

1.2.1 Effect of soil erosion

Erosion is the removal of a mass of soil from one part of the earth and its relocation to other parts of the earth, including raindrops, water flowing over through the soil profile, wind velocity and gravitational force (Laflen and Roose, 1998). Soil erosion has both off-site and on-site effects; on-site effects are particularly important on agricultural land where the redistribution of soil within a field, the loss of soil from a field, the breakdown of soil structure and the decline an organic matter and nutrient thereby the reduction of cultivable soil depth and a decline in soil fertility. Off-site problems arise from sedimentation downstream or downwind, which reduces the capacity of rivers and drainage ditches, enhances the risk of flooding, blocks irrigation canals and shortens the design life of reservoirs (Morgan, 2005).

1.2.2 Global states of soil erosion

Soil erosion is the biggest environmental problem which threatens both developed and developing countries. Global assessment of human induced water and wind erosion shows that more than 1600 million hectares of land are already affected by soil erosion (Table 1.1). Asia region to soil erosion is 663 million hectares. It is the highest proportion when compared with other parts of the world. Data shows that the water induced erosion is more in comparison to wind induced erosion. It means the water induced soil erosion is a greater problem facing humankind in throughout the world.

Table 1.1 Global extent of land affected by wind and water erosion

No	Region	Land area affected by erosion (million hectares)	
		Water erosion	Wind erosion
1	Africa	227	186
2	Asia	441	222
4	South America	123	42
5	Central America	46	5
6	North America	60	35
7	Europe	114	42
8	Oceania	83	16
	Total	1094	548

Source: Oldeman, 1992

1.2.3 Type of soil erosion

Soil erosion is generally classified as geological soil erosion and accelerated soil erosion. Geological erosion is the natural and inevitable process which represents the erosion of soil in it is normal conduction without influenced by the human being. The various topography features, stream channels, valleys, lakes, bays are the results of geologic erosion. Accelerate soil erosion it an excess of geologic erosion. It occurs when human activities due to changes in natural cover and soil conditions (Morgan, 2005). Soil erosion due to agricultural activities, deforestation, erosions from the construction sites is the example of accelerated soil erosion. Soil erosion due to cause classified as fluid and gravity (Fig. 1.5). Soil erosion by water, which includes in the cause by fluid classification the greatest, particularly in semi-arid and arid regions.

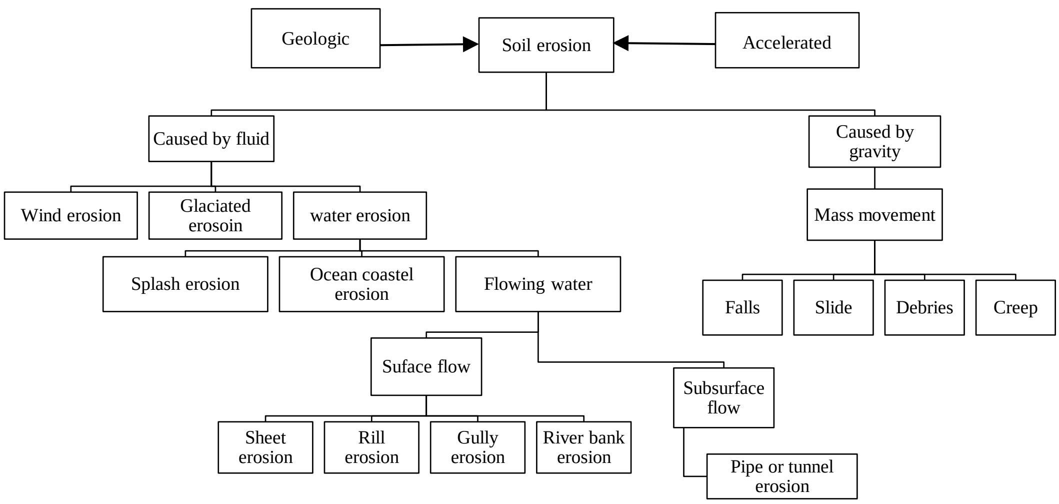

Fig. 1.5 Type of soil erosion

Source: Lal, 1990

Afghanistan has suffered from lack of data, information, particularly soil and water conservation plans. Universities and research institutions are inadequately equipped and professional staff. However, soil erosion is the biggest challenge throughout in the country, due to the topography of the landscape, arid and semi-arid climates and barren nature of the land. For that reason, about 80% of land could be subject to soil degradation (Daud, 2001). Afghanistan has experienced widespread soil degradation, soils highly susceptible to the processes of salinization and water logging (Jeffery, 2009). Rainfall patterns over the country vary from year to year and periods of heavy rains' sweep away the porous, silty, friable loess soil (Shareq et al., 1980). Consequently, these conditions adversely affect in socio economics.

1.2.4 Soil erosion models

Modeling soil erosion is the process of mathematically describing soil particle detachment, transport and deposition on a land surface. Erosion models can be used as predictive tools for assessing soil loss, conservation planning and project planning. The model can be used as tools for understanding erosion processes and their interaction and for setting research priorities (Nearing et al., 1994). Nevertheless, there are many soil erosion modules were developed to assess soil erosion losses and risk (Table 1.2).

Table 1.2 Soil and water erosion models

No	Model	Reference
1	Soil Erosion Model for the Mediterranean Region (SEMMED)	De Jong et al., 1999
2	European Soil Erosion Model (EUROMEM)	Morgan et al., 1998
3	Soil and Water Assessment Tool (SWAT)	Arnold et al., 1998
4	Water Erosion Prediction Model (WEPP)	Ascough et al., 1997
5	Revised Universal Soil Loss Equation (RUSLE)	Renard et al., 1997
6	Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS)	Rudra et al., 1985
7	Universal Soil Loss Equation (USLE)	Wischmeier and Smith, 1978
8	Modified Universal Soil Loss Equation (MUSLE)	Williams, 1975

The arid and semi-arid climates soil more vulnerable to erosion (high erodibility) due to poor soil texture, structure, chemical and physical properties. Although soil erosion is not only reduced soil fertility and degraded water quality but also severely interrupts the irrigation networks. Sparse vegetation, steep slopes, deforestation, poor soil structure and high-intensity rainfall in short, times are the main factors influenced soil erosion. It is ordered to evaluate the impact of these factors on sustainable agriculture and the environment, to quantify the extent of soil erosion it is needed for appropriate and applicable erosion model. However, USLE model has been widely used worldwide, approximately more than four decades to predict soil erosion as well as better tools for preparing soil conservation planning.

Recently, there have been many types of research were conducted with the USLE model in conjunction with GIS technology has been used to predict the annual soil loss. GIS techniques have become valuable tools, especially when assessing erosion at larger scales or some area cannot access transportation and insecure. Using of these techniques has been widely adopted and currently there are several studies that show the possibility of remote-sensing techniques integrated with GIS in soil erosion mapping. Maybe it is not high accuracy to predict soil erosion by USLE model with ArcGIS but with low accuracy would be given a big meaning for making and applying soil conservation strategy.

1.3 Soil and water conservation

The strong relations between a measure of soil and water conservations, this applies equally in semi-arid and arid regions. The decreasing of surface runoff by soil structures and land management that could help to reduce erosion. Similarly, the formation of crusts, breakdown of structure, all will be increased infiltration and help the water conservation (Hudson, 1995). Conservation of soil and water is indispensable for sustaining agriculture practice, hence rapidly increasing population, it's required to protect the environment, particularly in semi-arid and arid regions. However, soil conservation strategy of cultivated land can be divided into three big categories: agronomic measures, soil management and mechanical methods (Fig. 1.6).

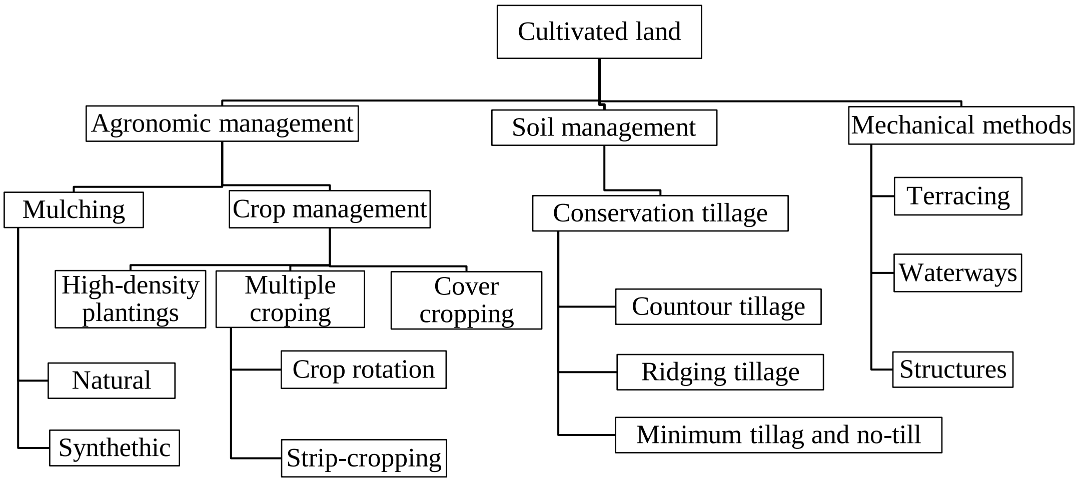

Fig 1.6 Cultivated land conservation strategy

Source: El-Swaify et al., 1982

Soil conservation depends on strongly the agronomic method combined with excellent soil management and mechanical measures playing a supporting role to maintain valid ground cover. Therefore, currently the applications of these strategies are hardly due to attainable localized materials, including organic materials are limited, crop cultivation is not available during the period of insufficient irrigation water and maybe not economically in semi-arid regions. Accordingly, research more interest was focused on gypsum ($CaSO_4 \cdot 2HO_2$) application as an alternative conservation strategy could be advantageous in reducing surface runoff and soil loss and as well locally available with very cheap price in Afghanistan.

1.4 Gypsum mineral and its application

1.4.1 Characteristic of gypsum mineral

Gypsum mineral is a general association with anhydrite, calcite, halite, sulphur and dolomite. Gypsum is a composed of calcium sulphate dihydrate with the chemical formula of $CaSO_4{\cdot}2H_2O$, containing 23% calcium and 19% sulphur in the pure form. Gypsum is used for making of cement, Paris plaster, wallboard and soil amendment. Gypsum is not a liming agent like $CaCO_3$, CaMg (CO_3)2, Ca (OH)2 and CaO and 200 times more soluble than agricultural limes. Gypsum mineral uses for the amelioration of acid subsoils, but not changing the soil pH, because gypsum does not neutralize the hydrogen ion of the soil solution (Chen and Dick, 2011).

Gypsum mineral also receives from byproducts of industrial processing as called synthetic gypsum. It is composed of calcium sulphate dihydrate and similar characteristics as natural gypsum with high quality and environmental friendly. The most common synthetic gypsum is Flue Gas Desulfurization (FGD), which product of coal-fired power plants. FGD gypsum can be used as a soil amendment, soil hydrological condition, nutrient source for crops, improve soil physical properties (Liming et al., 2013 and US-EPA, 2008).

The major benefits of gypsum mineral related to agriculture; source of calcium and sulphur for plant nutrition, improve acid soils and treats aluminium toxicity, improves soil structure, improves water infiltration and reduces runoff and soil loss (Greenleaf Advisors, 2015; US-EPA, 2008; Hopkins, 2013).

1.4.2 Soil loss

Gypsum mineral is generally used mostly because of its availability and its low cost. Gypsum application to the soil can minimize clay dispersion, which improves the permeability of the soil and increases the stability aggregates at the soil surface (William, 1998). Studied by Mahardhika et al., 2008 they applied gypsum at a rate of 10 t/ha, polyacrylamide (PAM) 40 kg/ha and combined application of both amendments (PAM + gypsum) at the same rates, total soil loss was reduced by 39%, 43% and 74%, respectively compared to the control moreover, combined application of PAM + gypsum more significantly reduced soil loss. The application of FGD gypsum at the rate of 13.44 t/ha, thereby infiltration rate was increased by 17%, decreased surface runoff by 36% and total soil loss reduced by 77% (Fred et al., 2011). FGD gypsum has applied a broadcast that significantly increased electrolyte concentrations of water at the surface of the soil causing clay flocculation thus reducing soil loss and increased permeability (Wallace et al., 2001).

1.4.3 Sodic soil

Sodic and saline-sodic soils have exhibited structural problems such as swelling, surface crusting, slaking and clay dispersion. Such problems may hamper water and air movement, thereby, decrease plants available water, reduces nutrient uptake, seedling emergence and increase erosion potential (Qadir and Schubert, 2002). Accumulation of salts in such an agricultural soil changed its physic-chemical properties, including pH, exchangeable sodium, electrical conductivity, sodium adsorption ratio, hydraulic conductivity and soil available water (Al-Busaidi and Cooksen, 2003). This problem is more serious in arid and semiarid regions with poorly drained soils because of long-term use of saline water for irrigation (Ayars and Tanji, 1999).

The ameliorating saline sodic soil is much important for suitable agriculture and clay dispersion. Several amendments have been tried in the recent past to reduce soil erosion under saline conditions. Leaching has been shown to be the most effective method for removal of soluble salts from the rhizosphere (Abrol et al., 1988). Gypsum is the main chemical material used for sodic soil reclamation because it is calcium-rich, dissolves at high pH and replacement of sodium from an exchange site (Horneck et al., 2007). Ghadiri et al. (2007) tried Polyacrylamide (PAM) and gypsum, the results with PAM were very encouraging. They found that PAM can be successfully used for controlling or minimizing the adverse impacts of salinity, such as increased erosion, surface sealing, and poor runoff water quality. The solution PAM application was more effective in controlling soil erosion than the powdered PAM application (Dou et al., 2012).

There has been a little emphasis on the interaction between soil erosion and salinity in the past, because the salinity is associated with flat lands, has not been linked to soil erosion. Erosion can be able to breakdown of soil aggregate, which ultimately leads to soil salinity, while soil salinity affects vegetation cover, leaving the land bare and prone to erosion (Ghadiri et al., 2007). The gully is considered to be one of the most important soil erosion processes (Seeger et al., 1996). Soil characteristics such as SAR, EC and Na have been found to have more effects on gully erosion development (Shahrivar et al., 2012). Soils high in sodium content are more prone to piping and gulling (Mahangara, 2010). It is increasing in the soluble salts of soil such as sodium, the negative impact of clay on aggregate stability and erodibility of soil (Kemper and Koch, 1966).

1.4.4 Infiltration rate

The soil infiltration rate is defined as the volume flux of water flowing into the soil profile per unit surface area. An arid and semi-arid region's soil is generally low infiltration rate in result gradual deterioration of the soil surface structure. Gypsum mineral can be able to improve soil hydraulic conductivity has been conducted both in laboratory and field studies. For example, application of gypsum mineral on the soil surface that significantly increased infiltration conditions (Miller, 1987). Phosphogypsum more effective than mined gypsum because of its higher rate of dissolution (Keren and Shainberg, 1981).

The research was conducted in agricultural filed by Buckley and Wolkowski, 2014, the effects of FGD gypsum on soil physical properties; they applied four (4) rates of gypsum mineral (0, 1120, 2240 and 4480 kg/ha) at 11 sites. After 12, weeks measured soil bulk density, aggregate stability and hydraulic conductivity. Thus, significantly decreased in soil bulk density and improved in aggregate stability and soil structure, because those measurements would refer to increased infiltration rates of soil, less surface crusting and less compaction. It was an unexpected decrease in aggregate stability with the highest application rate of gypsum. The lower rates were not different from the control.

Shortage of fresh irrigation water is a very serious problem in arid and semi-arid parts of the world. Thus, utilization of marginal, saline-alkaline water is the only option left. Irrigation with slightly saline water is important to maintain crop yield in the regions where freshwater resources are limited (Fang and Chen, 2007). The chemical composition of irrigation water affects the hydraulic properties of soil, with an increase in salt concentration in water, soil hydraulic conductivity also increases (Kahlown and Azam, 2003). Similarly, an increase in SAR in irrigation water can lead to swelling and dispersion of soil clay (Li and Zhang, 2010) and decreases soil hydraulic conductivity leading to increased runoff and erosion (Tedeschi and Dell'Aquila, 2005).

1.4.5 Flocculation and dispersion

Flocculation is the process which clay particles, individual coagulate or aggregate, whereas the dispersion is the reverse action of flocculation such as the distinctive clay particles separate from one another (Bratby, 1980). Soil dispersion is related to the amount of sodium and calcium ions between the clay platelets. When sodium ions are adsorbed by soil particles as exchangeable cations, the soil becomes sodic and the soil structure is degraded because of clay swelling and dispersion (Carey, 2014).

Gypsum application to the soil can decrease clay dispersion, which improves the permeability of the soil and increases the stability aggregates at the soil surface due to dissolve quickly and releases electrolytes, which flocculate the soil particles and also gypsum releases calcium salt which replaces the exchangeable sodium and lower tendency of clay to disperse (Shainberg et al., 1989). The relative flocculate power was assigned to sodium 1, potassium 1.7, and magnesium 24 and calcium 43. It means calcium, and magnesium is good flocculators but sodium is poor flocculator (Marchuk and Rengasamy, 2010). Ghadiri et al., (2004) studied the effects of changing soil salinity and sodicity of soils on their erodibilities and erosion losses under simulated rainfall. High sodium concentration, thus contributed to the weakening of soil aggregates and their dispersion under the raindrop impact. Electrical conductivity and salt concentration in the runoff have decreased exponentially with time from sodium-treated soils.

1.4.6 Sodium adsorption ratio (SAR)

Sodium adsorption ratio (SAR) expresses the relationships between sodium content and calcium plus magnesium contents. This ratio reflects the amounts of sodium adsorbed onto clay and soil organic matter exchange surfaces, hence the potential for flocculation or dispersion processes within the soil (Keren, 1991). These processes influence the hydraulic properties of the soil, runoff and soil erosion (Lavee et al., 1991). The effect of SAR on dispersion depends on the electrolyte concentration: when both the electrolyte and SAR are relatively high soil structure is not affected by the SAR, whereas low electrolyte concentrations enhance clay dispersion (Shainberg et al., 1980). Dan and Yaalon (1982) showed that the SAR increased with decreasing rainfall and with increasing depth, in saline soils in Israel, SAR above 12-15 causes serious physical soil problems and plants had difficulty in absorbing water. Dispersive soils are widely distributed in South Africa and commonly found in regions where the annual rainfall is less than 850 mm. Dispersive soils can be stabilized by treatment with lime or gypsum (Bell and Maud, 1994).

1.4 Objectives

1.4.1 Overall objectives of this dissertation

According to a questionnaire survey and observed agricultural field conditions, no attention has been paid to try to address soil erosion problem in Paktya Province, Afghanistan and hence; this study was selected to help in developing suitable soil conservation strategy. This involves estimating soil erosion (t ha^{-1} yr^{-1}) through the application of the Universal Soil Loss Equation (USLE) on GIS and to discuss the effective conservation practices. As effective conservation practices, crop management and gypsum mineral ($CaSO_4.2H_2O$) application in agricultural lands were evaluated to reduce sediment concentration in runoff as well as soil erosion in agricultural lands. In this dissertation "*Erosion Assessment and Soil Conservation Strategy in Degraded Soil Conditions of Paktya Province, Afghanistan,*" the following objectives were set out;

1) To discuss the current condition of agricultural sectors and constraints of agriculture
2) To evaluate soil erosion risk using the GIS technique and empirical Universal Soil Loss Equation (USLE)
3) To determine the effectiveness of crop management and gypsum to reduce sediment concentration in runoff and total soil loss
4) To determine the effectiveness of gypsum application as a conservation practice factor using the USLE with GIS

1.4.2 Objective of each chapter

To achieve the overall objectives and make clear the following research structures were formulated (Fig. 1.7). **It was addressed within this chapter,** general review of Afghanistan, effect and the type of soil erosion, soil erosion models, soil conservation measures and the usage of gypsum mineral in the agriculture sector.

In chapter 2 it is discussed current agricultural conditions and constraints, a questionnaire survey was conducted Dawlatzai Village of Gardez District, Paktya Province. The main problems that Paktya Province is facing are; soil degradation, deforestation, inadequate of irrigation water, poor extension services and inadequate of agricultural inputs. In addition, based on the survey conducted in the study area, 32% of the farmers responded that soil erosion happens very severely and 50% responded as severely. **In chapter 3** it is discussed the estimating annual soil loss rate and risk categories by USLE on GIS. The object of this chapter to evaluate soil erosion risks using the GIS technique and empirical USLE. The USLE factors; R, K, L, S, C and P extracted as GIS layers (maps) and using mathematical equations, then multiplied within the raster calculator in ArcGIS. Soil loss map was obtained t ha^{-1} yr^{-1} a pixel levels. In addition, it suggested land use map was prepared, that could be highly essential recognizing the priority areas for the application of suitable land use practices and soil conservation measures. On the other hand, the USLE model was calibrated by the erosion pin method. The results of the calibration indicated that the observed soil losses with the erosion pin method in the field showed certain agreements with the calculated soil losses based on the USLE model in this study.

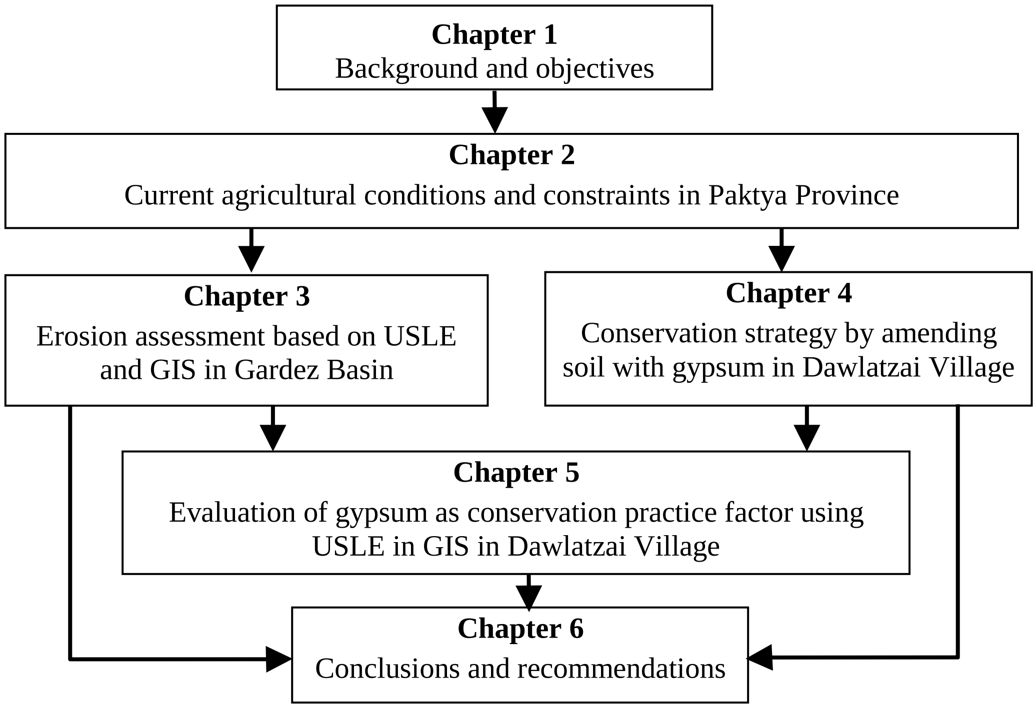

Fig. 1.7 Research structure of this dissertation

In chapter 4 dealt with soil conservation practice, crop management and gypsum application have been focused in this study. Preventing soil erosion with cultivating crops is a common farming practice in agricultural lands. Also, gypsum mineral is an amendment widely accepted in the recent days because of its availability in most regions and relatively low-cost. The objective of this chapter is to determine the effectiveness of crop management and gypsum mineral to reduce sediment concentration in runoff and total soil loss. A field experiment was conducted in the Dawlatzai Village in Gardez District of Paktya. Using a portable rainfall simulator, four erosion plots; gypsum-treated plot, gypsum at the rate of 5 t ha^{-1} was applied, clover plot, maize plot, and control plot were designed. The experimental results indicated that total soil losses from gypsum-treated, clover and maize cultivated plots were reduced to 67.3%, 92.0% and 54.3% of that from the control, bared plot. As crop cultivation is not available during the period of insufficient irrigation water in Dawlatzi Village of Gardez District, research interest was focused on gypsum application as an alternative conservation strategy. In addition, experiment was conducted for discussing more detail about the effects of gypsum application in the laboratory using two different soil textures; one is sandy loam and the other loamy soils. The results showed that reduction in surface runoff by 38.8% was observed for sandy loam soil and 37.0% for loamy soil texture compared to the control and infiltration volume was significantly increased. So, total soil losses from gypsum-treated plots were significantly reduced to 63.3 and 81.9% of the losses from the control for sandy loam and loam soils, respectively. Soil particles were well flocculated in gypsum-treated plot compared to the control. **In chapter 5** dealt to determine the effectiveness of gypsum application as a conservation practice in Dawlatzai Village, P factor was assumed as 0.33 based on the results of the field experiments. The maximum soil losses at 79 t ha^{-1} yr^{-1} from the agricultural lands without any conservation practices decreased to 20 t ha^{-1} yr^{-1} when gypsum application is done as a conservation practice. **In chapter 6** summarizes the result of this dissertation and addresses the overall conclusion of the present study entitled: "*Erosion Assessment and Soil Conservation Strategy in Degraded Soil Conditions of Paktya Province, Afghanistan*." And also, recommended that farmers of Paktya Province to apply gypsum mineral on their farmlands for reducing surface runoff and soil loss.

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Chapter 2--

Current agricultural conditions and constraints in Paktya Province

2.1 Objective of this chapter

The objective of this study is to discuss current conditions of agricultural sectors and constraints of agriculture in Paktya Province, Afghanistan.

2.2 Description of research site

2.2.1 General review of Paktya Province

Paktya province is in the southeastern region of Afghanistan. It is bordered by the provinces of Nangarhar to the North-East, Khost to the South-East, Paktika to the South-East, Ghazni to the West and Logar to the North (Fig. 2.1). The total area is approximately 6,259 km^2. Although, 65.1% of the province is mountainous/semi-mountainous terrain while a little more than one-third (32.3%) of the area is made up of flat lands (Table 2.1). This province is divided into 14 districts, and the capital is Gardez city. The total population of the province approximately one million (CSO, 2010).

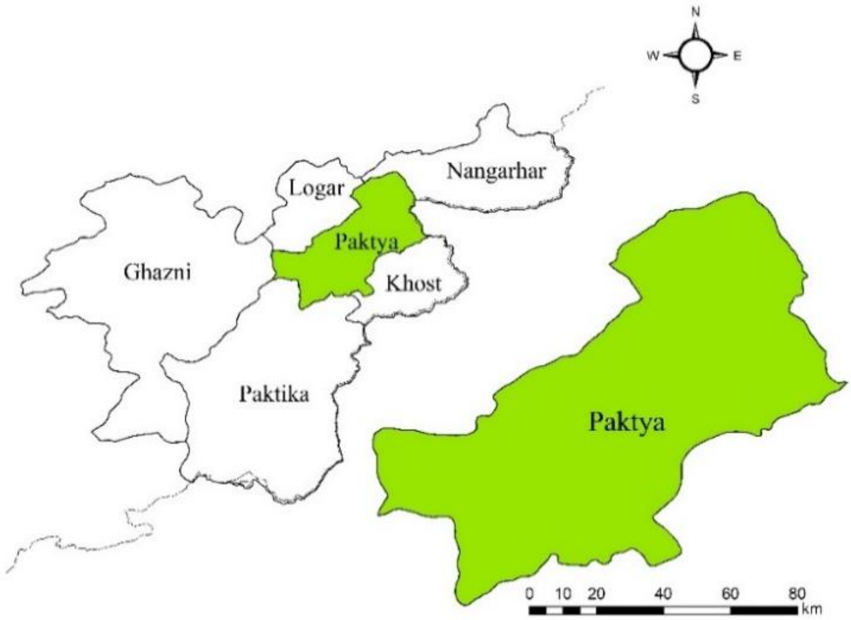

Fig. 2.1 Map of Paktya Province

Table 2.1 General topography of Paktya Province

Flat	Semi-flat	Mountainous	Semi mountainous	Not reported	Total
2.3%	1.9%	52.0%	13.1%	0.7%	100%

Source: Central Statistics Organization, 2007

Paktya province has an agricultural based economy and 61% of the population is depending on agricultural activities, approximately 96% of the population living in the rural areas (ANDS, 2008-2013). Most of these agriculture-related activities fall within small-scale production systems with only a few farmers being self-sufficient. Paktya province has both irrigated and rain-fed agriculture lands, the Chamkani and Dand Patan Districts have a warm climate with two seasons growing conditions the other districts have only one growing season conditions.

Wheat is a culturally most significant crop in the province and a staple food for all Afghans. Wheat is grown in 21,105 ha with a production of 75,203 tons (MAIL, 2014). About 90% of the wheat is fall-planted, and the rest is a spring planted. Although wheat straw has a relatively low nutrition for livestock, it is used for livestock feed. Therefore, higher seed rates are recommended to meet the additional need of straw to be used as fodder. The other important crops include maize, rice, barely, vegetable and fruits.

Land use map of the country was developed by FAO-UN, 1993 and subsequently updated in 2016 (FAO-UN). Land use map of Paktya province was extracted by ArcGIS (Fig. 2.2), that includes 12 classes. The rangeland land covers 55.6%, forest and shrub cover 20.3%, irrigated agricultural land covers 13.3%, and rest area covers 10.8% of other classes as shown in Table 2.2.

Similarly, soil classification map of the country was developed by USDA-SCS, 2001, then extracted soil map of Paktya province by ArcGIS (Fig. 2.3), which includes

4 classes; clay and silty sand with rock fragments and exposed bedrock. Clay and silty sand (shallow), silt & clay (moderately deep to deep). Gravel overlain by caliche and silty sand. Gravel overlain by clay.

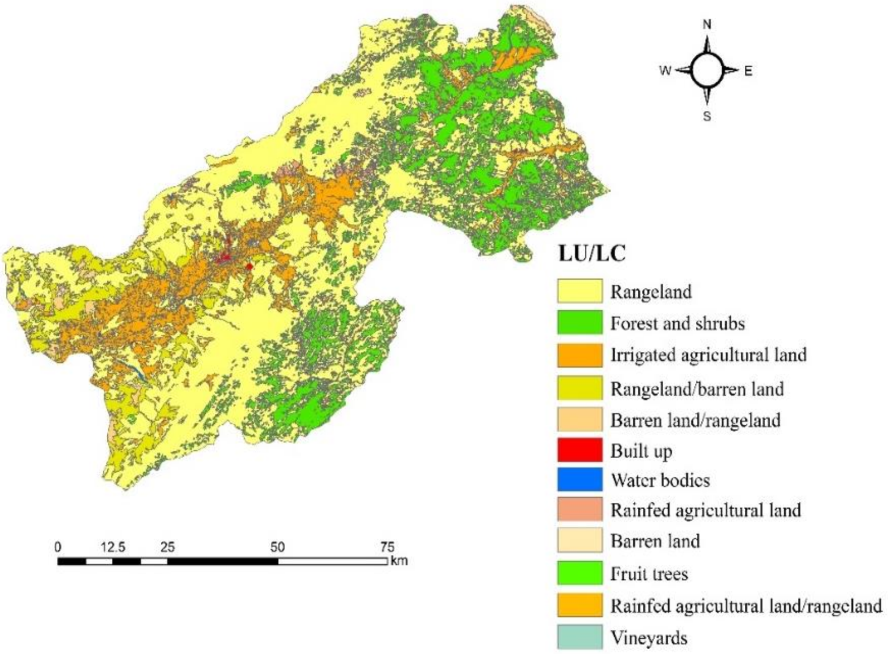

Fig. 2.2 Land cover map of Paktya Province

Source: FAO-UN, 1993

Table 2.2 Land use and land cover of Paktya Province

No	LULC	Area (ha)	Area (%)
1	Rangeland	293,075	55.6
2	Forest and shrubs	107,220	20.3
3	Irrigated agricultural land	70,119	13.3
4	Rangeland/barren land	34,190	6.5
5	Barren land/rangeland	6,888	1.3
6	Built up	4,666	0.9
7	Water bodies	4,271	0.8
8	Rain-fed agricultural land	4,244	0.8
9	Barren land	1,118	0.2
10	Fruit trees	732	0.1
11	Rain-fed agricultural land/rangeland	679	0.1
12	Vineyards	285	0.1

Soil erosion is severe in Paktya province due to poor land management and soil structure, barren vegetation and undulating topography.

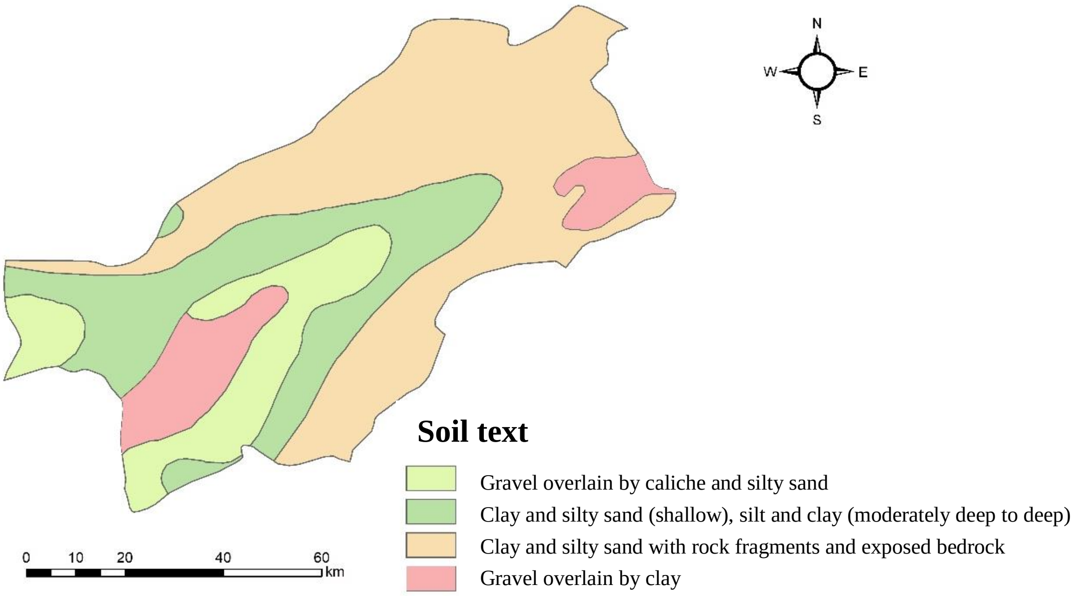

Fig. 2.3 Soil region map of Paktya Province

Source: USDA-SCS, 2001

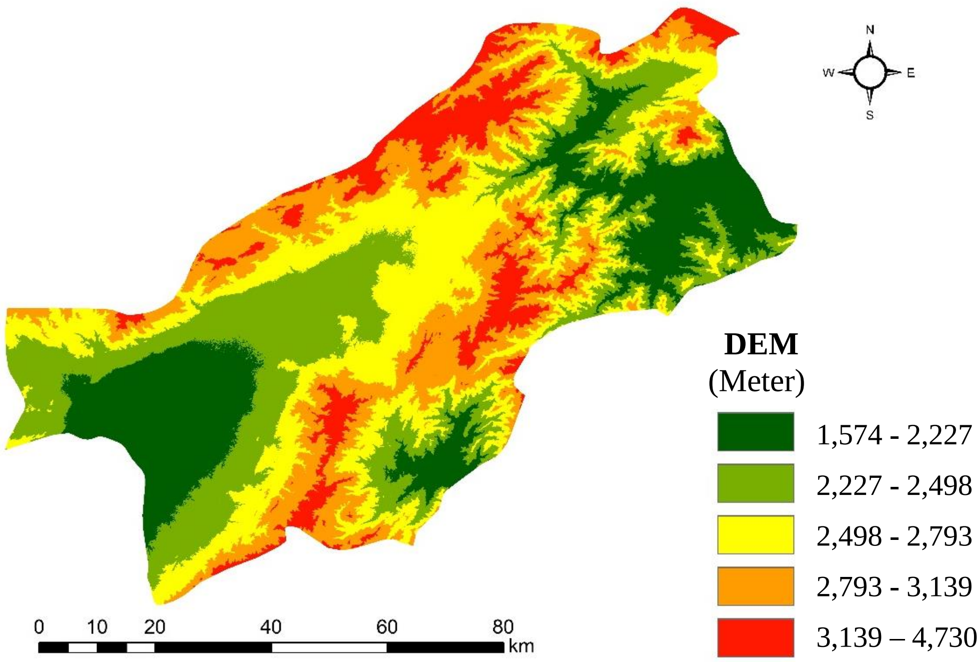

Fig. 2.4 Topography map of Paktya Province

Most of the areas are watersheds having very steep slopes. Therefore, the slope was derived from Digital Elevation Model (DEM). The DEM of the province from 1,574 to 4,730 m above the sea level (Fig. 2.4) and slops ranges between 0 to 72 degrees (Fig. 2.5). The steeper and longer the slope of a field the higher the risk of soil erosion. Soil erosion by water increases as the slope length increase because of greater accumulation of runoff.

A field experiment was conducted by US Military, Agriculture Development Team (US-ADT), 2011. The soil loss ranges from 500 to 1,200 t/ha, it is depending on the area. However, a large volume of water during the time of flood for a short period cause of serious soil degradation as gully type as well as sediment prevents a stabilization of the riverbanks and waterways (Fig. 2.6).

The flow rates of five (5) major water ways or rivers (Darbal, Zour, Sargand, Rodak and Lagarou Kana ways) during early summer were from 15 m^3/sec to 70 m^3/sec (US-ADT, 2011). It thereby causes an overflow of water on the agricultural land.

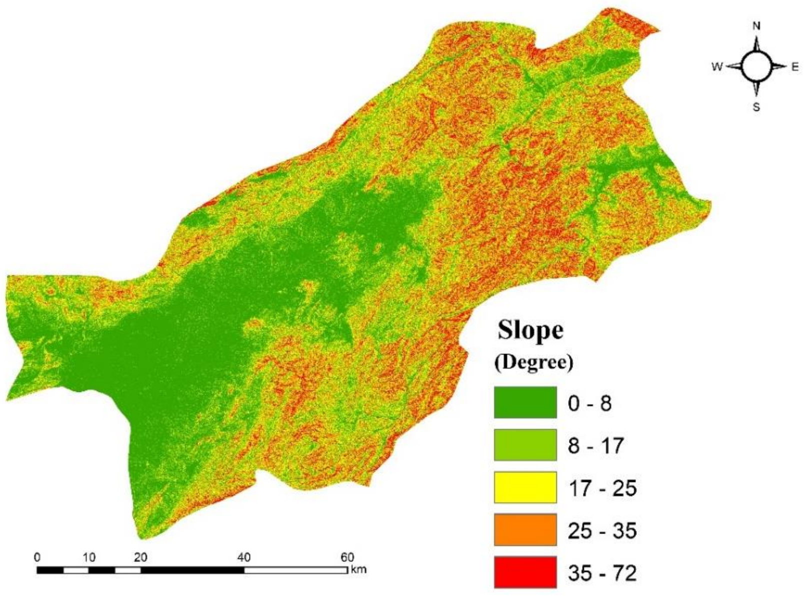

Fig. 2.5 Slope map of Paktya Province

Fig. 2.6 Soil erosion phenomena observed

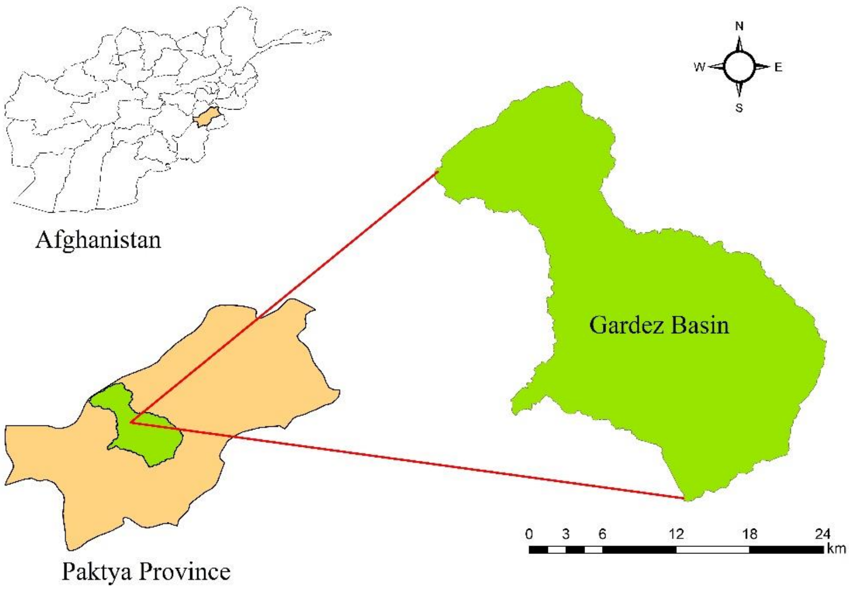

Fig. 2.7 Gardez Basin, Paktya Province, Afghanistan

Gardez Basin is located in the east part of the country which is also the capital of Paktya province, Afghanistan. The Basin covers approximately 48,104 hectares (Fig. 2.7). It is geographically positioned between latitude N 33° 46′ 0″- N 33° 28′ 0″ and longitude E 69° 26′ 30″- E 69° 26′ 30″. It topographically ranges in slope between 0 to 66 degrees with an elevation of approximately 3663 m above the sea level.

Dawlatzai Village is located in the Gardez district of Paktia province (Fig. 2.8). The village is about 5 km far from Gardez city and approximately 1,800 families live in the village.

Fig. 2.8 Dawlatzai Village in Gardez District, Paktya Province

2.2.2 Precipitation

Paktya province's climate is arid and semi-arid with dry summers and cold, snowy winters. Precipitation figure is low and mostly falls in the winter and spring. The automatic rain gauge was installed in the study area in 2015 and collected data from rain gauge the annual rainfall is 355 mm yr^{-1}, a minimum temperature -11 °C and maximum 41 °C (Fig. 2.9). The study area is surrounded by mountains, which are receiving the major share of the annual precipitation in the form of snow.

During the winter season, snow accumulates in the mountains during the spring and summer time the snow melts making a large portion of irrigation water.

Furthermore, precipitation is the main source of irrigation water approximately 67% of the irrigation water is provided by rainfall and snow cover in the mountains and rest on the irrigation water is supplied by the traditional method such as Karezes (underground water), springs and Tube wells.

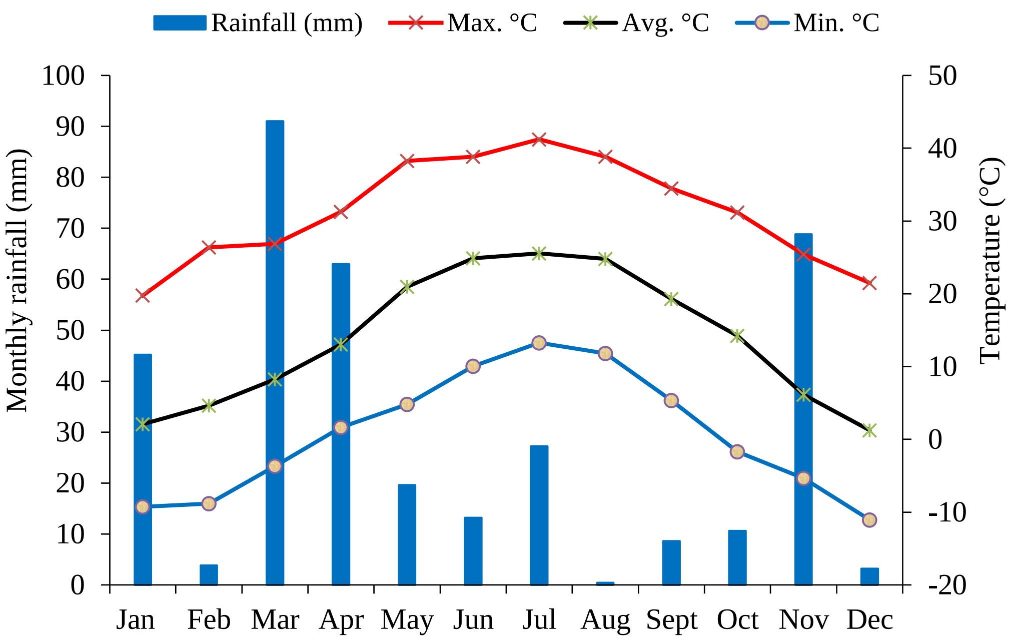

Fig. 2.9 Monthly rainfall and temperature of Dawlatzai Village in 2016

2.2.3 Questionnaire survey

In order to identify the current agricultural conditions and constraints, a survey was done in Dawlatzai Village of Gardez District, Paktya Province. Agriculture is the main economic activity in the village. Compared to other parts of the districts, it is safer and provides ample environment to conduct the research. A total of 43 farmers were randomly selected across the entire study area and interviewed in the survey. The questions in the questionnaire sheet were on the basic information such as household, farmland, crop cultivation, water resource, topography, fertilizer application, agricultural chemicals, soil degradation and agricultural extension services (Table 2.3).

Table 2.3 Questions in the questionnaire sheet

Category	Related question	Details
Basic information of household	-Farmer`s information	Name, age, gender, number of family members, and address
Farmland	-Cultivated area	Size (sq. meter, m^2)
Crop cultivated	-Kind of crops	Wheat, maize, barely, beans and vegetable
Water resource	-Source of irrigation water	Tube well, river and Karez
Topography	-Nature of terrain	Flat, semi flat, hilly and mountainous
Fertilization	-Type of fertilizers used	Urea, DAP (Diammonium Phosphate), farmyard manure, compost manure and ash
Agricultural chemicals	-Type of chemical used	Insecticide, herbicides, fungicides
Soil degradation	-Soil erosion effect -Effect soil erosion -Soil conservation measure	Damage level, Nutrient loss and water pollution, Agronomic and physical measures
Agricultural extension service	-Extension service provision	Awareness of agricultural extension service

Each farmer was requested to fill up one form. All forms were filled up after all columns were understood by respondents. The data recorded for various parameters were subjected to statistical analysis, Critical Difference (CD) at 1% or 5% level of probability was computed to compare the statistical significance of different parameters.

2.3 Results and discussion

2.3.1 Soil degradation

As shown in Table 2.3, soil degradation was a key challenge for farmers of Paktya Province. Environmental stress by the province's people has drastically altered the landscape and caused widespread environmental destruction. Since the people lack the adequate financial capability to purchase fuel, they mostly cut trees, uproot shrubs and collect animal dung as sources of fuel. This results in extensive soil erosion by both water and wind.

Based on the questionnaire survey, 32% of responding farmers answered soil erosion happens very severely, and 50% answered it happens severely (Fig. 2.10). It means that more than 80% of farmers require the proper conservation strategies for holding soil moisture and fertility.

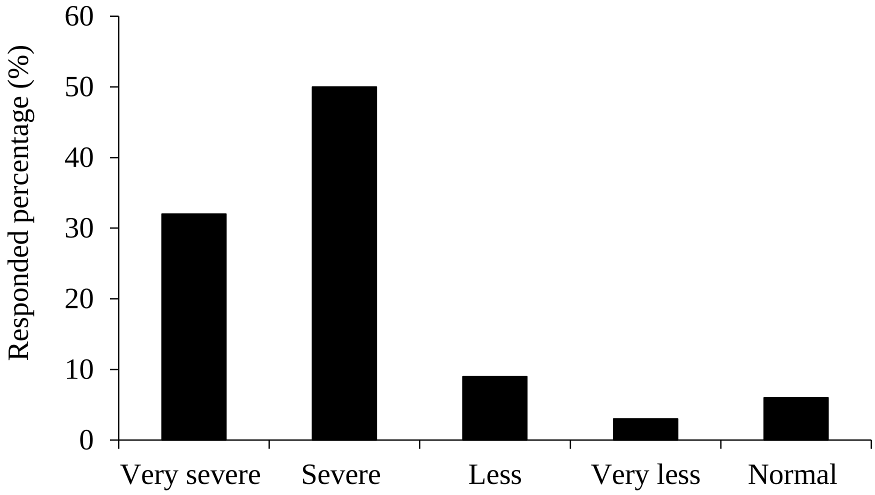

Fig. 2.10 Damage level of soil erosion in Dawlatzai Village

The geological, topographical and meteorological features of Paktya naturally increase the susceptibility to the processes of soil erosion. Furthermore, human activities significantly intensify them through farming on steep slopes, deforestation and de-vegetation of lands, as well as the unsustainable use of shrub and grasslands. Some degradation is too severe for recovery without human intervention (Fig. 2.11). One of the most threatening impacts arising from loss of soil and vegetation is desertification and increasing floods. Soil erosion causes a serious problem affecting the productivity of agricultural lands (Luis et al., 2010). The lack of information regarding the factors influenced by soil erosion in the dry regions hampers the formation of a proper soil and water conservation plans.

Fig. 2.11 Soil degradation observed in Dawlatzai Village

2.3.2 Water deficiency and drought

Paktya is one of the mountainous provinces; it is divided into different valleys and regions. The water of river resource is from Spin Ghar Mountains, which runs from high latitude to the eastern part of the Karma Agency region, and the mountains are the main source of irrigation water for Paktya. The quantity of water is related to rainfall and snow accumulated in the mountains.

Most of the rivers are impermanent with increased water levels from February to April and usually dry from June to October. Zarmal, Patan and Arub are the main rivers flowing through the province. Springs, Karezs and tube wells are also used as water sources. Unfortunately, during the last three-decade war, many Karezs and springs had been destroyed and most farmers are now digging the tube wells to get the water needed (Fig. 2.12). Fuel is required for engine pump to run these tube wells, but the high price of fuel has caused another acute problem to the farmers of the province. Accordingly, most of the agricultural lands are uncultivated under rain-fed with no alternative methods of artificial irrigation.

Fig. 2.12 Water problems in Dawlatzai Village Paktya Province

The average annual rainfall is below 400 mm yr^{-1}. The changes in monthly amounts of precipitation and average air temperature. Precipitation occurs mostly between the months of January to April. From June to October, Paktya Province receives hardly any rainfall (Fig. 2.13). As results, water shortages frequently occur in the latter part of the cultivating season in August up-to harvest time in October, causing major difficulties in crop cultivation.

According to the questionnaire survey, 88% of farmers reported lack of irrigation is the main problem that they are facing (Fig. 2.14). More than 85% of the land needs artificial irrigation.

This has been proven as one of the noticeable factors that are considerably reducing the agricultural productivity. Reported by UNEP (2003) Post-Conflict Environment Assessment Report on Afghanistan, the amounts of water used are less than one-third of total water potential at 75,000 million m^3. Studied by Habib, 2014 following more than three-decade civil war and political unrest in Afghanistan faces many different environmental problems. Shortage of irrigation water is a serious problem throughout the country since the drought between 1999 to 2003 obviously degraded widespread natural resources.

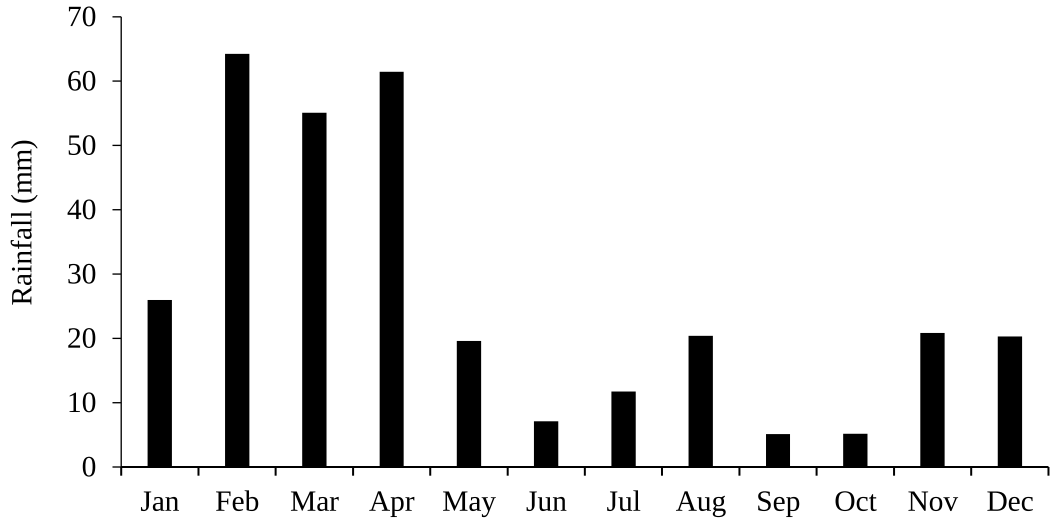

Fig. 2.13 Monthly precipitation in Paktya Province

Source: Ministry of Agriculture, 2004 to 2016

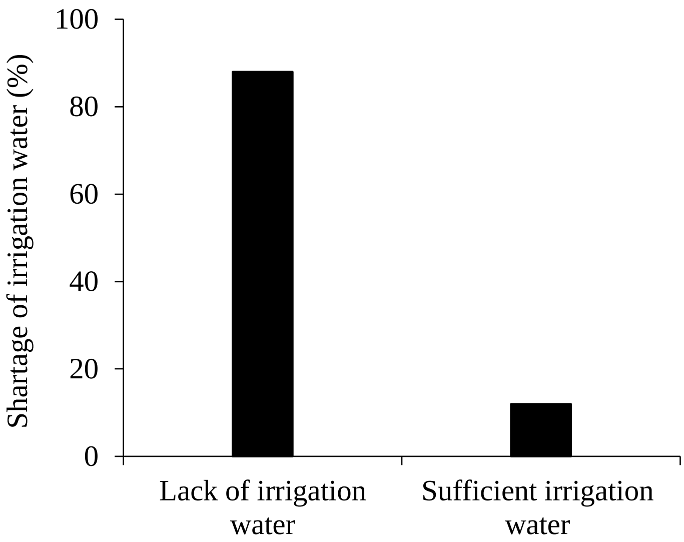

Fig. 2.14 Shortage of irrigation water

2.3.3 Agricultural extension services

Agricultural extension is one of the powerful forces that are responsible for the growth of crops by transferring the latest and improved technologies to the farmers and ultimately strengthens the national economy (Sadaf et al., 2005). Paktya Province has fourteen districts. Unfortunately, just one extension worker has been appointed for six districts while the other 8 districts have none. It is impossible for a person to reach the huge number of farmers and to solve their problems. According to the questionnaire survey, 64% of the farmers did not know about the active extension worker. As a result, the farmers lack a modern technical knowledge and still the old age traditional farming has been practised, which is in turn hampering the agriculture production and ultimately the lifestyle of people.

2.3.4 Lack of quality planting material

Quality seed is an important asset for the quality of production. It affects germination as well as the overall vigor of the plants, especially in the case of wheat (Barnard and Calitz, 2011). The Department of Agriculture, Irrigation and Livestock is responsible for seed distribution, but due to the limited availability of certified seed and misguidance by many local seed distributors, farmers are forced to use lower-quality uncertified seeds. More than 70% of the farmers were found not to have access to quality seeds. Utilization of poor quality seeds is one of the major problems in agriculture, which is responsible for low crop productivity (DAIL, 2014).

2.3.5 Use of adulterated or expired insecticides

Although Afghanistan Government has claimed that the pesticide contamination and requested to decrease its usage, but still there is a continuous use of low-quality insecticides. Poor-quality insecticides affect the natural environment and also induce some of the serious health issues due to their prolonged residual effects (Jabbar and Mallick, 1994). Some private agricultural companies and agro-clinics are importing the low-quality insecticide and pesticide from Pakistan, Iran and China (DAIL, 2014). About 31.6% of the farmers are using the pesticides that are not even recommended for application. Thus, the Afghan Government has been unable to complete ban or control such ill practices.

Besides, there are many other, factors were also identified, but their effect is not as profound as the above ones.

2.4 Conclusion of this chapter

Paktya Province is based on the agricultural economy, but the condition of the farmers is severe. According to the topographical and climatic conditions, modern farming methods employing artificial irrigation are indispensable. If some alternative sources of irrigation or new methods of irrigation are popularized among local farmers, the condition of agriculture would be largely improved. The main problems that Paktya Province is facing today are those of soil degradation, deforestation, lack of irrigation water, poor extension services and lack of agricultural inputs. These, in turn, contribute to the declining agricultural production. Based on the survey conducted in the study area, 32% of the farmers responded that soil erosion happens very severely, and 50% answered soil erosion happen severely. It means that more than 80% of farmers require proper conservation strategies for holding soil fertility. In addition, 88% of farmers reported lack of irrigation water and that more than 85% of arable land needs an artificial irrigation system.

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Chapter 3--

Estimation of soil erosion based on USLE and GIS in Gardez Basin, Paktya Province, Afghanistan

3.1 Objective of this chapter

The objective of this study is to evaluate soil erosion risk using GIS technique and empirical Universal Soil Loss Equation (USLE) in Gardez Basin, Paktya province, Afghanistan.

3.2 Materials and methods

3.2.1 Data used

The Universal Soil Loss Equation (USLE) model was developed by Wischmeier and Smith (1978), as an equation representing the main factors controlling soil erosion, namely climate, soil characteristics, topography and land covers management. They are well presented as considered by equation 3.1.

$$A = R \times K \times L \times S \times C \times P \qquad \text{(Eq. 3.1)}$$

Where;

A is computed annual soil loss per unit area (t ha^{-1} yr^{-1})

R is a runoff erosivity factor (MJ mm ha^{-1} yr^{-1})

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

L is a slope length factor

S is a slope steepness factor

C is cover management factor

P is supported practice factor.

In the present study, annual soil loss rates and scale were calculated based on USLE in GIS and different data sources were referred to analyze the estimation of soil loss in Gardez Basin, Paktya Province (Fig. 3.1).

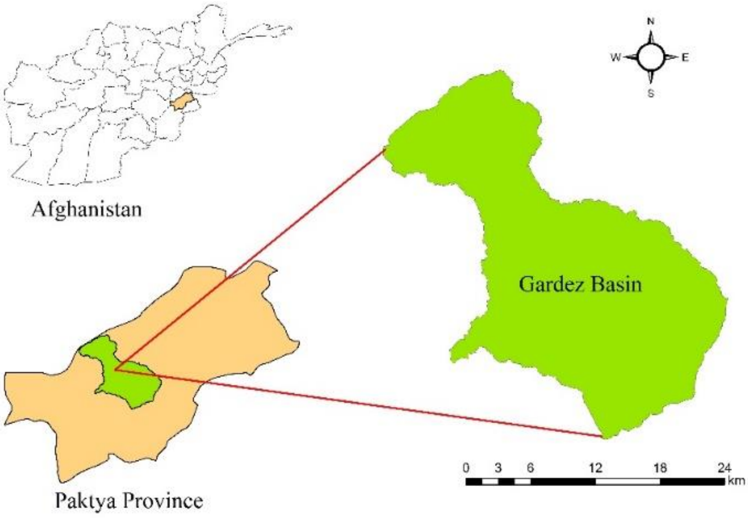

Fig. 3.1 Gardez Basin, Paktya Province

A digital elevation model (DEM) with 30 m resolution was downloaded from available online: https://asterweb.jpl.nasa.gov /gdem.asp, that developed by the United States Geological Survey (USGS). The DEM range is from 2,205 m to 3,663 m (Fig. 3.2). The DEM was used to estimate the slope gradient, flow direction, basin area, flow length and flow accumulation for the study area using ArcGIS 10.3.1.

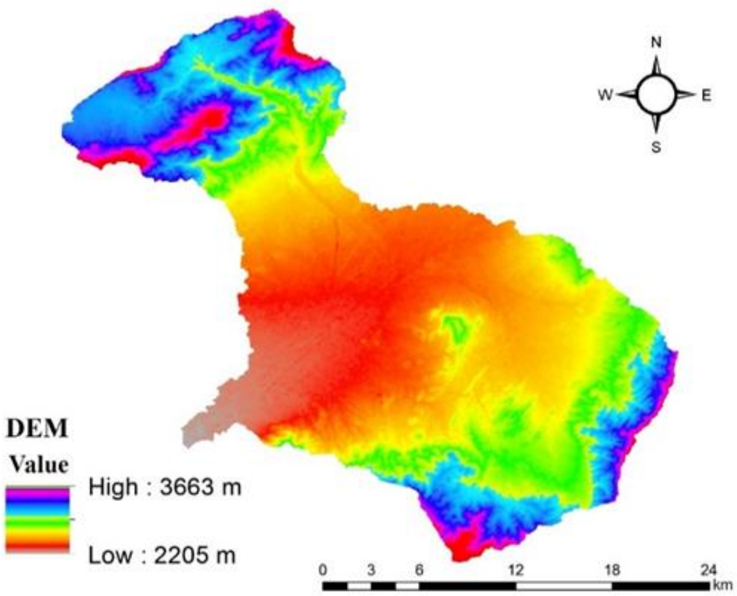

Fig. 3.2 DEM map of Gardez Basin

The slope length and slope steepness (LS) factor required by USLE was calculated. The slope was calculated from DEM for the Gardez Basin rang is from 0 to 65 degrees (Fig. 3.3). The land-cover classification map developed by the Food, Agriculture Organization (FAO, 2016), was used for the analysis of a crop management factor (C-value).

Soil classification map developed by the United States Department of Agriculture, Soil Conservation Services (USDA-SCS, 2001) was used for analyzing the soil erodibility factor (K-value).

The rainfall erosivity factor (R-factor) was calculated based on observed rainfall data (automatic rain gauge was installed in the study area) and annual rainfall data surrounding the study area. All the datasets utilized in this study were resampled to the same spatial resolution of 30 × 30 m ArcGIS and projected to the World Geodetic System (WGS) 1984, Universal Traverse Mercator (UTM) zone 42 the south.

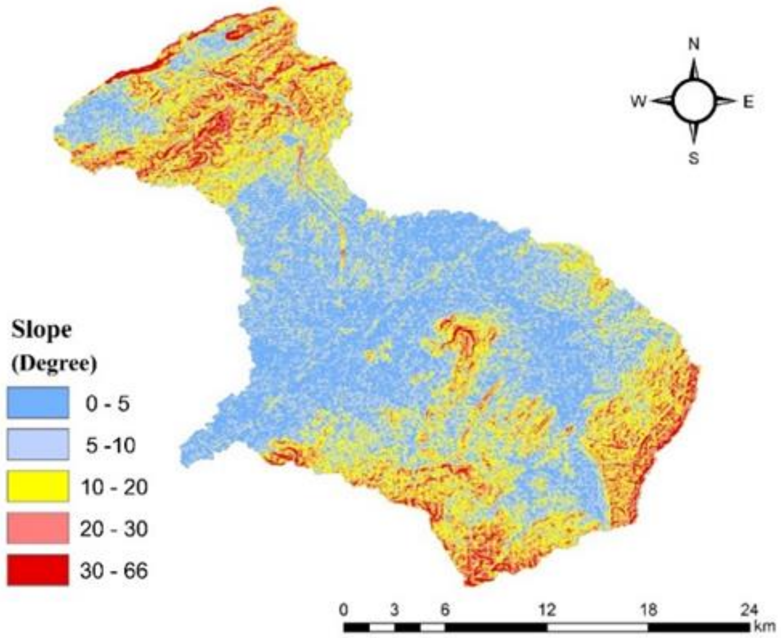

Fig. 3.3 Slope map of Gardez Basin

3.3 Results and discussion

3.3.1 Rainfall erosivity factor (R)

Rainfall erosivity is defined as the aggressiveness of the rain to cause erosion (Lal, 1990). Rain has a direct impact on the surface of the soil. The kinetic energy of the raindrops destroys the soil aggregates, making them susceptible to transfer by runoff water (Wischmeier and Smith, 1978). The R factor was calculated using the equations 3.2 and 3.3 developed by Wischmeier and Smith, 1978.

$$KE = 11.87 + 8.73 \log I \qquad \text{(Eq. 3.2)}$$

Where;

I is the rainfall intensity (mm h^{-1})

KE is the kinetic energy (Jm^{-2} mm^{-1}).

$$R = \frac{\sum EI_{\max}}{1000} \qquad \text{(Eq. 3.3)}$$

Where;

R is a rainfall erosivity factor in MJ m km^{-2} h^{-1} yr^{-1}

EI is the total storm energy in Jm^{-2} mm^{-1}

There are criteria for identification of erosive rainfall; storm period with less 1.3 mm over six hours is used as the rainfall event, the rainfall event less than 12.7 mm of an amount was excluded in R factor calculation assuming insignificant to cause soil erosion (Renard et al., 1997 and Wischmeier and Smith, 1978). The rainfall event of 12. 7 mm threshold is considered as a precipitation event have erosive power, which affects soil erosion.

The R value was calculated from energy-intensity relationships. Daily rainfall data was recorded using automatic rain gauge installed in the study area for the duration of one-year (July 15, 2015 to July 14, 2016). It was recorded 8 events of rainfall based on the original USLE method. The erosivity factor was calculated and used in equations 3.2 and 3.3 (Table 3.1).

Table 3.1 Calculation of the erosivity factor

No	Max. intensity (mm h^{-1})	Total energy (J m^{-2})	Rainfall factor (MJ m km^{-2} h^{-1} yr^{-1})	R factor (MJ mm ha^{-1} h^{-1} yr^{-1})
1	4.0	402.0	1.59	15.9
2	3.7	343.2	1.28	12.8
3	3.6	272.6	0.97	9.7
4	4.0	270.6	1.08	10.8
5	21.3	292.5	6.22	62.2
6	8.2	294.0	2.41	24.1
7	11.1	341.4	3.79	37.9
8	15.9	277.5	4.41	44.1
	Total		21.7	217.5

Using the data obtained from the automatic rain gauge installed in the study area for the period of one-year, the R-factor was calculated as 21.7 MJ m km^{-2} h^{-1} yr^{-1} (217.5 MJ mm ha^{-1} h^{-1} yr^{-1}). Due to lack of adequate meteorological data such as storm event, rainfall amount in mm, intensity mm h^{-1} and maximum 30-minute intensity in mm h^{-1} in whole Afghanistan, it is hard to apply equations 3.2 and 3.3. Therefore, it is necessary to interpolate between available data. Hence, attention should be paid to investigate new methods and equations to calculate the erosivity factor using annual rainfall. R factor based on annual precipitation was calculated using various equations (Table 3.2). However, the erosivity index calculated using equation 3.4 by Singh et al., 1981 indicated the best fit was achieved between R factor calculated with USLE and the mean annual precipitation in the Gardez Basin. The result based on equation 3.4 was summarized in Table 3.3.

$$R = 79 + 0.363P \qquad \text{(Eq. 3.4)}$$

Where;

P is the mean annual precipitation (mm)

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

Table 3.2 List of equations used to investigate correlation

No	Calculated the R factor (MJ mm ha^{-1} h^{-1} yr^{-1})	Equation	Reference
1	15.7	$R = 29 + 0.363P$	Parveen and Kumar, 2012
2	29.7	$R = 9.17P^{0.20}$	Cooper, 2011
3	129.5	$R = 23.61e^{(0.0048P)}$	Eltaif et al., 2010
4	40.7	$R = 12.98 + 0.0783P$	Deumlich et al., 2006
5	616.2	$R = 0.0438P^{1.61}$	Yu and Roswell, 1996
6	342.0	$R= 0.07397F^{1.847}/17.02$	Renard and Freimund, 1994
7	2,225.7	$R = 0.04830P^{1.510}$	Renard and Fremund, 1994
8	71.8	$R = (0.27P75)/100$	Foster et al., 1981
9	**207.7**	$\mathbf{R = 79 + 0.363P}$	**Singh et al., 1981**
10	2,097.1	$R = 0.03P^{1.9}$	Arnoldus, 1980
11	177.3	$R = 0.5P$	Roose, 1975
12	-8,029.1	$R = 2.28P - 8,838$	Morgan, 1974

Table 3.3 Rainfall erosivity (R value) based on mean annual rainfall

No	Station	Rainfall (mm yr^{-1})	R value (MJ mm ha^{-1} h^{-1} yr^{-1})
1	Tera Garden Gardez District (Paktya Province)	333	199.9
2	Rhoni Baba farm Zarmat District (Paktya Province)	216	157.4
3	Khost Bazar (Khost Province)	330	198.8
4	Sharana District (Paktika Province)	219	158.5
5	Urgoon District (Paktika Province)	252	170.5
6	Puli Alam Distric (Logar Province)	294	185.7

In terms of ArcGIS layers, each weather station was represented by a point. The Inverse Distance Weighted (IWD) interpolation method in ArcGIS was used to create a raster map for R factor. However, rainfall erosivity (R) was calculated using rainfall data from six rainfall stations across the Gardez Basin. High erosivity was found in the northeast, while low erosivity was found in the southwest part of the Basin. The R-factor varies from 157.6 to 199.7 MJ mm ha^{-1} h^{-1} yr^{-1} (Fig. 3.4).

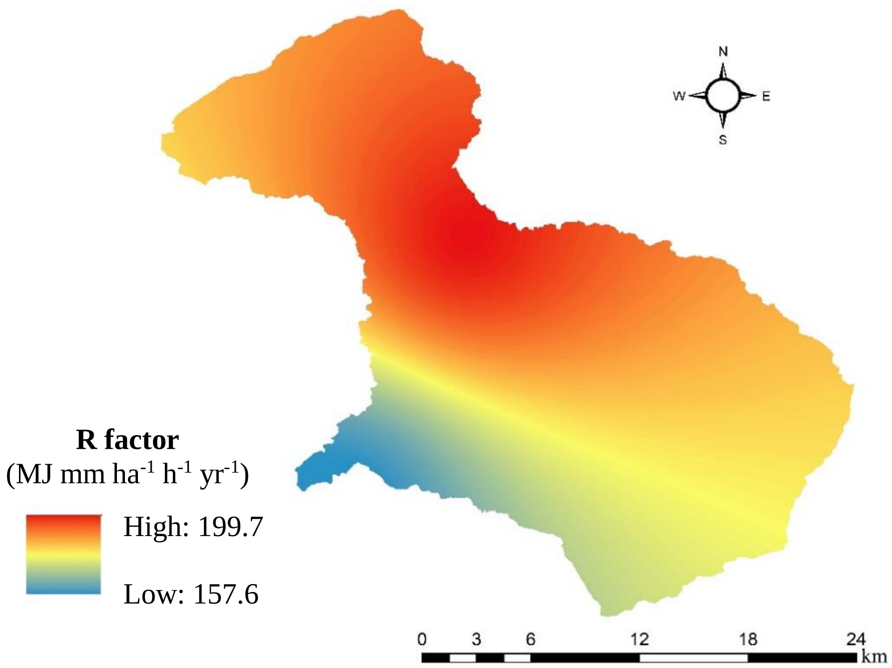

Fig. 3.4 Rainfall erosivity map of Gardez Basin

3.3.2 Soil erodibility factor (K)

The soil erodibility factor indicates susceptibility of soil particles or surface materials to be detached and transported by rainfall and runoff (Renard et al., 1997). The K factor measure under the standard unit has a 9% gradient slope and a length of 22.1 m in a continuous fallow condition with tillage performed upslope and downslope (Wischmeier and Smith, 1978).

Soil erodibility factor was obtained from the soil classification map of the country which is prepared by USDA-SCS, 2001. Based on the classification of soil and soil texture classes, the K factors (t ha h ha^{-1} MJ^{-1} mm^{-1}) summarized in Table 3.4. Meanwhile, soil samples were collected from the entire study area, that soil samples were analysed in the laboratory for soil particle distribution size (texture), organic matter content and permeability. Based on regression equation 3.5 (Wischmeier and Smith, 1978). The K factor values from 0.038 to 0.063 t ha h ha^{-1} MJ^{-1} mm^{-1} (Fig. 3.5).

$$K = \frac{[2.1 \times 10^{-4}\ (12 - OM) M^{1.14} + 3.25(S-2) + 2.5(P-3)]}{759} \qquad \text{(Eq. 3.5)}$$

Where;

K is soil erodibility t ha h ha^{-1} MJ^{-1} mm^{-1}

OM is organic matter content

M is the particles percentage (% of very fine sand + % of silt) (100-% clay)

S is the soil structure

P is the soil permeability

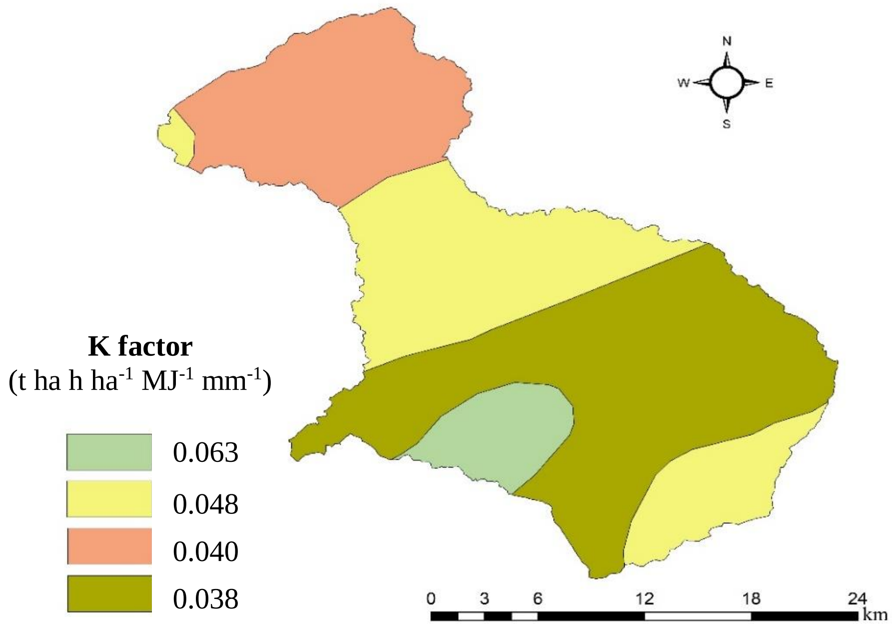

Fig. 3.5 Soil erodibility map of Gardez Basin

Table 3.4 Soil classification and erodibility values

No	Soil classification	Soil texture	Order	K factor (t ha h ha^{-1} MJ^{-1} mm^{-1})
1	Haplocambids with Torriorthents	Silt loam with fine sand	Aridic	0.063
2	Xerochrepts with Xerorthents	Silt loam	Xeric	0.048
3	Haplocambids with Torriorthents	Silt loam	Aridic	0.040
4	Torriorthents with Torrifluvents	Silt clay loam with cobbly loam	Aridic	0.038

3.3.3 Slope length and slope steepness factor (LS)

The influence of topography on soil erosion is calculated by the LS factor in USLE, which combines the effects of a slope length factor (L) and a slope steepness factor (S). Thus, an increase in the L factor results in an increase in soil erosion per unit area due to progressive accumulation of surface runoff on downslope direction. When a S factor increase, the velocity and soil erosion of surface runoff also increase. The LS factor has been used in a single index, which expresses the ratio of soil loss as defined by Wischmeier and Smith, 1978.

$$LS = (X/22.1)^{m} (65.41 \sin^2 \theta + 4.56 \sin \theta + 0.065) \quad \text{(Eq. 3.6)}$$

Where;

X is slope length (m)

θ is the angle of slope in degrees

m is a constant dependent on the value of the slope gradient: 0.50 if the slope angle is greater than 2.86 degrees, 0.40 with a slope of 1.72 to 2.85 degrees, 0.30 with a slope of 0.57 to 1.72 degrees, and 0.20 on slopes less than 0.57 degrees. However, the LS factor was calculated from DEM and using the equation 3.6. The DEM was modified by filling the sinks in the grid. Flow direction was derived from the filled grid and flow accumulation was calculated from the flow direction. The flow accumulation command recognizes that how much surface flow accumulates in each cell; cells with high accumulation values are usually streamed or river channels and identify the local topographic feature such as mountain peaks and ridgelines. The raster calculator function under Spatial Analyst tool was used to input the modified equation 3.8. The LS factor values between 0 to 176 as shown in Fig. 3.6.

X = (Flow accumulation × resolution), by substituting X value, LS factor will be:

LS = Power ([flow accumulation × resolution÷22.1, 0.4]) × {65.4 × Pow (Sin [slope of DEM×0.01745, 2]) + 4.56 × (Sin [slope of DEM×0.01745]) + 0.065} (Eq. 3.8)

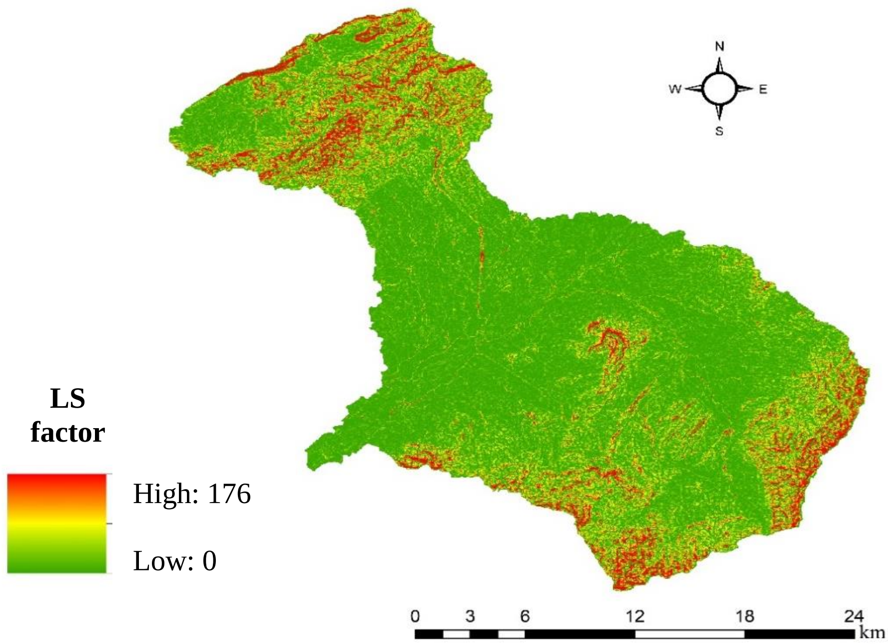

Fig. 3.6 LS factor map of Gardez Basin

3.3.4 Crop management factor (C)

Crop management factor (C factor) is the ratio of soil loss of a specific crop to the soil loss under the condition of continuous fallow (Renard et al., 1997). It measures the effect of canopy and ground cover on the hydraulics of raindrop impact and runoff. C-factor is a relation between erosion on bare soil and erosion observed under a cropping system. It varies from 1 on bare soil to 1/1000 under dense forest, 1/100 under grasslands and plants and 1 to 4/10 under root and tuber crops (Morgan, 2005). Based on the national land cover map published by FAO-UN, 2016, the land-cover classification of the Gardez Basin has 11 classes. Therefore, C factor was assigned to each land use type from the literature reviewed (Table 3.5). The C factor layer was finally obtained by adding the C values to the attribute table of the land use map is shown Fig. 3.7.

Table 3.5 Crop management factor of Gardez Basin

No	LULC	Area (ha)	Area (%)	C factor
1	Rangeland	28,529	59.3	0.15
2	Irrigated agriculture land	11806	24.5	0.31
3	Rangeland/barren land	3,731	7.8	0.30
4	Built-up	1,687	3.5	0.20
5	Forest and shrubs	1,045	2.2	0.01
6	Water bodies and marshland	427	0.9	0.00
7	Rainfed agriculture land	409	0.8	0.20
8	Fruit trees	273	0.6	0.05
9	Barren land/rangeland	191	0.4	0.80
10	Vineyards	4	0.0	0.50
11	Barren land	2	0.0	1.00
	Total	48,104	100	

LULC is land use or land cover, ha is hectare

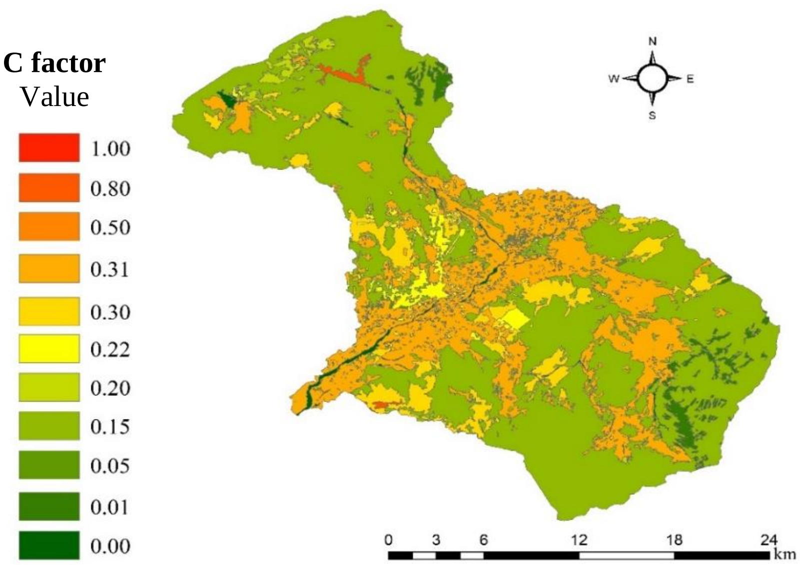

Fig. 3.7 C factor map of Gardez Basin

3.3.5 Conservation practice factor (P)

Conservation practices factor (P-factor) in USLE model expresses the effect of conservation practices that reduce the amount and rate of water runoff, which decrease erosion. It is the ratio of soil loss with the specific support practice of corresponding soil loss with upslope and downslope parallel tillage (Renard et al., 1997 and Wischmeier and Smith, 1978). Currently, there are no support practices in the study area, hence P is assigned value of 1 in the calculation.

3.4 Estimated soil loss (A-factor)

The data layers (maps) extracted for R, K, LS and C factors from the USLE model were multiplied within the raster calculator of ArcGIS spatial analysts in order, to generate the map of soil loss for the Gardez Basin. The final map presents the annual soil loss per hectare per year a pixel level. The soil loss values were estimated in the Gardez Basin range from 0 to > 100 t ha^{-1} yr^{-1} (Fig. 3.8).

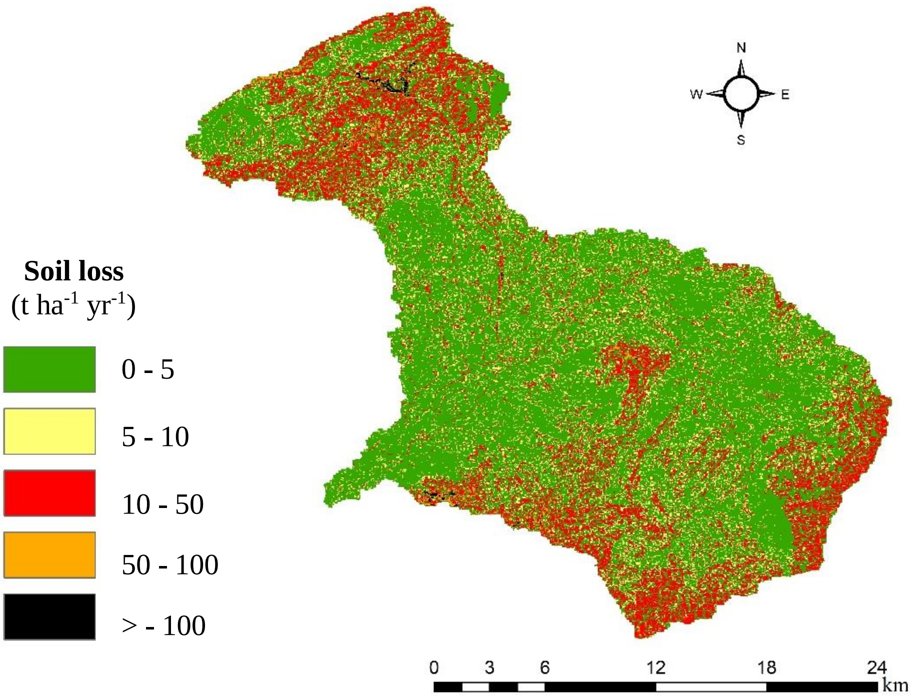

Fig. 3.8 Soil loss map of Gardez Basin

The annual soil loss map obtained was classified into five (5) classes. The results presented in Table 3.6 showed that about 64.3% of the study area is classified as slight erosion risk (0 - 5 t ha^{-1} yr^{-1}), 13.9% of the area is classified as moderate soil erosion risk (5 - 10 t ha^{-1} yr^{-1}), 19.8% of the area is classified as high soil erosion risk (10 - 10 t ha^{-1} yr^{-1}), 1.8% of the area is classified as severe soil erosion risk (50 - 100 t ha^{-1} yr^{-1}) and 0.2% of the area is classified as very severe soil erosion risk (greater than 100 t ha^{-1} yr^{-1}). The higher soil loss is due to high slope steepness, very poor vegetation and no conservation practices, which are the most prominent causes of soil erosion, severe and very severe soil erosion risk classes mainly located in the mountains/foothills.

Table 3.6 Annual soil loss rate and risk categories

No	Soil loss (t ha^{-1} yr^{-1})	Risk categories	Area (ha)	Area (%)
1	0 - 5	Slight	30,934	64.3
2	5 - 10	Moderate	6,713	13.9
3	10 - 50	High	9,503	19.8
4	50 - 100	Severe	847	1.8
5	> 100	Very severe	107	0.2
		Total	48,104	100

Risk categories assigned by Morgan et al., 2004

Table 3.7 Dominate land use/land cover in different mean annual soil loss rate

No	LULC	Area (ha)	Area (%)	Mean soil erosion (t ha^{-1} yr^{-1})
1	Rangeland	28,529	59.3	7.2
2	Irrigated agriculture land	11,806	24.5	3.5
3	Rangeland/barren land	3,731	7.8	11.3
4	Built-up	1,687	3.5	2.7
5	Forest and shrubs	1,045	2.2	2.2
6	Water bodies and marshland	427	0.9	2.8
7	Rainfed agriculture land	409	0.8	6.4
8	Fruit trees	273	0.6	2.3
9	Barren land/rangeland	191	0.4	74.8
10	Vineyards	4	0.0	2.9
11	Barren land	2	0.0	11.6

LULC is land use or land cover
ha is hectare

The land use map of the country was developed by FAO-UN (1993) and subsequently updated in 2016 (FAO-UN). Land use classification map of Gardez Basin consists of 11 classes (Fig. 3.9) including irrigated agricultural land, rain-fed agricultural land, rangeland, rangeland/barren land, barren land, barren land/rangeland, forest, and shrubs, fruit trees, vineyards, built-up and water bodies and marshland.

Rangeland is the most scattered land covering over 59.3% of the total area, irrigated agricultural land covers 24.5%, rangeland/barren land covers 7.8, built-up areas cover 3.5% and forest and shrubs cover 2.2% of the Gardez Basin (Table 3.7).

In order to identify average soil erosion rates on different land use classes of Gardez Basin, land use/land cover map of the study area was intersected with classified soil erosion map. Table 3.6 showed that high levels of soil erosion classes were found on the fallow land, barren land/rangeland, barren land, rangeland/barren land, rangeland and rain-fed agricultural land. The annual average soil erosion was lower in the forest/shrubs and fruit trees. Moreover, slight, moderate, high, severe and very severe soil loss area was estimated based on the land use map is 30,933, 6,713, 9,503, 847 and 107 hectares, respectively (Table 3.8). In addition, it irrigated, and the rain-fed agricultural land area was about 12,215 hectares of the total area. Those are the most parts soil losses occur in slight to high soil loss categories.

Since most of the agricultural lands were slight to high soil loss classes, immediate attention to soil conservation practices is required. To suggest site-specific sustainable land-use practices for controlling slight to high soil erosion risks, this result allows assessment of soil loss quantitatively, identified the risk zones and draws an appropriate planning measure for implementing optimal land use management practices.

Table 3.8 Risk categories of Gardez Basin area (ha) based on land use

Risk categories	Slight	Moderate	High	Severe	Very severe	Total
LULC	0-5 (t ha^{-1} yr^{-1})	5-10 (t ha^{-1} yr^{-1})	10-50 (t ha^{-1} yr^{-1})	50-100 (t ha^{-1} yr^{-1})	> 100 (t ha^{-1} yr^{-1})	
Rangeland	16,804.8	3,920.7	7,215.3	570.6	17.7	28,529
Rangeland/ barren land	2,089.4	511.2	893.2	210.8	26.5	3,731
Forest and shrubs	909.2	46.3	89.4	0.2	0.0	1,045
Built-up	1,365.0	215.9	102.1	2.4	0.7	1,687
Irrigated agriculture land	8,813.2	1,888.0	1,074.4	27.2	2.4	11,806
Water bodies and marshland	384.0	35.5	7.0	0.3	0.2	427
Fruit trees	259.0	12.0	0.79	0.22	0.00	273
Vineyards	3.8	0.2	0.0	0.0	0.0	4
Rainfed agriculture land	252.6	74.1	77.1	5.2	0.0	409
Barren land	0.0	0.0	2.0	0.0	0.0	2
Barren land/rangeland	52.1	7.5	41.9	30.1	59.4	191
Total	**30,934**	**6,713**	**9,503**	**847**	**107**	**48,104**

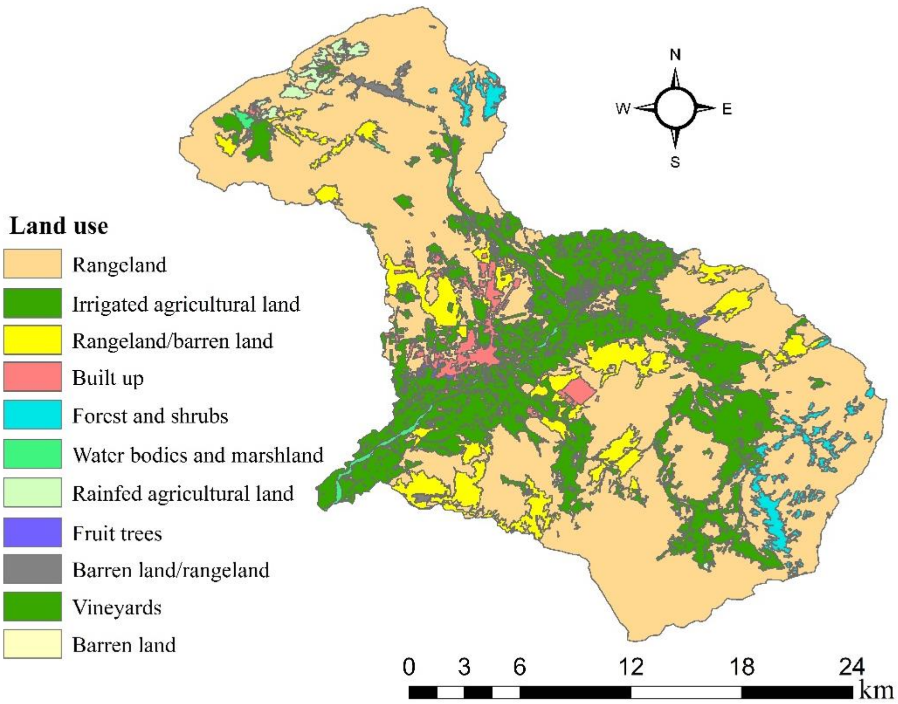

Fig. 3.9 Land use map of Gardez Basin

3.5 Calibration of USLE model in study area

3.5.1 Erosion pins method experiment

An erosion pins method was conducted to quantify and change the land surface. They may be used for short and long-term surveys and are quick and easy to install and measure. Erosion pins were particularly suited to bare, undisturbed environments such as badlands and sand dunes **(**Boardman and Mortlock, 2016). The erosion pins were a simple, robust and relatively cheap approach to the small-scale measurement of erosion rates. Results from pin's measurement may be correlated with other measurements, this measurement assumed of land surface change such as rainfall.

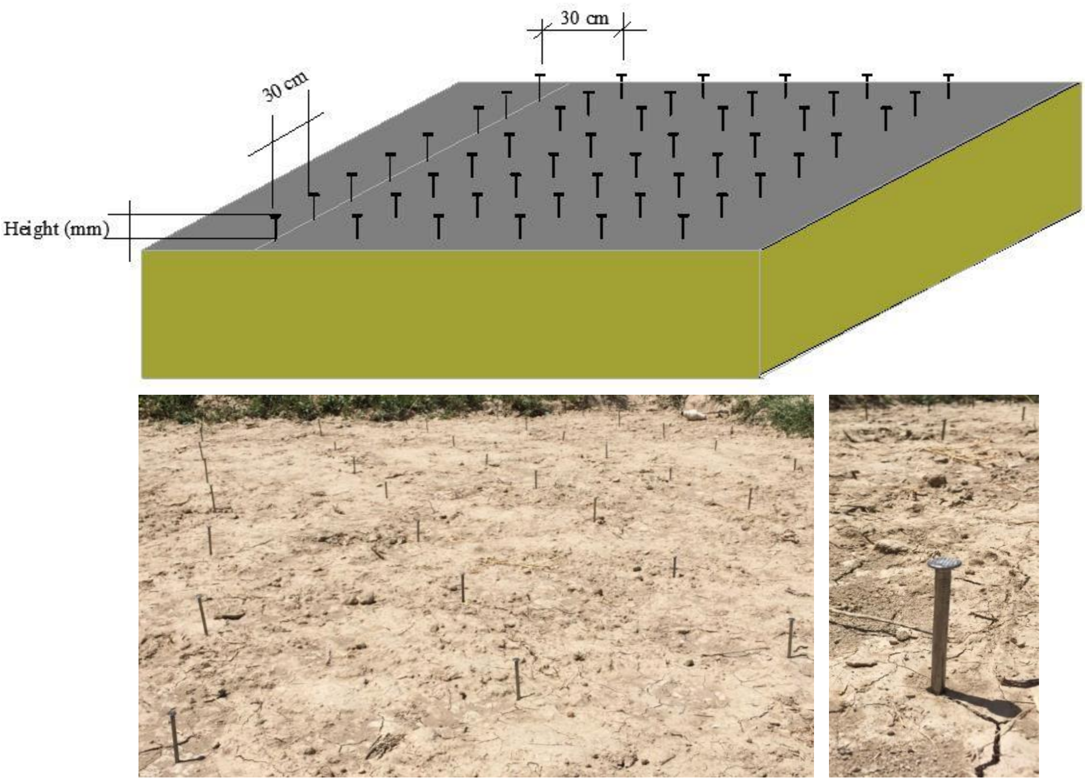

Fig. 3.10 Diagram of erosion pin method in study area

Erosion pins have been used to measure changes in surface land or geomorphology. Therefore, 48 erosion pins were installed, in the study area in undisturbed soil, the distances between pins were fixed to 30 cm, which covered 3.15 m^2 area (Fig. 3.10). The distance from the ground surface level to the top of the pins was measured before rainfall event and after the rainfall event in 73 days (Table 4.9)

Table 3.9 Measurement of distance from the ground surface to top of pin

Measurement distance from the ground surface level to the top of the pins (mm) during the installation time (2017/05/02)						Measurement distance from the ground surface level to the top of the pins (mm) after rainfall event (2017/07/13)					
44	53	63	62	66	42	41	49	65	59	63	41
40	64	41	57	74	53	44	51	41	57	77	54
50	61	70	50	70	52	54	59	70	51	69	54
43	39	55	49	77	50	45	34	53	54	81	50
38	50	32	53	76	65	39	47	39	56	75	69
60	41	40	35	66	60	63	46	41	33	65	57
72	66	65	70	56	70	74	63	66	76	54	73
92	85	80	87	86	101	90	81	77	90	89	104

3.5.2 Results of erosion pins experiment

The difference in pin height before and after rainfall, events were recorded. Meanwhile, rainfall data was recorded by an automatic rain gauge. The rainfall data were calculated for erosivity based on USLE method and equations 3.1 and 3.1. Total 9 events of rainfall were falling, but the rainfall event less than 12.7 mm of the amount was excluded in the R factor calculation based on USLE method. Only one rainfall event was recorded during 73 days with 14.6 mm accumulative rains, maximum intensity 13.33 mm h^{-1} and total rainfall erosivity 80.37 MJ mm ha^{-1} h^{-1} yr^{-1} (Table 3.10).

Most arithmetic means of measured changes in pin height exposure was used to quantify net erosion or net deposition at a site (Hancock and Lowry, 2015). The results of the erosion pin experiment, changes in pin exposure positive values for increased exposure and negative values for decreased exposure (negative for erosion and positive for deposition) are assumed for all pins, average of height of four erosion pins multiplied by area and dry density of soil results, soil loss t ha^{-1} yr^{-1}. However, based on equation 3.9 The results of the calibration indicated that the observed soil losses with the erosion pin method in the field showed certain agreements with the calculated soil losses based on the USLE model in this study (Fig 3.11).

$$\frac{\mathbf{R}}{\mathbf{r}} = \frac{\mathbf{A}}{\mathbf{a}} \qquad \text{(Eq. 3.9)}$$

Where;

R is rainfall erosivity for one year based on the USLE method (187.50 MJ mm ha^{-1} h^{-1} yr^{-1}).

r is rainfall erosivity for 73 days based on observed data USLE method (80.37 MJ mm ha^{-1} h^{-1} yr^{-1}).

A is soil loss by USLE with ArcGIS platform in a specific area which installed erosion pins (50 t ha^{-1} yr^{-1}).

a is observed soil loss by erosion pin method (t ha^{-1} yr^{-1})

Table 3.10 Calculation of the erosivity factor

Event rainfall (mm)	Max. intensity (mm h^{-1})	Total energy (J m^{-2})	Rainfall erosivity (MJ m km^{-2} h^{-1} yr^{-1})	R value (MJ mm ha^{-1} h^{-1} yr^{-1})
0.6	0.3882	4.9166	0.0019	0.0191
0.2	0.1311	0.8396	0.0001	0.0011
0.6	0.7216	5.9362	0.0043	0.0428
0.4	0.4032	3.0534	0.0012	0.0123
0.6	6.3830	7.3870	0.0472	0.4715
4	1.2422	34.1828	0.0425	0.4246
5.4	7.1856	46.6448	0.3352	3.3517
1	1.2876	11.6567	0.0150	0.1501
14.6	13.3333	602.8033	8.0374	80.3738

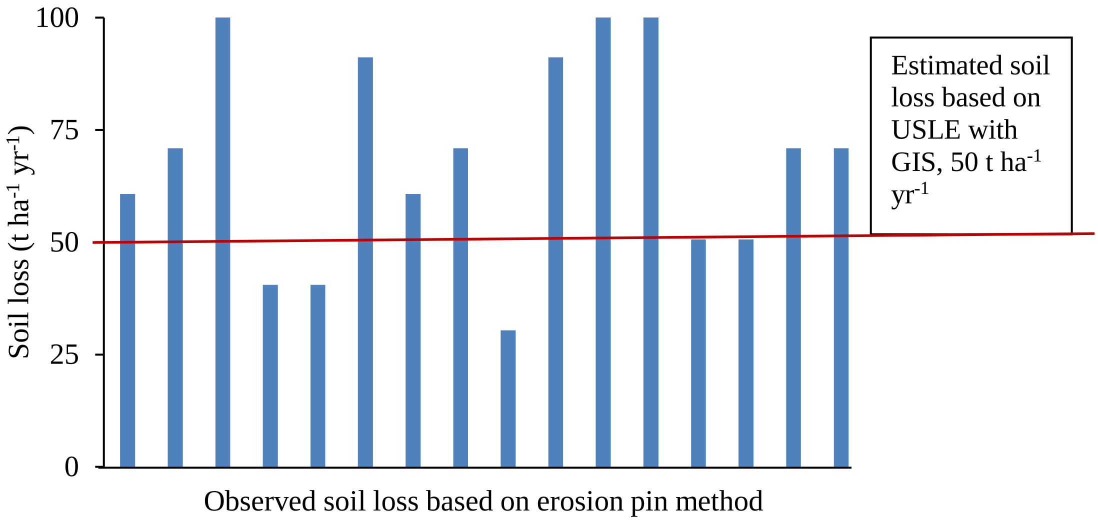

Fig. 3.11 Compared observed soil loss based on erosion pin method and estimated soil loss with USLE and GIS

3.6 Conclusions of this chapter

The present study indicates that using GIS technologies for soil loss mapping, based on the USLE model provided satisfactory results. Different components of USLE model were used with mathematical equations. The rainfall erosivity R-factor was calculated, using USLE method (rainfall in mm, the intensity in mm h^{-1}, and maximum 30-minute intensity in mm h^{-1}). The calculated value of a daily automatic rain gauge is 217.5 MJ mm ha^{-1} h^{-1} yr^{-1} and the R-factor calculated based on the annual rainfall amount using various equations, range between 157.6 to 199.7 MJ mm ha^{-1} h^{-1} yr^{-1}. However, the best fit was achieved between the R-value of USLE method and annual rainfall in Gardez Basin. Soil erodibility factor (K) obtained from a soil classified map range between 0.038 to 0.063 t ha h ha^{-1} MJ^{-1} mm^{-1}. Slope length and slope steepness factor (LS) values obtained from DEM range between 0 to 1756. Crop management factor (C) values were obtained from land cover classified map range between 0 to 1.

The final map represents the annual soil loss t ha^{-1} yr^{-1} a pixel level. The soil loss values estimated for Gardez Basin ranges from 0 and greater than 100 t ha^{-1} yr^{-1}, and classified into five (5) classes which, showed that about 64.3% of the study area is a slight erosion risk (0 - 5 t ha^{-1} yr^{-1}). 13.9% of the area is moderate soil erosion risk (5 - 10 t ha^{-1} yr^{-1}). 19.8% of the area is at high soil erosion risk (10 - 50 t ha^{-1} yr^{-1}), 1.8% of the area is classified as severe soil erosion risk (50 - 100 t ha^{-1} yr^{-1}) and 0.2% of the area is classified as very severe soil erosion risk (greater than 100 t ha^{-1} yr^{-1}).

Most of the agricultural lands are classified as slight to high soil loss categories. However, high soil erosion is found in the barren land, rangeland and rain-fed agricultural land. The soil erosion risk is extremely high on the steep slope and mountains/foothills. The land use map of the study area was prepared, and the average annual soil loss for different land use will be highly useful in recognizing the priority areas for application of land use practices and soil conservation measures in Gardez Basin. The rain-fed and irrigated agricultural lands require immediate attention to soil conservation practices. Based on the results of this study, the estimated soil loss and proposed land use map could be an effective input for the future planning and implementing soil conservation strategy in the eastern part of Afghanistan.

On the other hand, the USLE model was calibrated by the erosion pin method. The results of the calibration indicated that the observed soil losses with the erosion pin method in the field showed certain agreements with the calculated soil losses based on the USLE model and GIS in this study.

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Chapter 4--

Conservation strategy by crop management and gypsum mineral application in Dawlatzai Village, Gardez District

4.1 Objectives of this chapter

The objective of this research is to evaluate the effectiveness of crop management and gypsum application to reduce sediment concentration in runoff and total soil loss in the Dawlatzai Village of Gardez District, Paktya Province, Afghanistan.

4.2 Materials and methods

4.2.1 Soil samples

Soil samples were collected from various fields; wheat field, maize field, alfalfa field, orchard, uncultivated land and Chashma-maran research farm of Gardez District, Paktya Province (Fig. 4.1). Soil samples were analysed in the Laboratory of Land and Water Use Engineering, Tokyo University of Agriculture for chemical and physical properties of soil the results were summarized in Table 4.1 and Table 4.2. Soil textures were classified based on the International Union of Soil Science (IUSS). Farmlands, Chashma-maran farm and orchards' soil had loamy soil textures and uncultivated land's soil had sandy loam soil texture (Table 4.3).

Fig. 4.1 Soil samples were collected from different agricultural fields

Meanwhile, soil samples were determined for Sodium Adsorption Ratio (SAR). Thereby, soil solution was extracted by high-speed centrifuge then analysed for calcium, magnesium and sodium contents, SAR was calculated by equation 4.1 the SAR ranges for farmlands 1.8, for the governmental farm 3.6, for Orchard 1.4 and for uncultivated lands 3.0 (Fig. 4.2).

Table 4.1 Chemical properties of soil

Soil	pH	Ca (mg/kg)	Mg (mg/kg)	Na (mg/kg)	EC (mS/cm)	N (mg/kg)	P (mg/kg)	OC (%)
Farmlands	8.4	7.5	0.6	225.0	0.3	630.4	549.0	5.4
Chashma-maran farm	8.4	9.3	0.7	167.0	0.3	434.7	495.2	6.2
Orchards	8.2	9.0	0.8	160.7	0.3	900.7	516.2	5.8
Uncultivated lands	8.6	4.1	0.3	70.3	0.2	383.6	288.3	3.8

Ca calcium, Mg magnesium, Na sodium, EC electrical conductivity, N nitrogen, P phosphorus and OC is organic carbon

Table 4.2 Physical properties of soil

Soil	WC (%)	SG	Wd (mg/cm^3)	Dd (mg/cm^3)	P (%)	SP (%)	LP (%)	GP (%)
Farmlands	13.1	2.7	1.7	1.5	44.8	55.2	19.3	25.5
Chashma-maran farm	15.9	2.7	1.7	1.5	45.0	55.0	23.7	21.3
Orchards	21.5	2.7	1.8	1.5	45.7	54.3	31.6	14.0
Uncultivated lands	2.3	2.7	1.6	1.6	40.7	59.3	3.7	37.0

WC water content, SG specific gravity, Wd wet density, Dd dry density, P porosity, SP solid phase, LP liquid phase and GP gas phase

Table 4.3 Soil texture classification (IUSS)

Soil	Particle size distribution %					Soil texture
	Gravel	Coarse sand	Fine sand	Silt	Clay	
Farmlands	0.2	7.1	30.2	40.2	22.3	Loam
Chashma-maran farm	1.6	5.5	31.3	35.9	25.7	Loam
Orchards	0.2	4.0	29.7	39.7	26.4	Loam
Uncultivated lands	0.5	12.2	55.1	20.9	11.3	Sandy loam

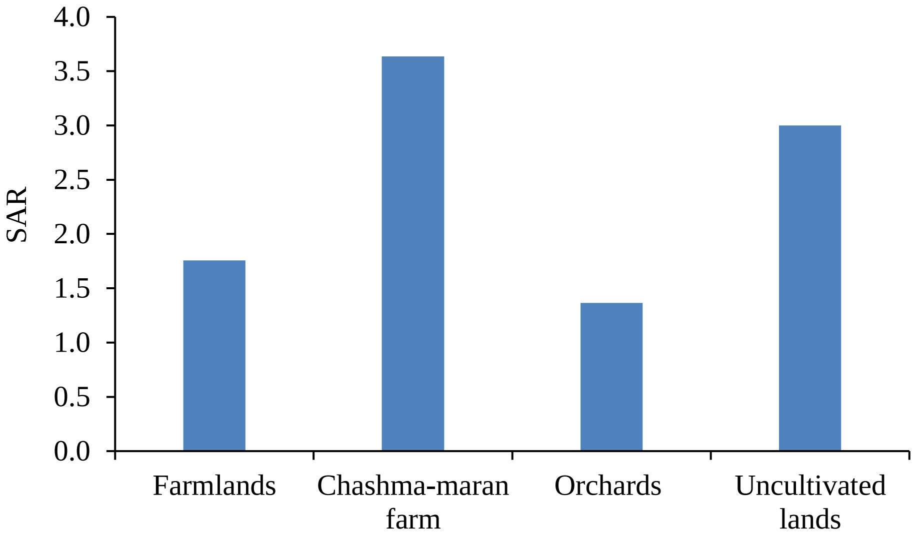


Fig. 4.2 Sodium adsorption ratio (SAR) extracted soil water

4.2.2 Field experiment

A field experiment was conducted in the Dawlatzai Village in Gardez District, Paktya Province (Fig. 4.3). It evaluates the effectiveness of crop management and gypsum application in agricultural lands to reduce sediment concentration in runoff and total soil loss of loamy and sandy loam soil textures. Four erosion plots were designed the length was 1.1 m and width 0.2 m. Two replications were applied as gypsum-treated field, clover field, maize field and control field (Fig. 4.4 and Table 4.4).

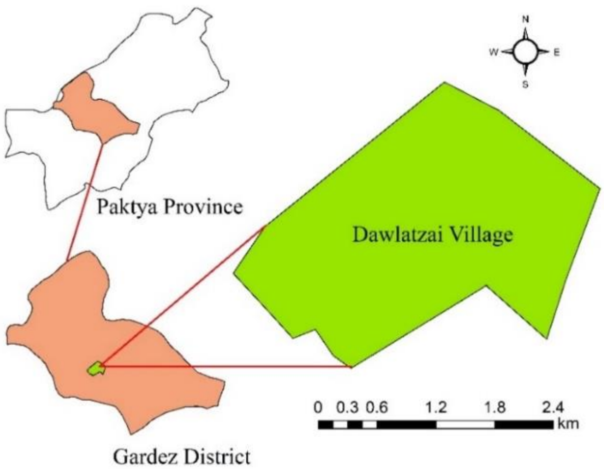


Fig. 4.3 Dawlatzai Village in Gardez District, Paktya Province

Gypsum mineral was applied over the surface at the rate of 5 t ha^{-1}. Runoff collector was installed on the downstream side, depending on the direction of sloppy field. The soil was pre-wetted for 24 hours before the application of rainfall using a portable rainfall simulator.

Fig. 4.4 Field experiment was conducted in various fields

Table 4.4 List of treatments and application rate of gypsum

Material	Treatment	Application rate of gypsum (t ha^{-1})	Replication
Soil	Gypsum	5	2
	Clover	0	2
	Maize	0	2
	Control	0	2

A portable rainfall simulator was simply made and designed, it can be used and applied laboratory experiment and field experiment scales, the intensities approximate such as natural rainfall, raindrop sizes about 3.42 mm and kinetic energy of approximately 1.6×10^{-5} J, which was distributed uniformly along all the 24 needles and Marriotte bottle generated constant pressure of about 981 Pa (Maore and Mihara, 2017). Surface runoff was collected at an interval of 5 minutes for a duration of 30 minutes (Fig. 4.5). Surface runoff water was analysed in the laboratory for chemical and physical properties.

Fig. 4.5 Portable rainfall simulator and surface runoff collection

4.2.3 Laboratory experiment (surface runoff)

The surface runoff experiment was conducted in the Laboratory of Land and Water Use Engineering using a triangular erosion plot. The length was 91.0 cm, and width 3.0 cm and height 2.5 cm, respectively. The slope of a plot was arranged at 8.0 degrees (Fig. 4.6). Using sandy loam and loamy soil textures and soil sample were analysed for particle size distribution, specific gravity and permeability as shown in Table 4.5.

Soils were compacted under a dry density of 1.61 g/cm^3 and 1.47 g/cm^3 for sandy loam and loamy soil textures, respectively. Marriotte bottle with constant pressure was used to supply water. Surface runoff water and percolation water were collected at 5 minutes interval and experiments were run for 30 minutes. Two treatments were applied with three replications; control and gypsum-treated and gypsum mineral was applied at the rate of 5 t ha^{-1}. The soil was saturated for 24 hours before the experiment was conducted. The surface runoff water was analysed for calcium, magnesium, sodium, and soil loss.

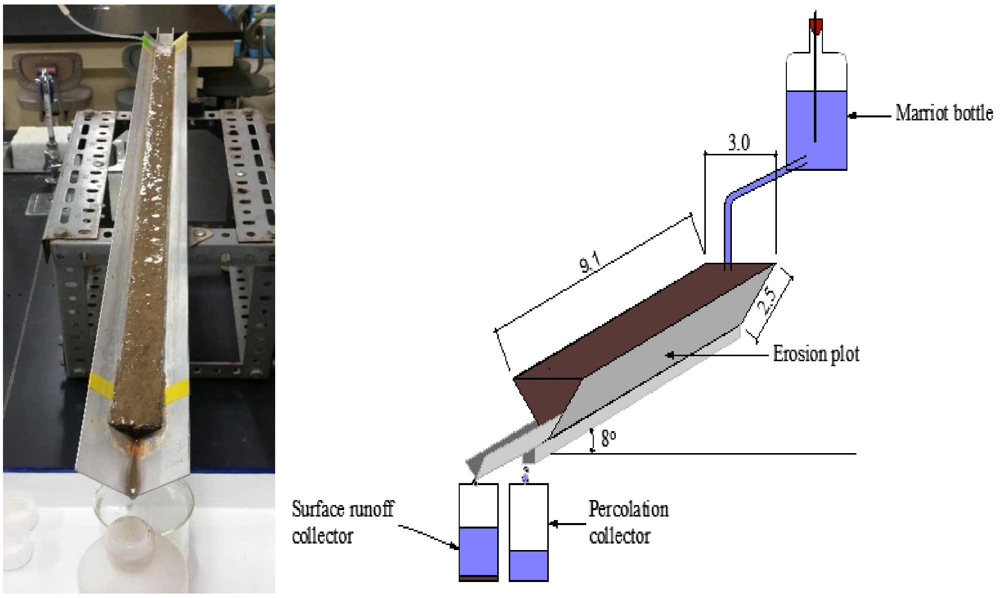


Fig. 4.6 Diagram of surface runoff experiment

Table 4.5 Physical properties of soil using for surface runoff experiments

Soil particle size distribution	Plot 1	Plot 2
Sampled location	Dawlatzai Village, Paktya Province	Dawlatzai Village, Paktya Province
Specific gravity	2.7	2.7
Gravel (%)	0.5	0.7
Coarse sand (%)	12.2	5.5
Find sand (%)	55.1	30.4
Slit (%)	20.9	38.6
Clay (%)	11.3	24.8
IUSS classification	Sandy loam	Loamy
Permeability (10^{-5} cm/sec)	19.3	3.4

4.3 Results and discussion of field experiment

4.3.1 Surface runoff

Gypsum mineral has used for amending and controlling crust formation of the soil surface, that enhancing water infiltration rate (Agassi et al., 1981 and Miller, 1987). However, the results of a field experiment showed, the total surface runoff water for all treatments' gypsum treated field, clover field, maize field and control field as by 3.40 L, 3.06 L, 4.01 L and 4.23 L, respectively (Table 4.6).

Table 4.6 Changes in surface runoff volume in each treatment

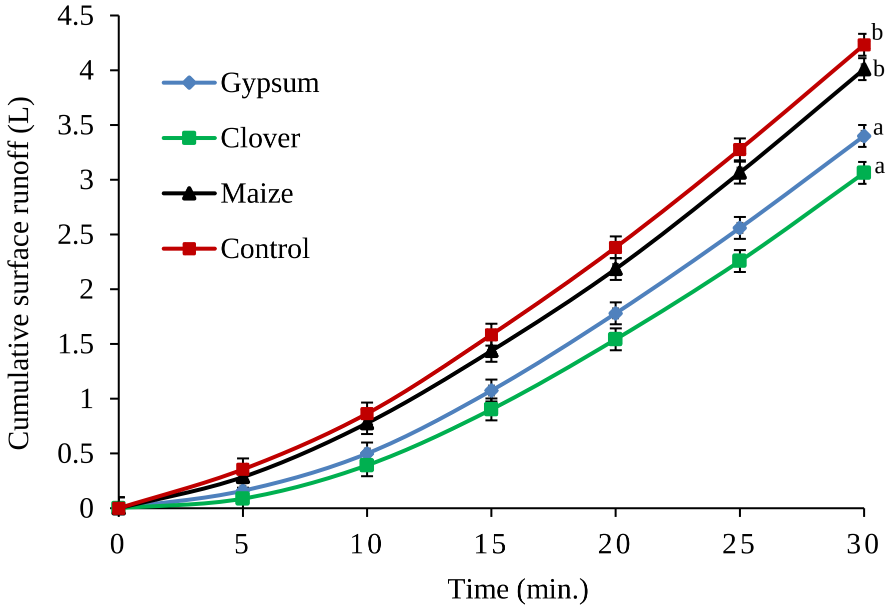
Time (min.)	5	10	15	20	25	30	Total surface runoff (liter)
Gypsum	0.16	0.34	0.58	0.71	0.78	0.84	3.40[b*]
Clover	0.09	0.31	0.51	0.64	0.72	0.81	3.06[b*]
Maize	0.29	0.49	0.66	0.75	0.90	0.88	4.01[a*]
Control	0.36	0.51	0.72	0.80	0.90	0.96	4.23[a*]

Table 4.7 Statistical analysis (ANOVA) surface runoff of field experiments

Source of variation	Degrees of freedom	Sum of squares	Mean sum of squares	F calculated	F probability
Treatments	3	1.655	0.551	20.674	0.007
Error	4	0.104	0.026	-	-
Total	7	-	-	-	-

Treatment No.	Gypsum	Clover	Maize	Control
Treatment Average	3.40	3.06	4.01	4.23
Critical Difference (CD) at p<0 .05 compared	b	b	a	a

Statistical analysis showed that gypsum treated and clover fields significant difference ($p<0.05$) when compared with control and maize fields as shown in Table 4.7. Gypsum mineral providing a high concentration of calcium, which increases ionic strength and electrolyte into the soil solution. That leads to increase permeability by shrinking double layer and allow water through into the soil profile. The results showed that reduction in surface runoff by 19.6% was observed compared to control. The surface runoff water was changed with times for gypsum-treated, clover, maize and control fields as shown in Fig. 4.7.



*Significant difference at p<0 .05

Fig. 4.7 Changes in surface runoff in each field with time

4.3.2 Soil loss

The results of field experiments showed that the gypsum-treated, clover and maize fields reduced the total soil loss by 67.3%, 92.0% and 54.5% compared to control. Likewise, specific loads generated under different treatments; gypsum-treated, clover, maize and control fields were 4.11×10^6 g ha^{-1}, 1.00×10^6 g ha^{-1}, 5.72×10^6 g ha^{-1} and 12.56×10^6 g ha^{-1}, respectively (Table 4.8). Statistical analysis showed that gypsum treated and clover fields soil loss significant difference ($p<0.05$) when compared with control and maize fields soil loss as shown in Table 4.9.

In addition, Fig. 4.7 indicated the sediment concentration was more in the early stage (5 to 10 minutes) for all treatments and decreased with time until it reached a steady state condition. Thus, an increase of sediment concentration in the early stage was because of the fine particles in the eroded sediment, and it generated from the breakdown of aggregates from the soil.

Mahardhika et al. (2008) reported that they applied gypsum mineral at a rate of 10 t ha^{-1}, polyacrylamide 40 kg ha^{-1} and combined application of both amendments (polyacrylamide + gypsum) at the same rates. Total soil loss was reduced by 39%, 43% and 74%, compared to the control. The application of polyacrylamide + gypsum more significantly was reduced soil to compare with other treatments. The application of gypsum mineral was effective in considerably reducing total soil loss from agricultural land.

Table 4.8 Specific loads of soils in each field

Field	Soil loss (mg/L)	Q (L)	Specific load (g ha^{-1})	Total soil loss decreased from control (%)
Gypsum	26,460	3.40	4.11×10^6	67.3
Clover	7,250	3.06	1.00×10^6	92.0
Maize	31,410	4.01	5.72×10^6	54.5
Control	65,760	4.23	12.56×10^6	

L = liter, Q = discharge, g = gram and ha = hectare

Table 4.9 Statistical analysis (ANOVA) of soil loss from field experiment

Source of variation	Degrees of freedom	Sum of squares	Mean sum of squares	F calculated	F probability
Treatments	3	143.21	47.74	7.67	0.039
Error	4	24.89	6.30	-	-
Total	7	-	-	-	-

Treatment No.	Gypsum	Clover	Maize	Control
Treatment Average	4.11	1.00	5.72	12.56
Critical Difference (CD) at p<0 .05 compared	b	b	a	a

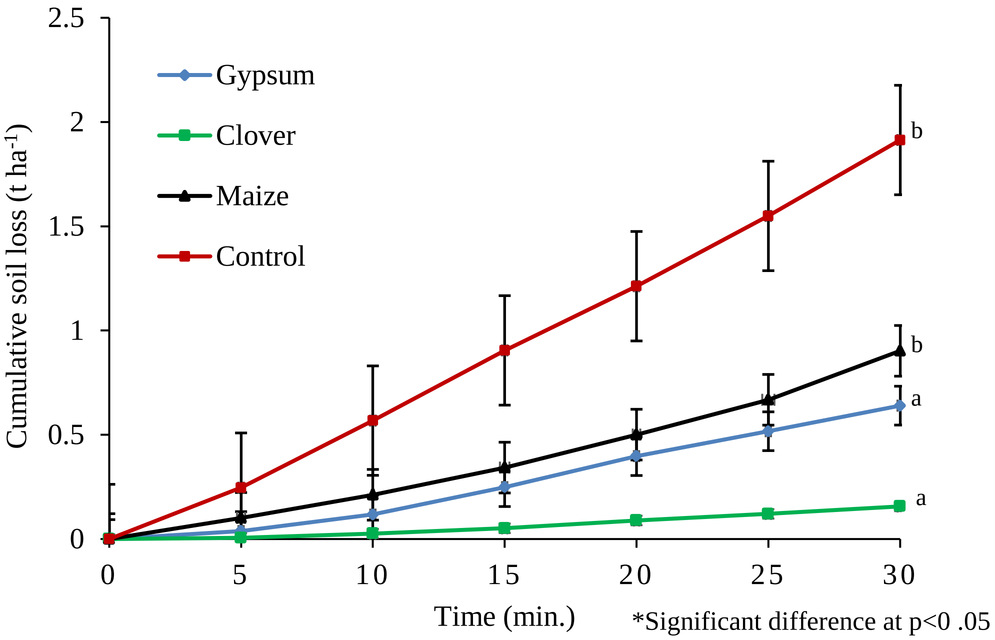


Fig. 4.8 Changes the sedimentation in surface runoff with time of each field

4.3.3 Crop management as soil conservation

During the experiments, it was observed that soil left bare (uncultivated) that more susceptible to erosion because of raindrops or wind in warmer climates. However, a portable rainfall simulator was applied in the arable land; clover field, maize field and bare soil. The results showed that soil loss from clover field 1.0 t ha^{-1}, maize field 5.7 t ha^{-1} and the bare soil 12.6 t ha^{-1} as shown in Fig. 4.9. In addition, that the greatest intensities of soil loss were achieved by the bare soil without vegetation and clover the lowest soil loss was achieved. The clover plant belongs to the legume plant family like other legumes it fixes nitrogen in the soil, which vigorously increasing the nutrient levels in the agricultural land. The Preventing soil erosion with cultivating crops is a common farming practice in agricultural lands but crop cultivation is not available during the period of insufficient irrigation water in the Dawlatzi Village of Gardez District. The dense plant growth and soil improvement that protects the soil against erosion. In the dry region with hot summer rainfall, poor cover plant and low organic matter contribute the soil more vulnerable to erosion. Crop management using as conservation of soil, it is the relatively easy way to conserve soil. Studied by Hlavcova, et al., (2017) based on the modeling soil loss from winter wheat field, maize field and bare soil were 8.93 t ha^{-1} yr^{-1}, 45.41 t ha^{-1} yr^{-1} and 74.45 t ha^{-1} yr^{-1}, the greatest soil loss found in bare soil without any vegetation and agronomic measures based on strip cropping reduced the sediment transport by 50 - 60% compared the row crops.

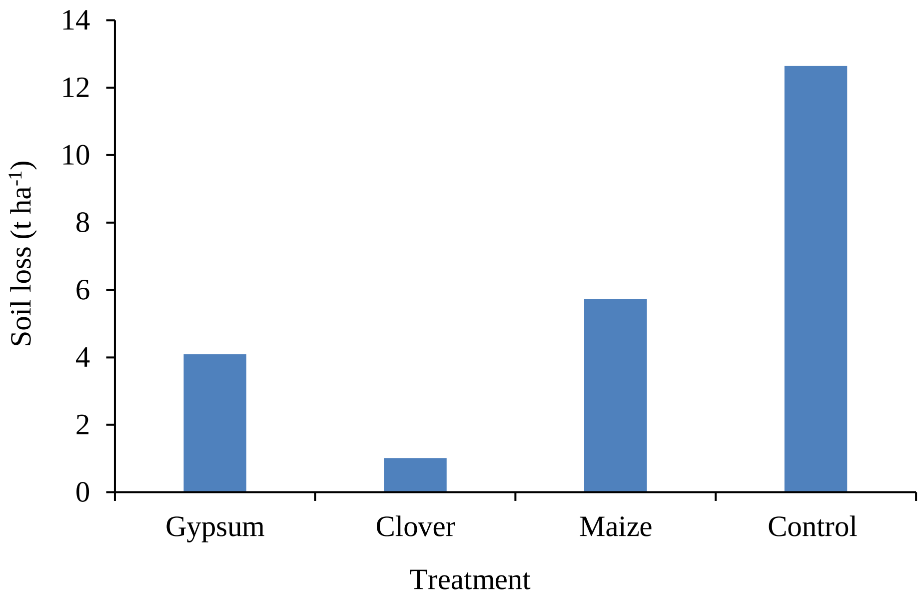


Fig. 4.9 Soil loss from different agricultural field

4.3.4 Cation concentration

Gypsum mineral is an amendment generally in the recent days because it is available, relatively low-cost and has benefits such as a source of calcium and sulphur for the plants, improves acid soils and treats aluminium toxicity, enhance soil structure, increase water infiltration and reduce runoff and erosion (Hopkins, 2013). Gypsum mineral significantly increased the calcium content when compared with other treatments (Fig. 4.10). Calcium is a secondary nutrient it is needed in large amounts by all plants for the formation of cell walls and cell membranes, and it plays a vital role in soil structure.

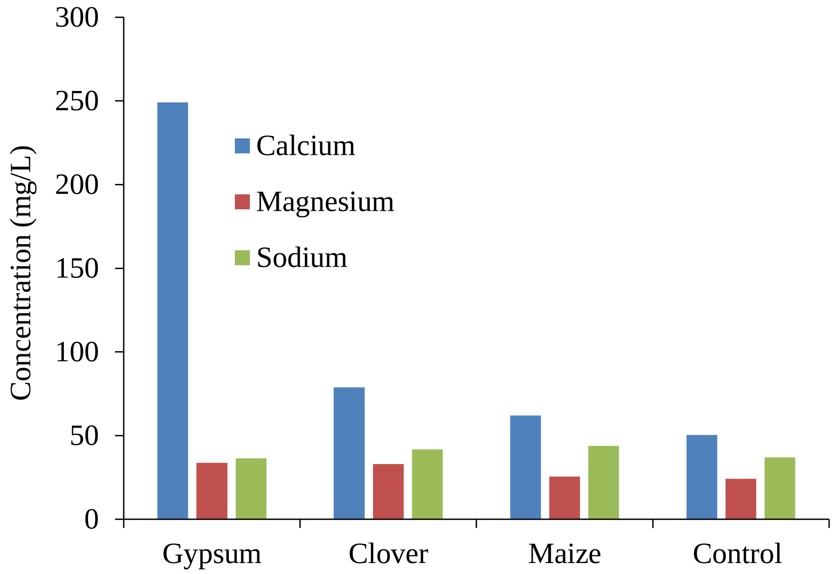


Fig. 4.10 Cation concentration in surface runoff of field experiment

4.3.5 Sodium adsorption ratio (SAR)

Sodium adsorption ratio (SAR) expresses the relationships between sodium content and calcium plus magnesium contents as shown in equation 4.1. This ratio reflects the amounts of sodium adsorbed onto clay and soil organic matter exchange surfaces, hence the potential for flocculation or dispersion processes within the soil (Keren, 1991). These processes influence the hydraulic properties of the soil, runoff and soil erosion (Lavee et al., 1991).

$$\text{SAR} = \frac{[Na^{+}]}{\sqrt{\frac{[Ca^{+2} + Mg^{+2}]}{2}}} \qquad \text{(Eq. 4.1)}$$

Where;

Na^{+}, Ca^{+2} and Mg^{+2} concentrations in milliequivalent per liter (mEq/L) or millimoles per liter (mole/L).

The highest SAR the more likely the soil is to disperse, but SAR decreased soils tend to flocculate. Dispersion soils, water infiltrates and drains slowly the water is run off the soil, increasing the potential for erosion and limiting the amount of water available for crops and also soil be very poorly aerated due to lack of the large pores. Gypsum mineral can decrease clay dispersion thereby improving permeability of the soil and improving the aggregate stability of soil surface. Quickly dissolves gypsum mineral and releases' electrolyte soil solution as the result flocculates and aggregate soil particles. Gypsum releases calcium salt, which replaces the exchangeable sodium and lower tendency of clay to disperse (Shainberg et al., 1989).

Surface runoff was collected at an interval of 5 minutes for a duration of 30 minutes and analysed SAR in the Laboratory. The results showed the gypsum-treated field significantly reduced SAR value compared to other treatments. The SAR value for gypsum-treated, clover, maize and control fields were as by 0.6, 1.0, 1.2 and 1.1, respectively (Fig. 4.11).

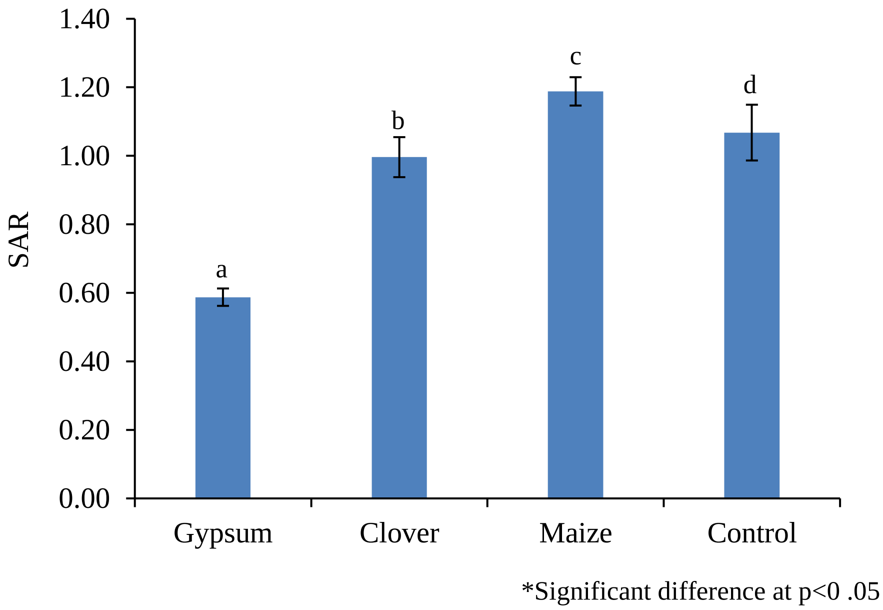


Fig 4.11 Sodium adsorption ratio (SAR) of surface runoff

4.3.6 Electrical conductivity (EC) and pH

The results of field experiment showed, that the application of gypsum mineral was slightly increased EC of soil solution because the gypsum mineral is sparingly soluble salt. However, it was not changed the pH of the soil solution (Table 4.10). Gypsum improves chemical properties of soil such as aluminium toxicity caused by subsoil (Chen and Dick, 2011). It does not neutralize the hydrogen ion in soil solution because of gypsum mineral is a neutral salt and not a liming agent (Fisher, 2011).

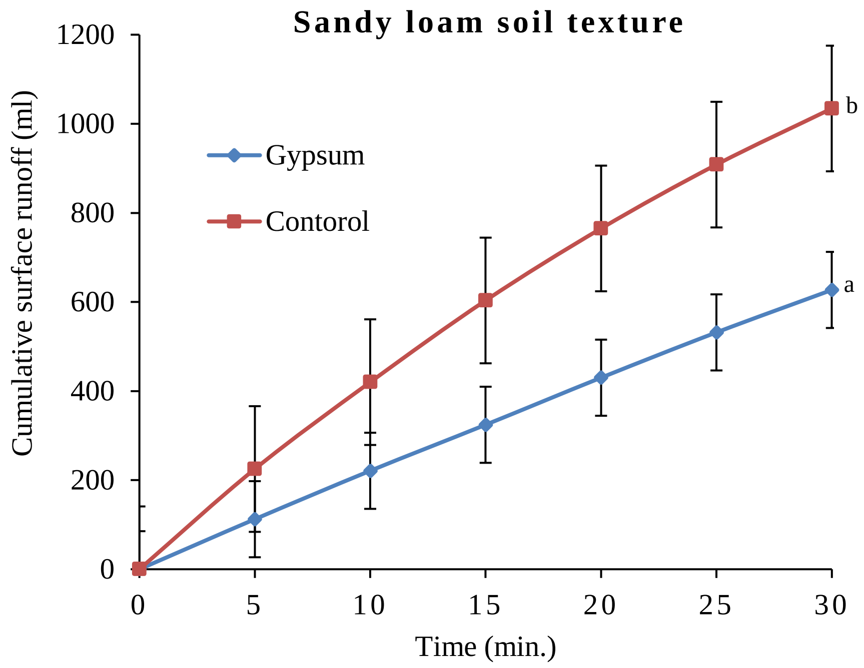
Table 4.10 EC and pH in surface runoff of field experiment

No	Treatment	EC (mS/m)	pH
1	Gypsum	77.9	7.8
2	Clover	67.1	7.9
3	Maize	59.1	8.0
4	Control	55.0	7.8

4.4 Results and discussion of laboratory experiment

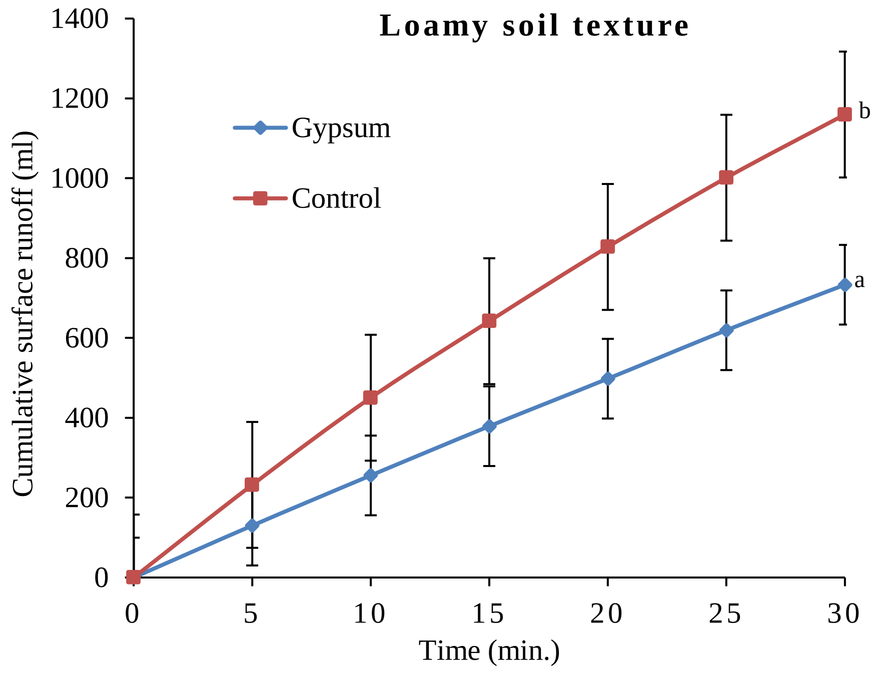
4.4.1 Surface runoff

Surface runoff was collected at an interval of 5 minutes for the duration of 30 minutes from sandy loam and loamy soil textures. Total surface runoff for gypsum-treated plots were 0.63 and 0.73 litres and for control plots; 1.03 and 1.16 litres, respectively. The results showed that the application of gypsum significantly reduced runoff by 38.8% for sandy loam soil texture and 37.0% for loamy soil texture compared to the control (Table 4.11). Statistical analysis showed that gypsum treated plots surface runoff water significant difference ($p<0.05$) when compared with control plots of surface runoff water for both soil textures. In addition, the Fig 4.12 and Fig. 4.13 indicated changed in surface runoff by addition of gypsum with times.



*Significant difference at p<0 .05

Fig. 4.12 Changes in surface runoff by gypsum application with times



*Significant difference at p<0 .05

Fig. 4.13 Changes in surface runoff by gypsum application with times

Table 4.11 Discharge volume and decreasing percentage from the control

Soil texture	Treatment	Total discharge (L)	Total surface decreased from control (%)
Sandy loam soil	Gypsum	0.63	38.8
	Control	1.03	
Loamy soil	Gypsum	0.73	37.0
	Control	1.16	

4.4.2 Percolation

Percolation is the flow of water through soil and porous. Likewise, percolation water was collected at an interval of 5 minutes for a duration of 30 minutes. Total percolation water for gypsum-treated plots were 0.81 and 0.71 litres and for control plots; 0.35 and 0.31 litres, respectively. Gypsum-treated soils the percolation volume was increased by 2.31 times for sandy loam soil texture and 2.29 times for loamy soil texture compared to the control (Table 4.12 and Fig. 4.14). Gypsum-treated plots showed the significant difference ($p<0.05$) when compared to control plots for both soil texture as shown in Fig. 4.15 and 4.16. Reported by Miller, 1987, he was applied by-product phosphogypsum (PG) at the rate of 5 t ha^{-1} on the surface of soil that infiltration rate was significantly higher for all the PG-amended soils and very low for untreated soils therefore, PG maintains a high enough electrolyte level to keep soil clays flocculated thus reducing crusting and soil loss.

Table 4.12 Percolation volume and changing from the control

Soil texture	Treatment	Total percolation (L)	Total percolation changed from control (time)
Sandy loam soil	Gypsum	0.81	2.31
	Control	0.35	
Loamy soil	Gypsum	0.71	2.29
	Control	0.31	

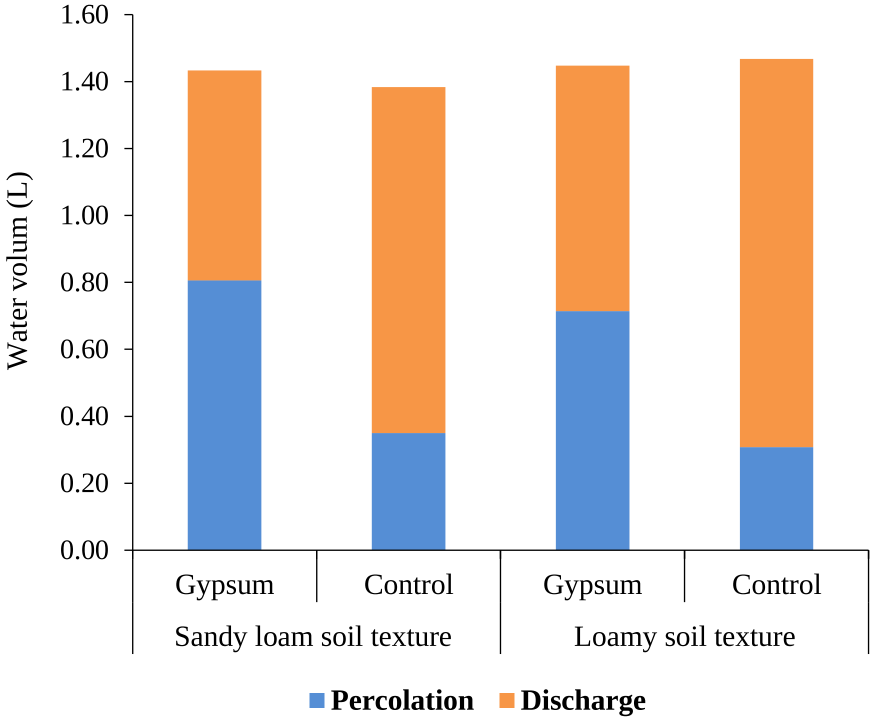


Fig. 4.14 Percolation and surface runoff of sandy loam and loamy soil textures

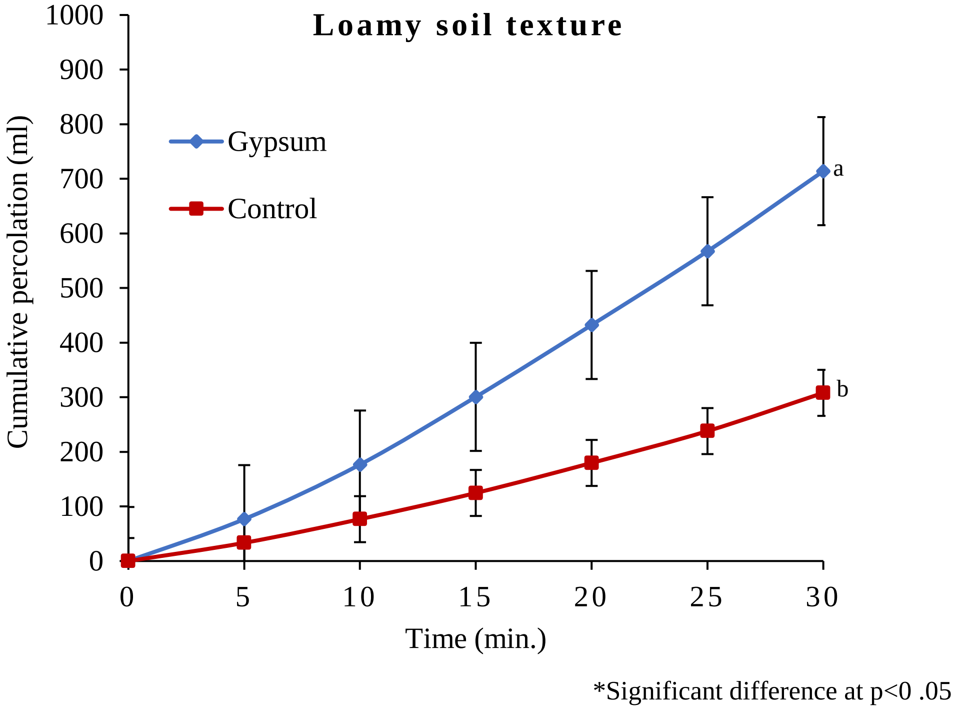


Fig. 4.15 Changes in percolation by application gypsum with times

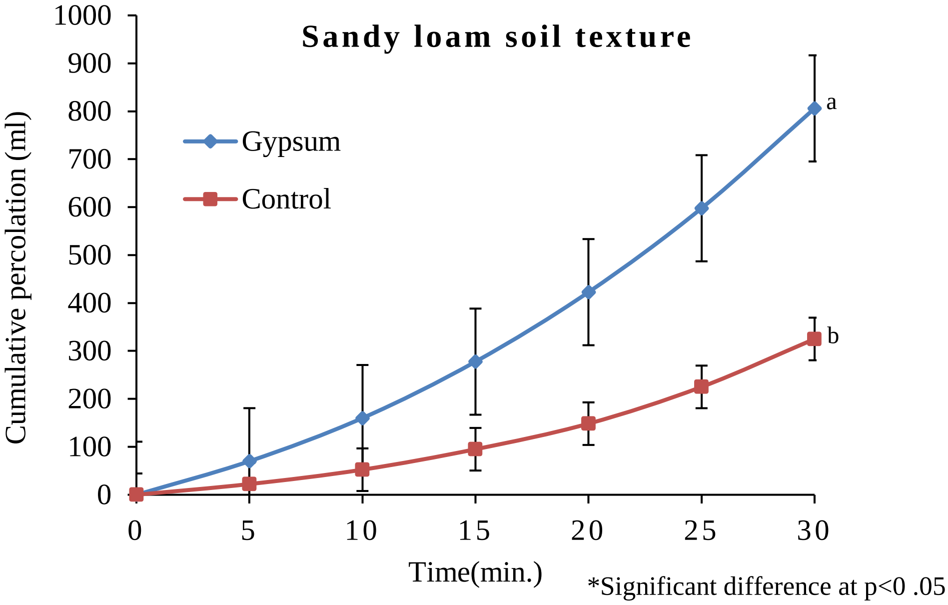


Fig. 4.16 Changes in percolation by application gypsum with times

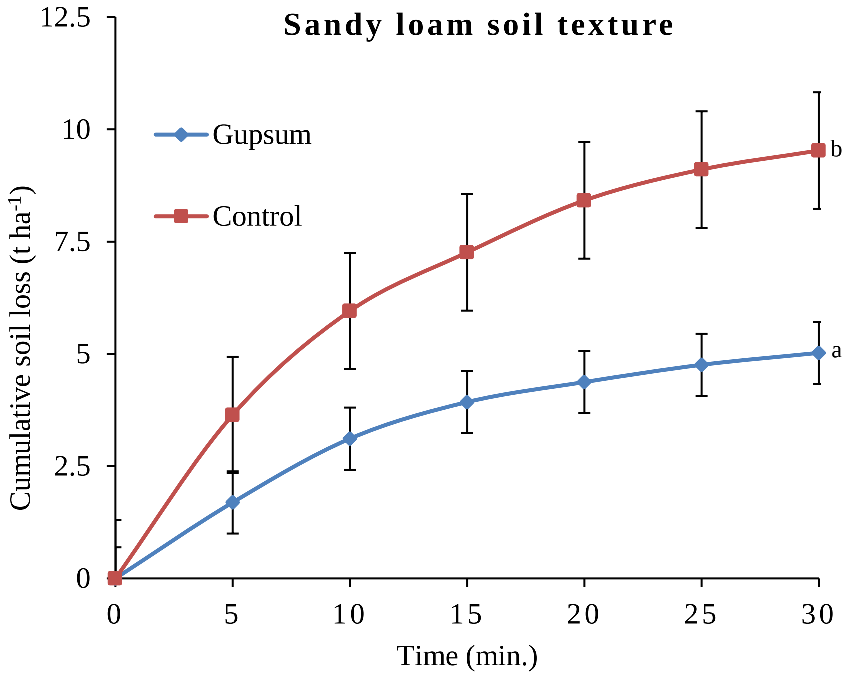
4.4.3 Soil loss

The application of gypsum mineral significantly reduced the total soil loss by 60.3% and 81.9% from sandy loam soil and loamy soil textures compared to control. The specific load of soil was recorded for sandy loam and loamy soil textures for gypsum-treated 16.98×10^6 g ha^{-1} and 5.34×10^6 g ha^{-1} and for control 42.72×10^6 g ha^{-1} and 29.50×10^6 g ha^{-1}, respectively as summarized in Table 4.13. Statistical analysis showed that gypsum treated plots significant difference ($p<0.05$) when compared to control plots as shown in Table 4.14.

Table 4.13 Specific loads of soil from sandy loam and loam soil textures

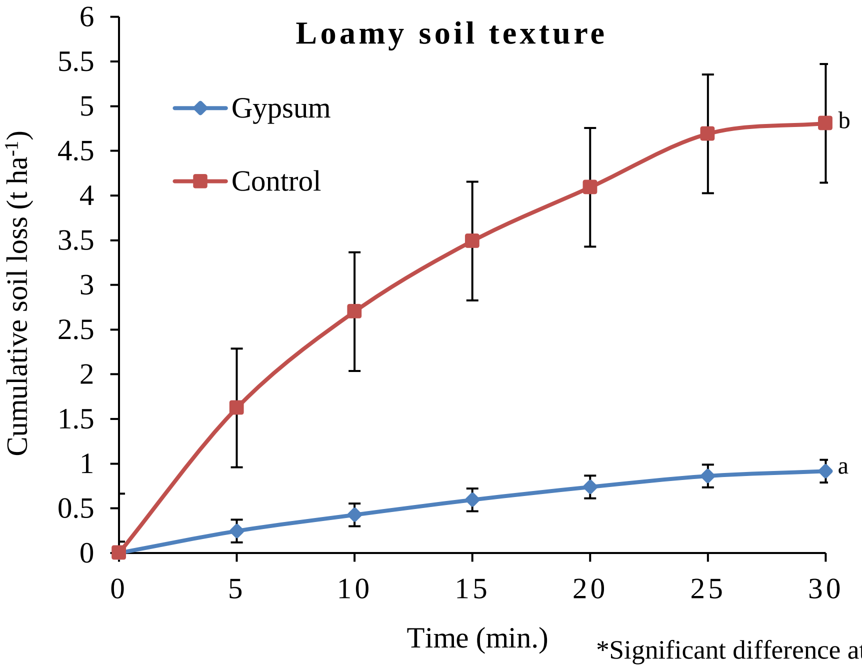
Soil	Treatment	Soil loss (mg/L)	Q (L)	SP (g ha^{-1})	Total soil loss decreased from control (%)
SLS	Gypsum	73,923	0.63	16.98×10^6	60.3
	Control	112,753	1.03	42.72×10^6	
LS	Gypsum	19,863	0.73	5.34×10^6	81.9
	Control	69,455	1.16	29.50×10^6	

SLS sandy loam soil, LS loam soil, L liter, Q discharge, SL specific load, g gram and ha is hectare



*Significant difference at p<0 .05

Fig. 4.17 Changes in soil loss by gypsum application with times



*Significant difference at p<0 .05

Fig. 4.18 Changes in soil loss by gypsum application with times

Table 4.14 Statistical analysis of soil loss from surface runoff experiment

Soil	Source of variation	Degrees of freedom	Sum of squares	Mean sum of squares	F calculated	F probability
Sandy loam soil	Treatments	1	980.73	980.73	16.17	0.018
	Error	4	242.74	60.68	-	-
	Total	5	-	-	-	-
Loamy soil	Treatments	1	853.94	853.94	19.51	0.015
	Error	4	175.07	43.76	-	-
	Total	5	-	-	-	-

Soil texture	Sandy loam		Loamy	
Treatment No.	Gypsum	Control	Gypsum	Control
Treatment average	17.17	42.73	5.4	29.26
Critical Difference at P<0.05 compared	a	b	a	b

In addition, during the experiment was observed the sediment concentration was more in the early stage in sandy loam and loamy soil textures, it considerably decreased with time until reached a steady state condition as indicated in Fig. 4.17 and Fig. 4.18. According to Fred et al. (2011) and Wallace et al. (2001), they were applied FGD gypsum at the rate of 13.44 t ha^{-1}, significantly increased total infiltration rate by 17%, surface runoff reduced by 36% and soil loss reduced by 77%. Thereby, applied gypsum mineral as a broadcast that increased electrolyte concentration in soil solution on the surface of the soil causing clay flocculation and reducing soil loss and increased permeability condition.

4.4.4 Cation concentration

The surface runoff was analysed for calcium, magnesium and sodium contents. The result showed the gypsum-treated soils increased the calcium content for sandy loam and loamy soil textures (Fig 4.19). While the calcium concentration a slightly more for loamy soil texture because of Cation Exchange Capacity (CEC) of soil. Gypsum mineral boosted soil condition and improved crop yields as well as increasing the sulphur content which is an essential nutrient for plant growth (Chen and Dick, 2011). Reported by Fisher, 2001 calcium ion is very important for cell walls, membrane and developing root growth.

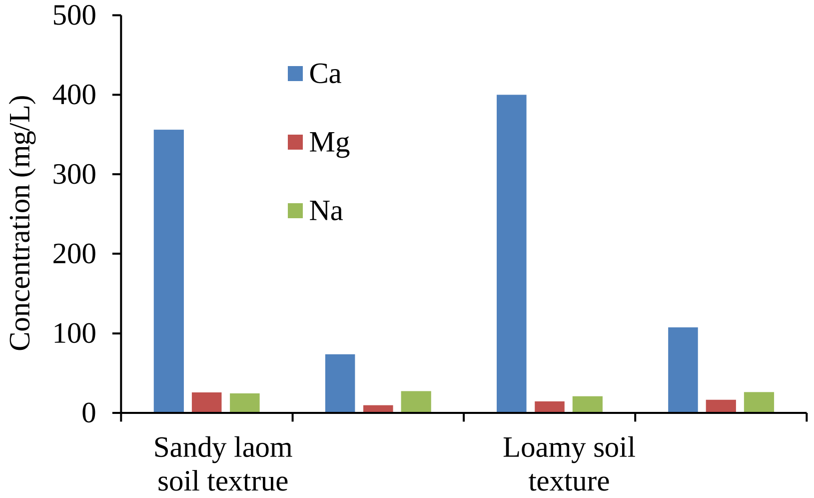
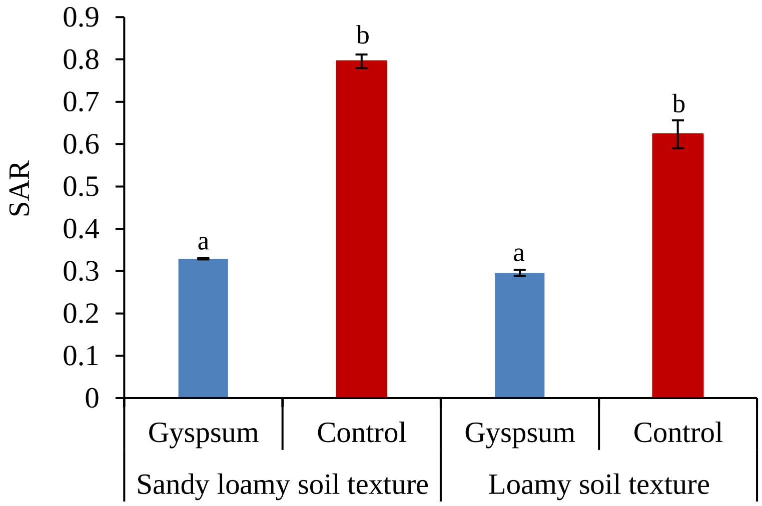


Fig. 4.19 Cation concentration in surface runoff

4.4.5 Sodium adsorption ratio (SAR)

Sodium adsorption ratio was reduced for gypsum-treated soils by 59% and 52% from sandy loam and loamy soil textures compared to the control, respectively (Fig. 4.20).



*Significant difference at p<0 .05

Fig. 4.20 Sodium adsorption ratio (SAR) of surface runoff

4.4.6 Flocculation and dispersion

Flocculation is the process which clay particles, individual coagulate or aggregate, whereas the dispersion is the reverse action of flocculation such as the distinctive clay particles separate from one another. Soil dispersion is related to the amount of sodium and calcium ions between the clay platelets. If the clay platelets are dominated by calcium, the dispersion phenomenon cannot occur because calcium ions are small with two positive charges that attach to negative clay platelets' binding together. When the calcium ions are hydrated, expanded and swollen, but the expansion is not large to break the electrostatic binding. If sodium ions are more than calcium ions in the two platelets of clay when sodium ions are a hydrate, much larger than hydrate calcium ions. So, increases the space between clay platelets leading to the breaking of the electrostatic bonds as the result dispersion process occurs.

Therefore, flocculation and dispersion experiments were conducted in the laboratory. Gypsum mineral was applied at the rates of 2.5 t ha^{-1}, 5 t ha^{-1}, 7.5 t ha^{-1} and 10 t ha^{-1} with loamy soil texture. Soil and gypsum were put into tubes and 100 ml deionized water was added, then shaking mechanically for a minute (Fig. 4.21).

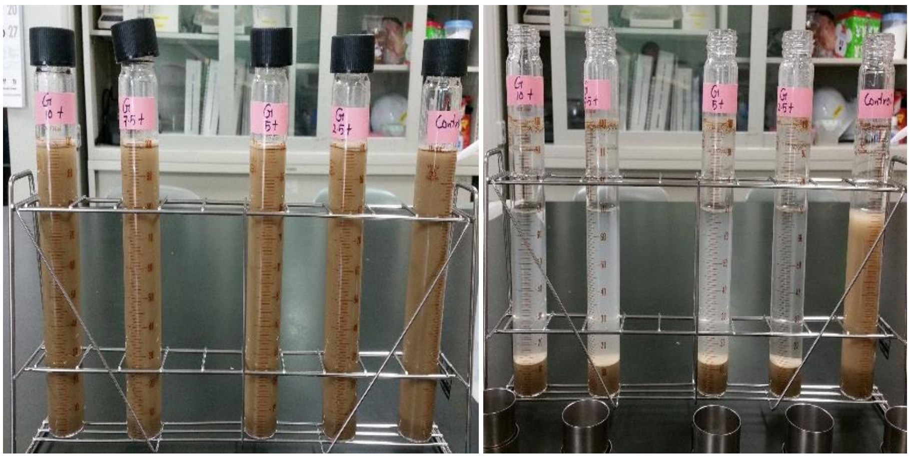
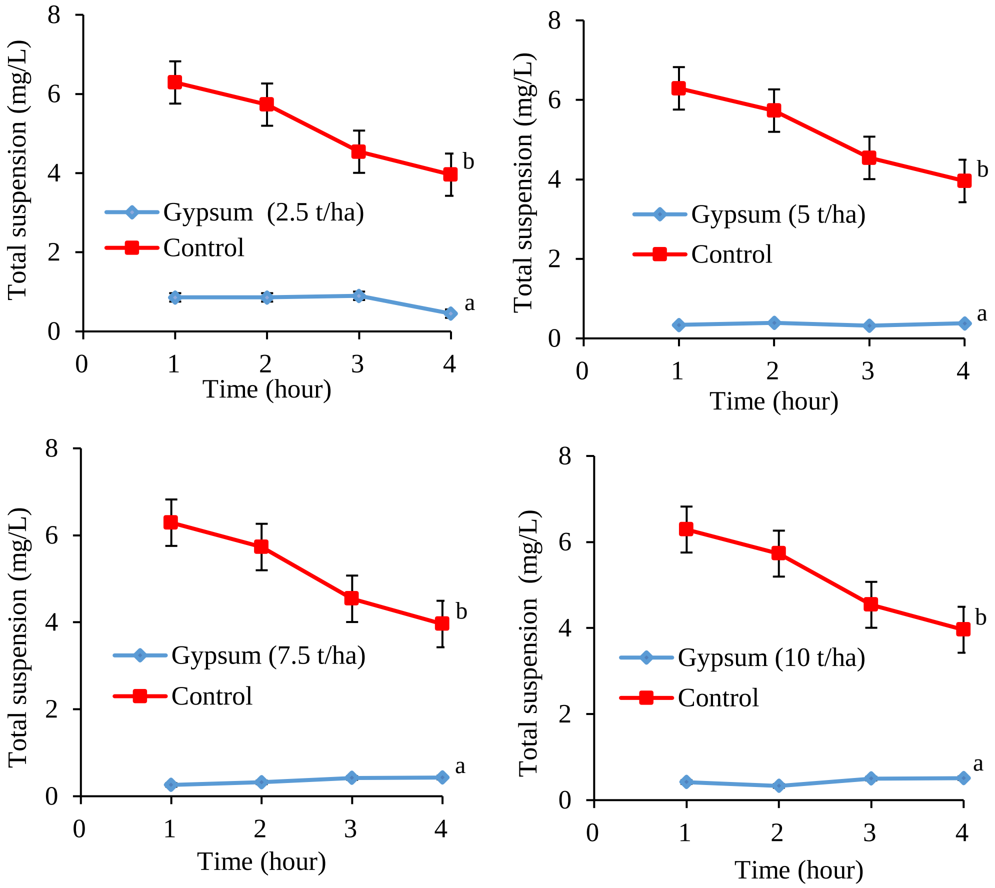


Fig. 4.21 Flocculation and dispersion experiment results

Samples were taken after an interval one hour and experiment were run for four hours. The samples were kept in the oven for 24 hours and analyzed for suspended solids.



*Significant difference at p<0 .05

Fig 4.22 Effects of gypsum mineral at differ rate on suspend soils

The results indicated the addition of gypsum mineral at the rates of 2.5, 5, 7.5 and 10 t ha^{-1} significantly difference ($p<0.05$) flocculated the soil particles compared to the control. However, there is a negligible difference between high and low rates of gypsum application (Fig. 4.22). It means the application of high rate gypsum mineral similar affected as medium rate and the high rate of gypsum is not economical.

In addition, the flocculation experiment was conducted to identify the effect of gypsum at the rate of 5 t ha^{-1}. Samples were taken after an interval 5 minutes about 2 cm depth and experiment was run for 30 minutes (Fig. 4.23).

Fig. 4.23 Sedimentation as observed at 5 minutes interval

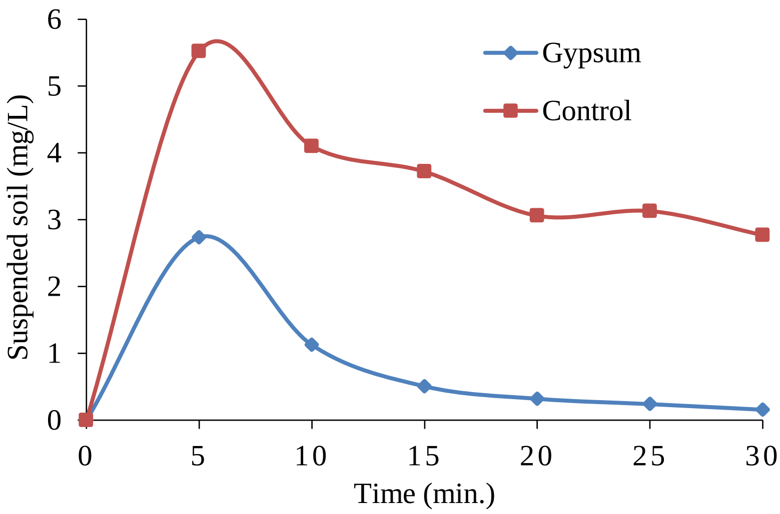


Fig. 4.24 Effects of gypsum mineral on suspend soils

The results showed gypsum at the rates of 5 t ha^{-1} significant well flocculated the soil particles compared to the control as shown in the Fig. 4.24. However, dispersion soil plug soil pores over enhance surface runoff and reduce water infiltration and drainage thereby increases soil erosion. Gypsum is known to flocculate the soil and pull together clay particles an aggregate. The relative flocculation power of cation for sodium is 1, Potassium is 1.7, magnesium is 24 and calcium is 43 (Sumner and Naidu, 1998).

4.5 Conclusion of this chapter

The soil conservation practices by crop management and gypsum application have been studied. However, the preventing soil erosion with cultivating crops is a common farming practice in agricultural lands. Also, gypsum mineral is an amendment widely accepted in the recent days because of its availability in most regions and relatively low-cost.

The experimental results indicated that total soil losses from gypsum-treated, clover and maize plots were reduced to 63.3%, 92.0% and 54.3% of that from the control. As crop cultivation is not available during the period of insufficient irrigation water in Dawlatzai Village of Gardez District but research was more interested on gypsum application as an alternative conservation strategy. So, an additional experiment was conducted for discussing more about the effects of gypsum application in the laboratory using two different soil textures as sandy loam and loamy soils. The results showed that total soil losses from gypsum-treated were 60.3% and 81.9% of the losses from the control for sandy loam and loam soils, respectively. Soil particles were well flocculated in gypsum-treated plot compared to the control, and it was considered this flocculation contributed to reduce sediment concentration and soil erosion. It significantly increases the calcium content but reduced SAR value. Accordingly, it is suggested and recommended that farmers in Paktya Province apply gypsum mineral into their farmlands for reducing surface runoff and soil loss.

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Chapter 5--

Evaluation of gypsum application as conservation practice factor using USLE with GIS in Dawlatzai Village of Gardez District

5.1 Objective of this chapter

The objective of this research is to determine the effectiveness of gypsum application as a conservation practice factor using USLE model with GIS in Dawlatzai Village of Gardez District, Paktya Province.

5.2 Materials and methods

The Universal Soil Loss Equation was developed by Wischmeier and Smith, 1979. The equation represents the main factors controlling soil erosion, namely, soil characteristics, topography and land cover management as explained in equation 5.1.

$$A = R \times K \times L \times S \times C \times P \qquad \text{(Eq. 5.1)}$$

Where;

A is annual soil loss per unit area (t ha^{-1} yr^{-1})

R is a runoff erosivity factor (MJ mm ha^{-1} yr^{-1})

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

L is a slope length factor

S is a slope steepness factor

C is a cover management factor

P is a supporting conservation practice factor.

5.2.1 Used data

In this study, the annual soil loss rates were calculated based on USLE in ArcGIS platform, and different data sources were referred to analyze the estimation of soil loss without conservation practice and with conservation practice in Dawlatzai Village Gardez District Paktya Province, Afghanistan (Fig. 5.1).

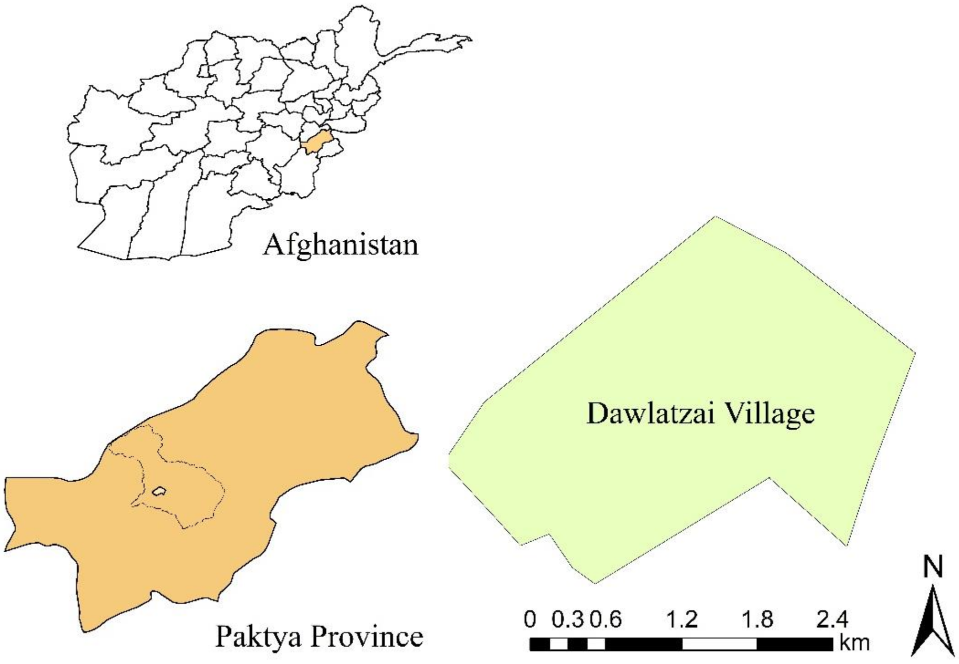

Fig. 5.1 Dawlatzai Village Paktya Province, Afghanistan

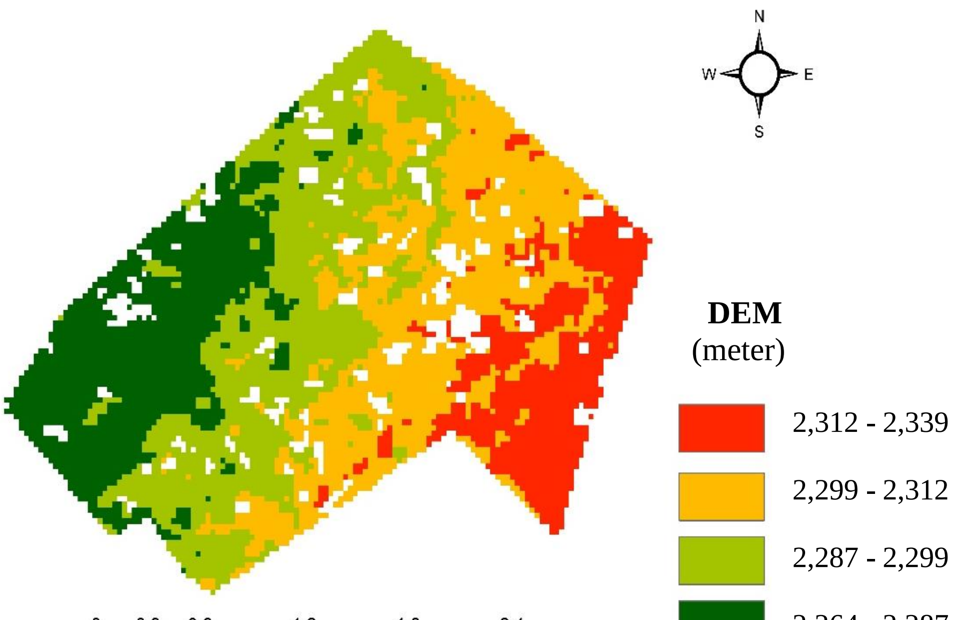

Fig. 5.2 DEM map of Dawlatzai Village

The Digital Elevation Model (DEM) with 30 m resolution produced by the United States Geological Survey (USGS), the elevation range is from 2,264 m to 2,339 m above the sea level (Fig. 5.2). DEM was used to estimate the slope gradient, flow direction, flow length, and flow accumulation.

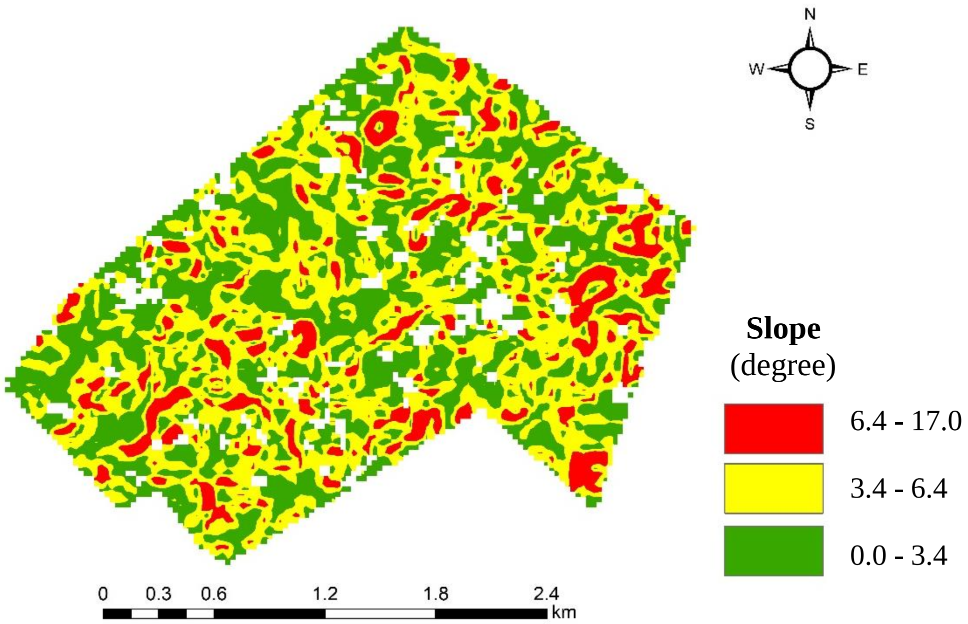

Fig. 5.3 Slope map of Dawlatzai Village

The slope length and slope steepness (LS) factor required by USLE was calculated. The slope was derived from DEM the ranges between 0 to 17.08 degrees (Fig. 5.3). Approximately 99% of area covers by irrigated agricultural land, hence slope range is low. Rainfall erosivity factor (R-factor) was calculated based on the mean annual rainfall data in surrounding areas and automatic rain gauge, which was installed in the study area.

Land use map was developed by (FAO, 2016) and used it for the analysis of the crop management factor (Fig. 5.4). Soil erodibility factor (K-factor) was calculated from soil samples, which were collected in the entire study area, then soil samples were analyzed in the laboratory for soil particle distribution size (texture), organic matter content and permeability.

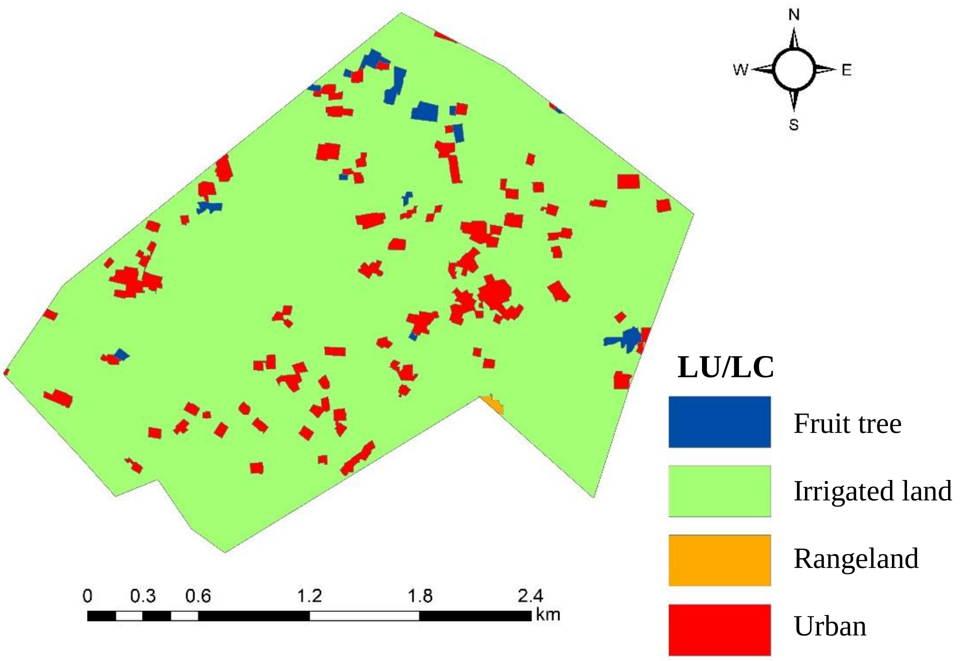

Fig. 5.4 Land use map of Dawlatzai Village

Conservation practices factor (P-factor) was estimated based on the conducted field experiments in the research area with gypsum mineral applied as supporting conservation practices for reducing runoff volume and velocity. The ratio was calculated gypsum-treated field to control field. P-factor value is 0.31.

5.3 Results and discussion

5.3.1 Rainfall erosivity factor (R)

The erosivity factor is required for long-term annual rainfall event, kinetic energy and the maximum rainfall intensity in 30 min mm hr^{-1} (Wischmeier and Smith, 1978). The erosivity factor was calculated based on the USLE and means annual rainfall for the Dawlatzai Village used the method as explained in chapter 3 (page, 49-52). However, the R factor varied from 171 to 184 MJ mm ha^{-1} h^{-1} yr^{-1} (Fig. 5.5).

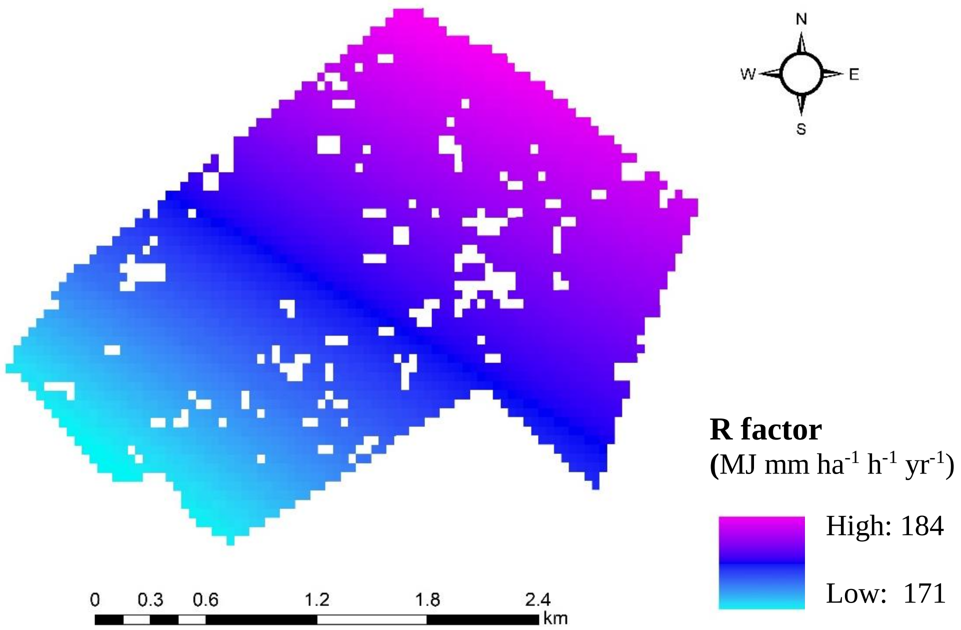

Fig. 5.5 Rainfall erosivity map of Dawlatzai Village

5.3.2 Soil erodibility factor (K)

The soil erodibility factor (K) measures the susceptibility of soil particles or surface materials to transportation and detachments by the amount of rainfall and runoff (Renard et al., 1997). K factor is related to soil texture, soil structure, organic matter and permeability. The most easily eroded soil particles are silt and very fine sand since is easy to detach and transport by water (Kim, 2006). The K factor range is from 0 to 1, where 0 refers to soils with less susceptibility to erosion, 1 refers to the soil, which is highly susceptible to erosion by water.

Equation 5.2 was derived from a standard unit plot. It has a 9% gradient slope and a length of 22.1 m in a continuous fallow condition with tillage performed upslope and down the slope (Wischmeier and Smith 1978).

$$K = \frac{[2.1\times10^{-4}(12-OM)M^{1.14} + 3.25(S-2) + 2.5(P-3)]}{100} \qquad \text{(Eq. 5.2)}$$

Where;

K is expressed as ton. acre^{-1} per erosion index unit with U.S. customary units of t.acre.h (hundreds of acre.ft-ton.in)$^{-1}$. Division of the right side of this equation with factor 7.59 will yield K values expressed in SI units of t ha h ha^{-1} MJ^{-1} mm^{-1}.

M is the particles percentage (% of very fine sand + % of silt) (100 - % clay)

OM is organic matter content (%)

S is the soil structure (mm)

P is the soil permeability (mm h^{-1})

Texture grading is described in the following classes in International Soil Science Society (ISSS)

1. Coarse sand: 0.2 to 2.0 mm diameter (200 to 2,000 microns)
2. Fine sand: 0.1 to 0.2 mm diameter (100 to 200 microns)
3. Very fine sand: 0.02 to 0.1 mm diameter (20 to 100 microns)
4. Silt: 0.002 to 0.02 mm diameter (2 to 20 microns)
5. Clay - <0.002 mm diameter (<2 microns)

The soil structure is described in the following grades:

1. Very fine granular where particles are mostly less than 1 mm diameter
2. Fine granular where particles are mostly 1 to 2 mm diameter
3. Medium or coarse granular where particles are mostly 2 to 10 mm diameter
4. Block, platy or massive

Profile permeability refers to the rate of infiltration of water into the whole soil profile as follows:

1. Rapid: greater than 130 mm h^{-1}

2. Moderate to rapid: 60 to 130 mm h^{-1}
3. Moderate: 20 to 60 mm h^{-1}
4. Slow to moderate: 5 to 20 mm h^{-1}
5. Slow: 1 to 5 mm h^{-1}
6. Very slow: less than 1 mm h^{-1}

Table 5.1 Soil erodibility (K factor) of Dawlatzai Village

Soil sample	FS (%)	S (%)	C (%)	P (mm h^{-1})	OC (%)	SS (code)	P (code)	K
Farmlands	31.8	41.3	20.7	1.0	5.1	3	5	0.048
	32.1	40.3	21.6	1.7	5.6	3	5	0.045
	26.9	38.9	24.5	2.4	5.6	3	5	0.040
Orchard	29.6	41.4	25.1	1.2	5.7	3	5	0.041
	26.6	39.8	29.3	2.0	5.7	3	5	0.038
	32.9	37.6	24.8	1.3	5.9	3	5	0.040
Uncultivated land	52.6	22.2	11.6	3.9	3.9	2	5	0.054
	55.4	20.6	11.5	9.4	3.6	2	4	0.057
	57.3	20.0	10.5	7.5	3.6	2	4	0.058

FS find san, S silt, C clay, P permeability, OC organic content, SS soil structure and K soil erodibility factor (t ha h ha^{-1} MJ^{-1} mm^{-1})

Soil samples were collected from various agricultural lands in the entire study area. Soil samples were analyzed for soil particle distribution size (texture), organic matter and permeability in the laboratory. Soil erodibility (K factor) was calculated by regression equation 5.2, the results summarized in Table 5.1. Three broad and fundamental groups of soil structure are recognized as sands, loam and clays. Soil textural pyramid developed by the United States Geology and Soil (USGS) and assigned the soil structure code (Fig. 5.6). The locations of the soil samples were controlled by GPS, to generate GIS layer. The map was generated using the Inverse Distance Weighted (IDW) interpolation method on point data of soil samples then obtained the K factor map. The range is varied from 0.038 to 0.057 t ha h ha^{-1} MJ^{-1} mm^{-1} (Fig. 5.7).

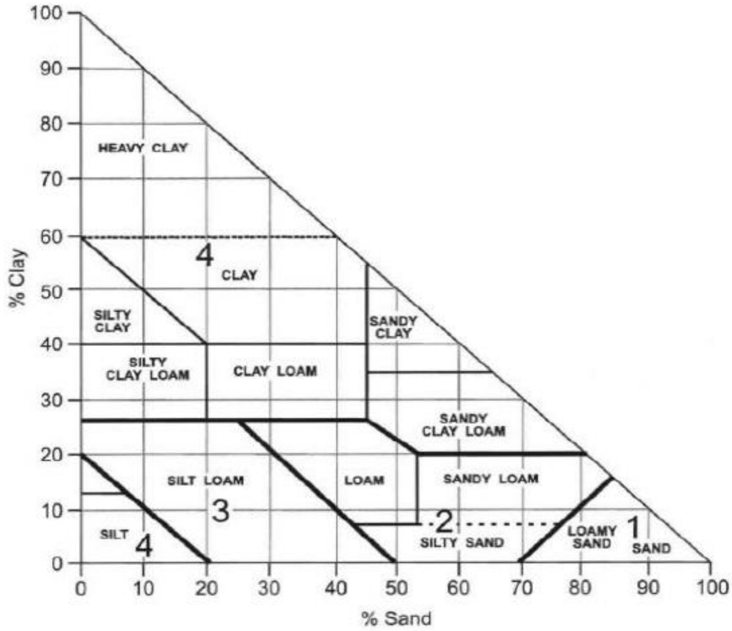

Fig. 5.6 Soil structure code based on textural classification

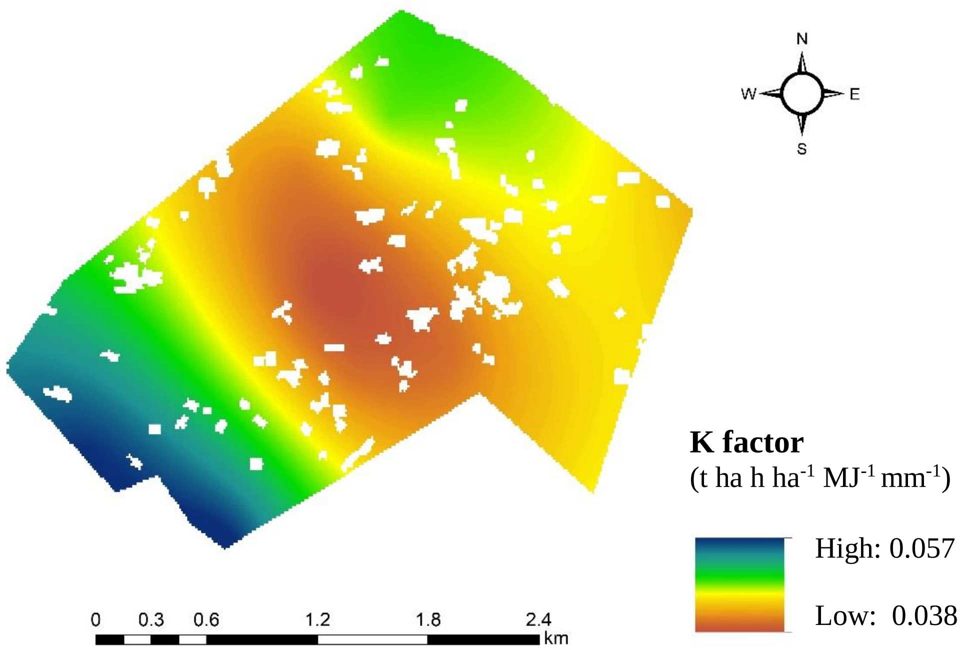

Fig. 5.7 Soil erodibility map of Dawlatzai Village

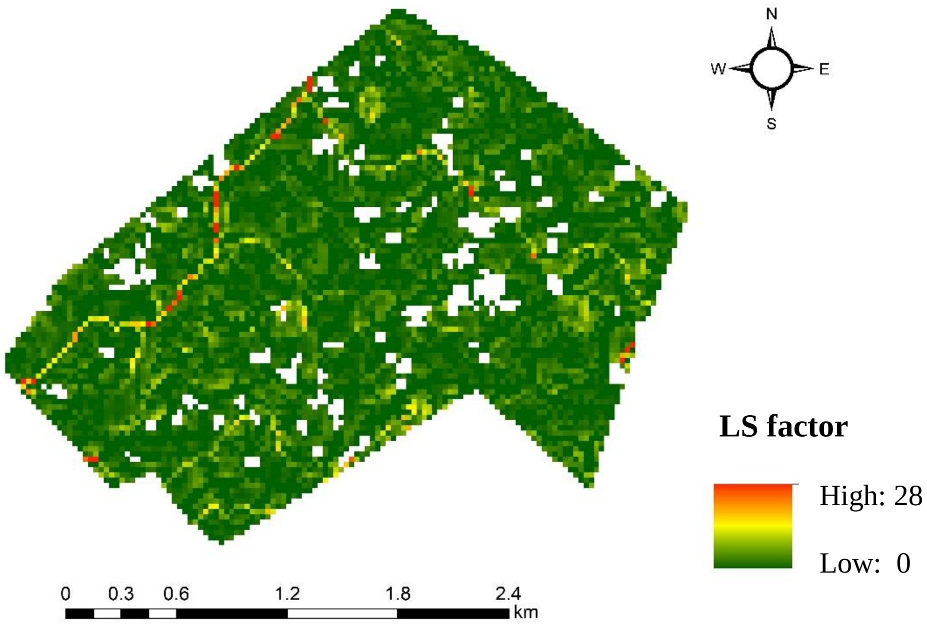

Fig. 5.8 LS factor map of Dawlatzai Village

5.3.3 Slope length and steepness factor (LS)

The LS factor uses in a single index, which expresses the ratio of soil loss as defined by Wischmeier and Smith, 1978. The LS factor was calculated same procedure as explained in chapter 3 (page, 54-55). The obtained LS factor map with range is between 0 to 28 (Fig. 5.8).

5.3.4 Crop management factor (C)

The crop management factor (C) is the ratio of soil loss of a specific crop to the soil loss under the condition of continuous fallow (Renard et al., 1997). In this study, the C factor map was extracted from the national land cover map which is developed by FAO-UN, 2016. Therefore, C factor values were assigned for each land use type from the literature review (Fig. 5.9). The leave of crops protects the soil from raindrop impact and reduces the volume of overland flow running downslope (Ranzi et al., 2012).

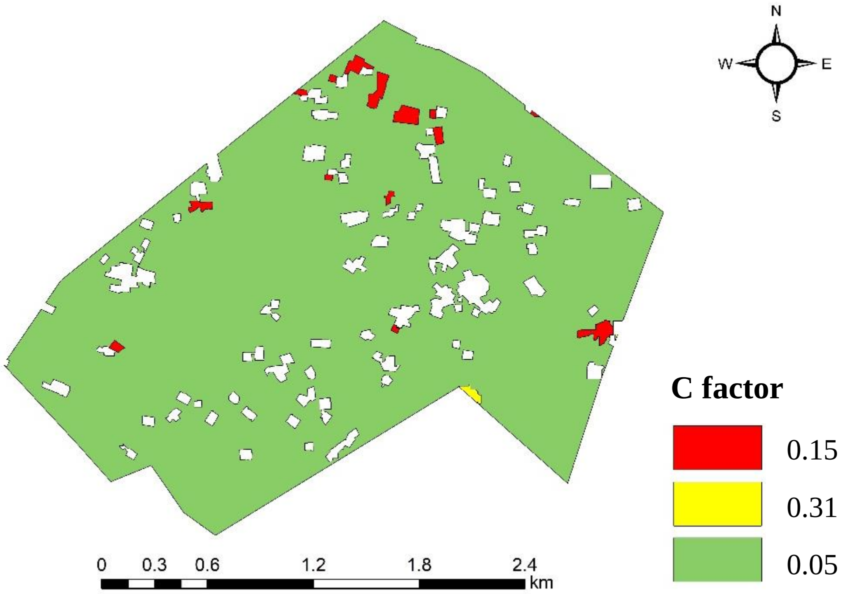

Fig. 5.9 C factor map of Dawlatzai Village

5.3.5 Conservation practice factor (P)

Conservation practice factor relates to the practice, which restricts surface runoff and reduces the effective soil erosion. The range of P-factor is from 0 to 1, where one is assigned to areas with no conservation practices. However, the lower the P-factor value the better supporting practice is for controlling soil loss. The value of P-factor decreases by adopting, supporting conservation practices that reduce runoff volume and velocity and enhance the deposition of sediment from the high to a downslope surface.

P factor use as control practices which reduce the erosion potential of runoff by influence on drainage, runoff velocity and hydraulic forces used by the runoff on the soil surface (Renard et al., 1991). The literature reports indicated various tables and formulas suggesting for the supporting conservation practices' values. However, in this study, the conservation practice factor was estimated based on the field and laboratory experiments through the application of gypsum mineral at 5 t ha^{-1}, the ranges from 0.19 to 0.39. Accordingly, the estimated P factor with gypsum-treated at 0.33 was substituted into the USLE and GIS for re-calculating the soil losses in agricultural land of Dawlatzai village (Table 5.2 and Fig. 5.10).

Table 5.2 Calculating the P factor based on field experiment

Field	Soil loss (mg/L)	Q (L)	Specific load (g ha^{-1})	Total soil loss decreased from control (%)
Gypsum	26,460	3.40	4.11×10^6	67.3
Control	65,760	4.23	12.56×10^6	

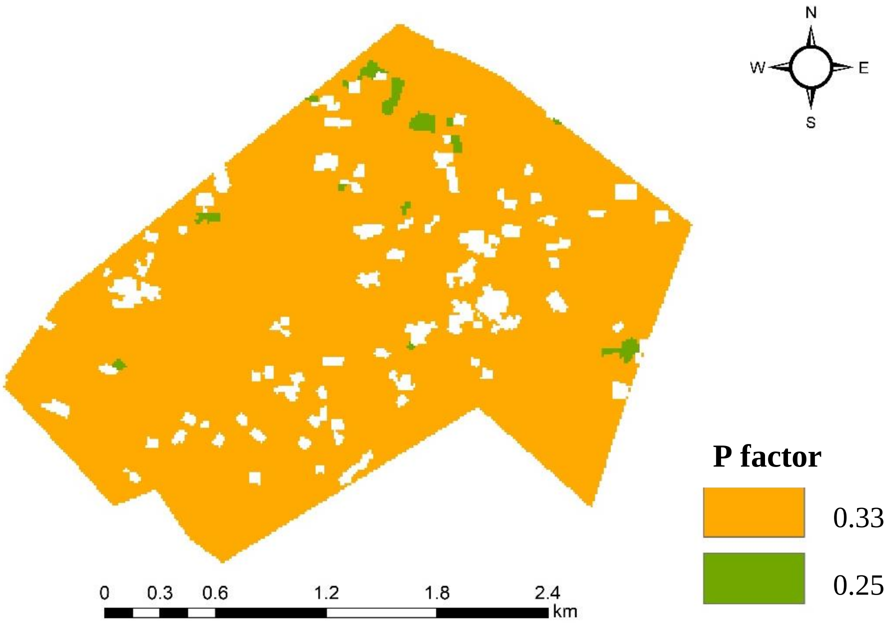

Fig. 5.10 P factor map of Dawlatzai Village

The P-factor was considered a contour farming, stone walls and grass margins in the European Union was estimated at 0.97. Grass margins having the largest impact by 57% of the total erosion risk reduction, stone walls 38% and contour farming contributes very little. It is only used on very steep slopes less than 10% (Panagos et al., 2015).

5.4 Estimated soil loss

5.4.1 Estimated soil loss without any conservation practice

The R, K, LS and C factors map created as data layers in ArcGIS; Rainfall erosivity map (R factor) was calculated based on mean annual rainfall the ranges from 171 to 184 MJ mm ha^{-1} h^{-1} yr^{-1}. The soil erodibility factor (K) was calculated based on soil samples ranges varied from 0.038 to 0.057 t ha h ha^{-1} MJ^{-1} mm^{-1}. The LS factor was calculated through DEM the value is between 0 to 28. Crop management factor map was extracted from the land use map of the country the values were assigned for each land use type from the literature review ranges from 0.05 to 0.31. There are no support practices for the study area, hence P is assigned the value of one (1) in the calculation.

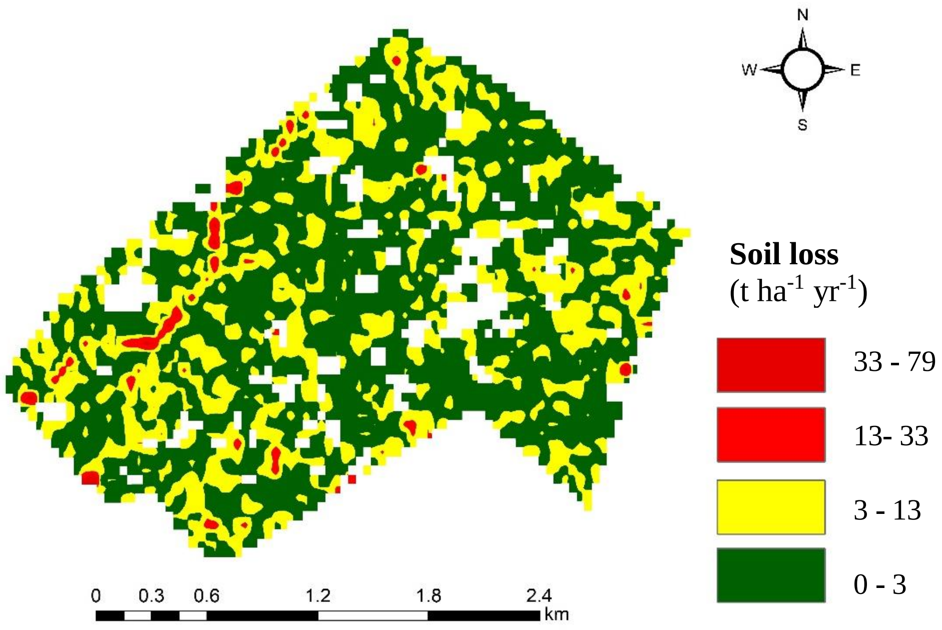

Fig. 5.11 Soil loss map without any conservation practice

All factors were multiplied as the raster layer in the raster calculator and the soil erosion map was obtained t ha^{-1} yr^{-1} at a pixel level. Soil loss value for the

Dawlatzai Village of Gardez District (irrigated agricultural land) ranges from 0 to 79 t ha^{-1} yr^{-1} with an average of 2.9 t ha^{-1} yr^{-1}, estimated at pixel level soil loss value was grouped into 4 classes based on the natural break classification in ArcGIS platform (Fig. 5.11 and Table 5.3).

Table 5.3 Annual soil loss without any conservation practice (P = 1)

No	Soil loss (t ha^{-1} yr^{-1})	Area (ha)	Area (%)
1	0 - 3	392	73.1
2	3 - 13	132	24.6
3	13 - 33	10	1.9
4	33 - 79	2	0.4
Total		536	100

5.4.2 Estimated soil loss with conservation practice

The conservation practice factor was estimated based on the field experiment through the application of gypsum mineral into agricultural land. However, estimated soil loss with conservation practice thereby the P factor was assigned based on the field experiment ranged 0.33 and the other factors were same as mentioned before. Likewise, the final soil loss map was obtained t ha^{-1} yr^{-1} at a pixel level and ranges from 0 to 20 t ha^{-1} yr^{-1} with an average of 0.75 t ha^{-1} yr^{-1} (Fig. 5.12). The soil loss value classified into 4 classes due to natural break classification in ArcGIS platform (Table 5.4).

Table 5.4 Annual soil loss with conservation practice (P = 0.33)

No	Soil loss (t ha^{-1} yr^{-1})	Area (ha)	Area (%)
1	0 - 1	389	72.6
2	1 - 5	140	26.1
3	5 - 10	5	0.9
4	10 - 20	2	0.4
Total		536	100

The application of gypsum mineral as a conservation practice in agricultural land significantly reduced soil loss by 75% compared to soil loss without any conservation practice factor for Dawlatzai Village. It should be mentioned, gypsum mineral is an excellent and effective, remarkable for decreasing surface runoff, velocity and controlling soil erosion.

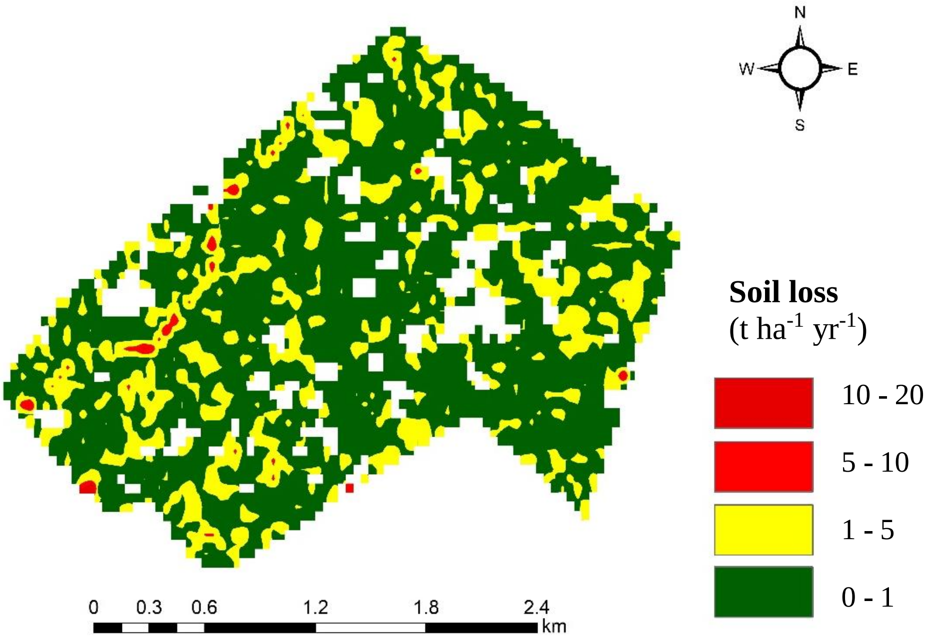

Fig. 5.12 Soil loss map of with conservation practice

5.5 Conclusion of this chapter

To determine the effectiveness of gypsum application as a conservation practice in Dawlatzai Village, P-factor was assumed as 0.33 based on the field experiments. The soil losses from 0 to 79 t ha^{-1} yr^{-1} from the agricultural lands without any conservation practices changed to 0 to 20 t ha^{-1} yr^{-1} when gypsum application is done as a conservation practice. Accordingly, it was concluded that conservation practice with applying gypsum mineral in agricultural lands in Dawlatzai Village is one of the effective ways for reducing soil erosion.

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Chapter 6--

Conclusions and recommendations

Afghanistan is suffering from lack of data, information, particularly soil and water conservation plans. Therefore, soil erosion is one of the serious problems throughout the country due to topography of the landscape, arid and semi-arid climates, barren nature of the land and desertification. Agriculture plays an indispensable role in the livelihood of Afghans as approximately 80% of the population depends on agricultural activities and 90% of the population lives in rural areas. Although total arable land is 12%, only 6% is cultivated. Rainfall is infrequent with very low precipitation; around 300 mm yr^{-1} annually but having high rainfall intensity. However, little attention has been paid to address soil erosion problem in the country, particularly in Paktya Province. Hence, this study was conducted to estimate soil erosion through the application of the Universal Soil Loss Equation (USLE) on GIS and discussed the effective conservation practice; crop management and gypsum mineral ($CaSO_4.2H_2O$) application in agricultural lands were evaluated to reduce sediment concentration in surface runoff and soil erosion.

Questionnaire survey was conducted in the initial stage of this study in Dawlatzai Village of Gardez District, Paktya Province and the key problems identified were; soil degradation, deforestation, inadequate of irrigation water, poor extension services and inadequate of agricultural inputs. In addition, based on the survey conducted in the study area, 32% of the farmers responded that soil erosion happens very severely and 50% responded as severely. It means that more than 80% of farmers require proper conservation strategies for holding soil fertility and reducing soil erosion.

USLE and GIS techniques were used to evaluate soil erosion risk in Gardez Basin, Paktya Province. Different components of USLE model were used with mathematical equation and created GIS layers. The rainfall erosivity factor (R-factor) observed with an installed rainfall gauge for a year at 217.5 MJ mm ha^{-1} h^{-1} yr^{-1} made a good agreement with that calculated at 207.7 MJ mm ha^{-1} h^{-1} yr^{-1} based on the annual amount of rainfall. Soil erodibility factor (K-factor) was obtained from the soil classification map, K factor ranged from 0.038 to 0.063 t ha h ha^{-1} MJ^{-1} mm^{-1}. And C factor was calculated based on the national land cover map. The LS factor was calculated from DEM, LS factor values were in the range from 0 to 176. Additionally, there are no conservation practices in the study area; hence a conservation practice factor P-factor was assigned 1 for the calculation. All factors were multiplied in raster calculator in ArcGIS and annual soil loss map obtained. The range is from 0 and greater than 100 t ha^{-1} yr^{-1} than classified into five classes; 0 to 5 t ha^{-1} yr^{-1}, 5 to 10 t ha^{-1} yr^{-1}, 10 to 50 t ha^{-1} yr^{-1}, 50 to 100 t ha^{-1} yr^{-1} and > - 100 t ha^{-1} yr^{-1}, respectively.

On the other hand, the USLE model was calibrated by the erosion pin method. The results of the calibration indicated that the observed soil losses with the erosion pin method in the field showed certain agreements with the calculated soil losses based on the USLE model in this study.

Although there are many soil conservation practices, crop management and gypsum application have been focused in this study. Preventing soil erosion with cultivating crops is a common farming practice in agricultural lands and gypsum mineral is an amendment widely accepted in the recent days because of its availability in most regions and relatively low-cost. Therefore, to evaluate the effectiveness of gypsum application in reducing sediment concentration in surface runoff to minimize soil erosion in agricultural lands, a field experiment was conducted in Dawlatzai Village using a portable rainfall simulator and four plots were designed; gypsum-treated, clover, maize and control felids. However, the total soil losses from the gypsum-treated, clover and maize plots were reduced by 67.3%, 92.0% and 54.3% respectively compared to the control. Gypsum mineral slightly increased EC of surface runoff because it is sparingly soluble salt but did not change the pH values of surface runoff. So, it was considered that gypsum is not a liming agent and does not neutralize the hydrogen ion in the soil solution. As crop cultivation is not available during the period of insufficient irrigation water in Dawlatzi Village of Gardez District, research interest was focused on gypsum application as an alternative conservation strategy. So, an additional experiment was conducted for discussing more about the effects of gypsum application in the laboratory using two different soil textures; a sandy loam and loamy soil textures and gypsum was applied at the rate of 5 t ha^{-1}. The results showed a reduction in surface runoff by 38.8% for sandy loam soil and 37.0% for loamy soil texture compared to the control but percolation was increased by 2.31 times for sandy loam soil and 2.29 times for loamy soil textures. Also, the total soil losses were significantly reduced by 60.3% and 81.9% for sandy loam and loam soils, respectively. It was considered that gypsum mineral addition is effective in enhancing flocculation and aggregated of soil particle and reduced soil loss. Improved surface conditions in gypsum-treated soil, which contributed to reduction of sediment concentration in surface runoff and total soil loss.

In addition, to determine the effectiveness of gypsum application as a conservation practice in Dawlatzai Village, P-factor was assigned as 0.33 based on the field experiments. The soil losses from 0 to 79 t ha^{-1} yr^{-1} from the agricultural lands without any conservation practices changed to 0 to 20 t ha^{-1} yr^{-1} on application of gypsum as a conservation practice. Accordingly, it was concluded based on results that conservation practice with application of gypsum mineral in agricultural lands is one of the effective and economical conservation strategies. It is recommended that farmers in Paktya Province apply gypsum mineral on their farmlands for reducing surface runoff and soil loss. Clover plant is alternatively being recommended for areas that have enough irrigation water. Therefore, Gypsum mineral application should be adopted as a policy and be provided through agricultural extension services to farmers to enhance their knowledge and skill regarding its benefits and proper application in their agricultural lands for reducing soil erosion.

Appendix

Rainfall events and erosivity factor

No:	Date time	Event (min.)	Accumulative rainfall (mm)	Intensity (mm/h)	Intensity (J/m^2)	R (MJ m km^{-2} hr^{-1} yr^{-1})	R (MJ mm ha-1 hr-1 yr-1)
21	9/11/15 1:53:22 to 10/11/15 19:4:42	46.03	0.2	0.26	1.36	1.59	15.9
		54.08	0.2	0.22	1.24		
		57.89	2.8	2.90	44.63		
		69.63	2	1.72	27.93		
		81.8	2.8	2.05	40.96		
		56.16	1	1.07	12.15		
		16.11	0.6	2.23	8.97		
		11.08	0.2	1.08	2.44		
		54.19	0.2	0.22	1.24		
		6.91	0.4	3.47	6.65		
		85.15	5.6	3.95	95.78		
		28.05	1.8	3.85	30.62		
		51.98	2.4	2.77	37.83		
		47	2.2	2.81	34.79		
		33.25	0.6	1.08	7.32		
		13.91	0.4	1.73	5.59		
		26	0.2	0.46	1.79		
		8.4	0.4	2.86	6.35		
		56.33	0.2	0.21	1.21		
		22.86	1.2	3.15	19.50		
		26.89	0.8	1.79	11.28		
		11.2	0.2	1.07	2.43		
23	12/11/15 8:53:22 to 12/11/15 23:55:5	59.11	0.2	0.20	1.17	1.28	12.8
		10.75	0.4	2.23	5.98		
		24.62	0.4	0.97	4.72		
		33.9	1.2	2.12	17.71		
		55.75	2	2.15	29.61		
		38.5	2	3.12	32.42		
		51.6	2.2	2.56	34.01		
		50.64	0.6	0.71	6.36		
		44.3	2	2.71	31.36		
		54.79	3.4	3.72	57.41		
		55.08	2.4	2.61	37.30		
		54.95	3.2	3.49	53.26		
		52.96	1.2	1.36	15.68		
		36.21	0.4	0.66	4.14		
		21	0.8	2.29	12.03		
30	3/1/16 17:3:31 to 4/1/16 13:28:34	38.19	0.6	0.94	7.01	0.97	9.7
		36.89	0.6	0.98	7.08		
		33.11	0.4	0.72	4.27		
		41.45	0.6	0.87	6.82		
		51.88	1	1.16	12.45		
		34.73	0.8	1.38	10.50		
		33.62	0.4	0.71	4.25		
		28.31	0.4	0.85	4.51		
		23.91	0.2	0.50	1.86		
		49.18	0.2	0.24	1.31		
		31.61	1.2	2.28	18.03		
		54.91	1.4	1.53	18.92		
		10.74	0.4	2.23	5.98		
		45.92	0.8	1.05	9.65		
		59	2	2.03	29.18		
		50.87	0.6	0.71	6.35		
		54.72	1.4	1.54	18.93		
		57.11	3.4	3.57	56.87		
		55.62	2.6	2.80	41.11		
		29.98	0.6	1.20	7.56		
51	15/3/16 10:53:22 to 17/3/16 7:50:57	57.24	0.2	0.21	1.20	1.08	10.8
		19.13	0.6	1.88	8.58		
		13.76	0.6	2.62	9.33		
		5.19	0.2	2.31	3.02		
		21.96	1.4	3.83	23.78		
		47.99	0.2	0.25	1.33		
		56.18	0.2	0.21	1.21		
		51.18	0.2	0.23	1.28		
		40.01	1.2	1.80	16.95		
		45.21	3	3.98	51.41		
		58.5	3.8	3.90	64.82		
		54.81	1.6	1.75	22.44		
		49.16	1	1.22	12.66		
		42.98	0.8	1.12	9.86		
		11.95	0.2	1.12	2.46		

		36.33	0.2	0.33	1.54		
		23.06	0.2	0.52	1.88		
		50.99	0.2	0.24	1.28		
		46.96	1.6	2.04	23.38		
		55.09	1	1.09	12.22		
54	24/3/16 4:48:48 to 24/3/16 6:58:5	3.95	1.4	21.27	32.89	6.22	62.2
		32.98	1	1.82	14.17		
		10.74	0.4	2.23	5.98		
		40.9	0.2	0.29	1.45		
		31.87	1.6	3.01	25.73		
		52.4	1.4	1.60	19.16		
		40.62	0.8	1.18	10.03		
		49.27	1.8	2.19	26.78		
		15.22	0.6	2.37	9.10		
		15.27	1.2	4.72	21.34		
		55.88	6.4	6.87	122.93		
		5.28	0.2	2.27	3.00		
56	1/4/16 12:11:2 to 1/4/16 18:31:7	41.9	4.4	6.30	83.07	2.41	24.1
		43.9	6	8.20	119.27		
		46.92	2.8	3.58	46.86		
		48.12	0.8	1.00	9.51		
		45.26	1	1.33	12.97		
		37.9	1.4	2.22	20.88		
		38.48	0.2	0.31	1.50		
57	2/4/16 4:47:32 to 3/4/16 9:6:51	6.28	1	9.55	20.46	3.79	37.9
		10	0.8	4.80	14.28		
		34.32	0.2	0.35	1.58		
		5.97	0.2	2.01	2.91		
		36.17	0.2	0.33	1.54		
		34.87	1.6	2.75	25.18		
		27.08	2	4.43	35.09		
		11.91	1.2	6.05	22.47		
		53.95	1	1.11	12.30		
		7.17	0.8	6.69	15.29		
		8.32	0.2	1.44	2.66		
		10.06	0.4	2.39	6.08		
		23.63	0.6	1.52	8.10		
		1.08	0.2	11.11	4.21		
		32.09	1.4	2.62	21.77		
		2.34	0.4	10.26	8.29		
		31.88	2.6	4.89	46.59		
		38.32	1	1.57	13.60		
		29.04	0.8	1.65	11.04		
		52.66	1.4	1.60	19.14		
		46.37	1.4	1.81	19.81		
		50.04	1.8	2.16	26.67		
		13.29	0.2	0.90	2.30		
73	4/6/16 2:53:22	56.28	0.2	0.21	1.21	4.41	44.1
		46.09	12.2	15.88	273.08		
		4.28	0.2	2.80	3.16		

Water content, dry density, wet density and three phases of soil

Sample	No of core	mass of core	Core mass + soil	Wet density	WC	Dry density	Porosity	Voids ratio	Degree of saturatio	Solid phase	Liquid phase	Gas phase
Farmlands	N12	90.00	241.47	1.51	3.29	1.47	45.78	0.84	10.60	54.22	4.83	40.95
	N25	94.18	274.18	1.80	18.8	1.52	42.27	0.73	67.84	57.73	28.54	13.74
	N30	92.64	259.30	1.67	17.25	1.42	46.46	0.86	53.09	53.54	24.56	21.89
Governmental farm	A60	95.12	274.04	1.79	15.93	1.54	43.98	0.78	56.26	56.02	24.63	19.35
	A12	94.56	279.06	1.85	15.49	1.60	40.50	0.67	61.54	59.50	24.79	15.71
	A14	94.90	250.14	1.55	16.17	1.34	50.41	1.01	43.09	49.59	21.65	28.76
Orchards	A9	94.54	271.01	1.76	19.75	1.47	44.49	0.80	65.83	55.51	29.16	15.33
	N23	94.15	269.69	1.76	22.63	1.43	47.85	0.91	68.09	52.15	32.45	15.40
	N2	92.99	277.28	1.84	21.98	1.51	44.76	0.80	74.66	55.24	33.27	11.49
Uncultivated lands	N14	94.20	284.49	1.90	2.32	1.86	30.47	0.43	14.30	69.53	4.32	26.15
	N9	93.15	243.07	1.50	2.35	1.46	46.64	0.87	7.42	53.36	3.45	43.19
	N7	94.83	249.07	1.54	2.27	1.51	45.06	0.81	7.65	54.94	3.43	41.63

Field experiment tabulated soil loss

Plots	Time (min.)	No of Can	Weight of Can	Weight of Can +Soil	Soil Loss (g/10 ml)	Soil Loss (mg/10 ml)	mg/L	Q (L)	Load (mg)	Area (sq.m)	Specific load (mg/sq.m)	Specific load (g/ha)
Control1	5	21	76.0246	76.2391	0.21	214.50	21450.00	0.31	6649.50	0.22	30225.00	302250.00
	10	M2	41.5288	41.7236	0.19	194.80	19480.00	0.47	9155.60	0.22	41616.36	416163.64
	15	31	77.0459	77.175	0.13	129.10	12910.00	0.70	9037.00	0.22	41077.27	410772.73
	20	11	76.2843	76.3922	0.11	107.90	10790.00	0.79	8470.15	0.22	38500.68	385006.82
	25	35	76.4727	76.5783	0.11	105.60	10560.00	0.89	9398.40	0.22	42720.00	427200.00
	30	M8	39.7155	39.815	0.10	99.50	9950.00	0.99	9850.50	0.22	44775.00	447750.00
			Total soil loss				85140.00	4.14	352479.60	0.22	1602180.00	16021800.00
Control2	5	36	76.2725	76.3773	0.10	104.80	10480.00	0.40	4192.00	0.22	19054.55	190545.45
	10	M5	41.4784	41.5692	0.09	90.80	9080.00	0.55	4994.00	0.22	22700.00	227000.00
	15	A53	43.3609	43.439	0.08	78.10	7810.00	0.74	5779.40	0.22	26270.00	262700.00
	20	K1	41.0522	41.1149	0.06	62.70	6270.00	0.81	5078.70	0.22	23085.00	230850.00
	25	M6	40.6197	40.68	0.06	60.30	6030.00	0.90	5427.00	0.22	24668.18	246681.82
	30	3	76.6880	76.7551	0.07	67.10	6710.00	0.92	6173.20	0.22	28060.00	280600.00
			Total soil loss				46380.00	4.32	200361.60	0.22	910734.55	9107345.45
Maize	5	A4	41.8693	41.9416	0.07	72.30	7230.00	0.29	2096.70	0.22	9530.45	95304.55
	10	A65	41.8527	41.9031	0.05	50.40	5040.00	0.57	2847.60	0.22	12943.64	129436.36
	15	A69	42.870	42.9103	0.04	40.30	4030.00	0.72	2901.60	0.22	13189.09	131890.91
	20	K20	42.0514	42.0974	0.05	46.00	4600.00	0.81	3703.00	0.22	16831.82	168318.18
	25	M7	39.8966	39.9438	0.05	47.20	4720.00	0.89	4200.80	0.22	19094.55	190945.45
	30	4	76.8851	76.931	0.05	45.90	4590.00	0.90	4131.00	0.22	18777.27	187772.73
			Total soil loss				30210.00	4.17	125975.70	0.22	572616.82	5726168.18
Maize	5	A55	41.8971	41.9816	0.08	84.50	8450.00	0.28	2366.00	0.22	10754.55	107545.45
	10	46	76.3847	76.4331	0.05	48.40	4840.00	0.42	2032.80	0.22	9240.00	92400.00
	15	A57	43.3131	43.3603	0.05	47.20	4720.00	0.60	2832.00	0.22	12872.73	128727.27
	20	A70	42.6382	42.6854	0.05	47.20	4720.00	0.69	3256.80	0.22	14803.64	148036.36
	25	A54	41.5737	41.6099	0.04	36.20	3620.00	0.87	3149.40	0.22	14315.45	143154.55
	30	M5	40.0084	40.071	0.06	62.60	6260.00	0.99	6197.40	0.22	28170.00	281700.00
			Total soil loss				32610.00	3.85	125548.50	0.22	570675.00	5706750.00
Clover	5	12	77.1511	77.1633	0.01	12.20	1220.00	0.09	103.70	0.22	471.36	4713.64
	10	K29	40.2020	40.216	0.01	14.00	1400.00	0.31	434.00	0.22	1972.73	19727.27
	15	A50	38.6406	38.6527	0.01	12.10	1210.00	0.50	605.00	0.22	2750.00	27500.00
	20	A20	38.3385	38.3512	0.01	12.70	1270.00	0.61	774.70	0.22	3521.36	35213.64
	25	26	75.9980	76.009	0.01	11.00	1100.00	0.70	770.00	0.22	3500.00	35000.00
	30	A66	42.6022	42.6123	0.01	10.10	1010.00	0.80	808.00	0.22	3672.73	36727.27
			Total soil loss				7210.00	3.01	21666.05	0.22	98482.05	984820.45
Clover	5	36	76.2725	76.2891	0.02	16.60	1660.00	0.09	149.40	0.22	679.09	6790.91
	10	M5	41.4784	41.4936	0.02	15.20	1520.00	0.30	456.00	0.22	2072.73	20727.27
	15	A53	43.3609	43.3709	0.01	10.00	1000.00	0.52	520.00	0.22	2363.64	23636.36
	20	K1	41.0522	41.0652	0.01	13.00	1300.00	0.67	871.00	0.22	3959.09	39590.91
	25	M1	40.6197	40.6283	0.01	8.60	860.00	0.73	627.80	0.22	2853.64	28536.36
	30	3	76.6880	76.6975	0.01	9.50	950.00	0.81	769.50	0.22	3497.73	34977.27
			Total soil loss				7290.00	3.12	22744.80	0.22	103385.45	1033854.55
Gypsume1	5	M8	40.4516	40.4997	0.05	48.10	4810.00	0.15	721.50	0.22	3279.55	32795.45
	10	A56	42.6753	42.7216	0.05	46.30	4630.00	0.30	1389.00	0.22	6313.64	63136.36
	15	A68	41.0629	41.1085	0.05	45.60	4560.00	0.53	2416.80	0.22	10985.45	109854.55
	20	A70	42.6382	42.6767	0.04	38.50	3850.00	0.66	2541.00	0.22	11550.00	115500.00
	25	A54	41.5737	41.5991	0.03	25.40	2540.00	0.76	1930.40	0.22	8774.55	87745.45
	30	M5	40.0084	40.0348	0.03	26.40	2640.00	0.85	2244.00	0.22	10200.00	102000.00
			Total soil loss				23030.00	3.25	74847.50	0.22	340215.91	3402159.09
Gypsume2	5	A55	41.8971	41.9536	0.06	56.50	5650.00	0.17	960.50	0.22	4365.91	43659.09
	10	46	76.3847	76.4397	0.06	55.00	5500.00	0.38	2090.00	0.22	9500.00	95000.00
	15	A57	43.3131	43.3676	0.05	54.50	5450.00	0.62	3379.00	0.22	15359.09	153590.91
	20	A85	41.7558	41.8092	0.0534	53.40	5340	0.75	4005	0.22	18204.55	182045.45
	25	M9	40.7732	40.8147	0.0415	41.50	4150	0.8	3320	0.22	15090.91	150909.09
	30	A51	42.5297	42.5677	0.038	38.00	3800	0.83	3154	0.22	14336.36	143363.64
			Total soil loss				29890	3.55	106109.5	0.22	482315.91	4823159.09

Surface runoff experiment tabulated soil loss

Plots	T (min.)	No of can	Weight of can	Weight of can +soil	Soil Loss (g/10 ml)	Soil loss (mg/10 ml)	mg/L	Q (L)	Load (mg)	Area (sq.m)	Specific load (mg/sq.m)	Specific load (g/ha)
Control-1	5	21	76.0246	76.2391	0.21	214.50	21450.00	0.31	6649.50	0.22	30225.00	302250.00
	10	M12	41.5288	41.7236	0.19	194.80	19480.00	0.47	9155.60	0.22	41616.36	416163.64
	15	31	77.0459	77.175	0.13	129.10	12910.00	0.70	9037.00	0.22	41077.27	410772.73
	20	11	76.2843	76.3922	0.11	107.90	10790.00	0.79	8470.15	0.22	38500.68	385006.82
	25	35	76.4727	76.5783	0.11	105.60	10560.00	0.89	9398.40	0.22	42720.00	427200.00
	30	M18	39.7155	39.815	0.10	99.50	9950.00	0.99	9850.50	0.22	44775.00	447750.00
			Total soil loss				85140.00	4.14	352479.60	0.22	1602180.00	16021800.00
Control-2	5	36	76.2725	76.3773	0.10	104.80	10480.00	0.40	4192.00	0.22	19054.55	190545.45
	10	M5	41.4784	41.5692	0.09	90.80	9080.00	0.55	4994.00	0.22	22700.00	227000.00
	15	A53	43.3609	43.439	0.08	78.10	7810.00	0.74	5779.40	0.22	26270.00	262700.00
	20	K1	41.0522	41.1149	0.06	62.70	6270.00	0.81	5078.70	0.22	23085.00	230850.00
	25	M16	40.6197	40.68	0.06	60.30	6030.00	0.90	5427.00	0.22	24668.18	246681.82
	30	3	76.6880	76.7551	0.07	67.10	6710.00	0.92	6173.20	0.22	28060.00	280600.00
			Total soil loss				46380.00	4.32	200361.60	0.22	910734.55	9107345.45
Maize-1	5	A4	41.8693	41.9416	0.07	72.30	7230.00	0.29	2096.70	0.22	9530.45	95304.55
	10	A65	41.8527	41.9031	0.05	50.40	5040.00	0.57	2847.60	0.22	12943.64	129436.36
	15	A69	42.870	42.9103	0.04	40.30	4030.00	0.72	2901.60	0.22	13189.09	131890.91
	20	K20	42.0514	42.0974	0.05	46.00	4600.00	0.81	3703.00	0.22	16831.82	168318.18
	25	M17	39.8966	39.9438	0.05	47.20	4720.00	0.89	4200.80	0.22	19094.55	190945.45
	30	4	76.8851	76.931	0.05	45.90	4590.00	0.90	4131.00	0.22	18777.27	187772.73
			Total soil loss				30210.00	4.17	125975.70	0.22	572616.82	5726168.18
Maize-2	5	A55	41.8971	41.9816	0.08	84.50	8450.00	0.28	2366.00	0.22	10754.55	107545.45
	10	46	76.3847	76.4331	0.05	48.40	4840.00	0.42	2032.80	0.22	9240.00	92400.00
	15	A57	43.3131	43.3603	0.05	47.20	4720.00	0.60	2832.00	0.22	12872.73	128727.27
	20	A70	42.6382	42.6854	0.05	47.20	4720.00	0.69	3256.80	0.22	14803.64	148036.36
	25	A54	41.5737	41.6099	0.04	36.20	3620.00	0.87	3149.40	0.22	14315.45	143154.55
	30	M15	40.0084	40.071	0.06	62.60	6260.00	0.99	6197.40	0.22	28170.00	281700.00
			Total soil loss				32610.00	3.85	125548.50	0.22	570675.00	5706750.00
Clover-1	5	12	77.1511	77.1633	0.01	12.20	1220.00	0.09	103.70	0.22	471.36	4713.64
	10	K29	40.2020	40.216	0.01	14.00	1400.00	0.31	434.00	0.22	1972.73	19727.27
	15	A50	38.6406	38.6527	0.01	12.10	1210.00	0.50	605.00	0.22	2750.00	27500.00
	20	A20	38.3385	38.3512	0.01	12.70	1270.00	0.61	774.70	0.22	3521.36	35213.64
	25	26	75.9980	76.009	0.01	11.00	1100.00	0.70	770.00	0.22	3500.00	35000.00
	30	A66	42.6022	42.6123	0.01	10.10	1010.00	0.80	808.00	0.22	3672.73	36727.27
			Total soil loss				7210.00	3.01	21666.05	0.22	98482.05	984820.45
Clover-2	5	36	76.2725	76.2891	0.02	16.60	1660.00	0.09	149.40	0.22	679.09	6790.91
	10	M5	41.4784	41.4936	0.02	15.20	1520.00	0.30	456.00	0.22	2072.73	20727.27
	15	A53	43.3609	43.3709	0.01	10.00	1000.00	0.52	520.00	0.22	2363.64	23636.36
	20	K1	41.0522	41.0652	0.01	13.00	1300.00	0.67	871.00	0.22	3959.09	39590.91
	25	M16	40.6197	40.6283	0.01	8.60	860.00	0.73	627.80	0.22	2853.64	28536.36
	30	3	76.6880	76.6975	0.01	9.50	950.00	0.81	769.50	0.22	3497.73	34977.27
			Total soil loss				7290.00	3.12	22744.80	0.22	103385.45	1033854.55
Gypsume-1	5	M8	40.4516	40.4997	0.05	48.10	4810.00	0.15	721.50	0.22	3279.55	32795.45
	10	A56	42.6753	42.7216	0.05	46.30	4630.00	0.30	1389.00	0.22	6313.64	63136.36
	15	A68	41.0629	41.1085	0.05	45.60	4560.00	0.53	2416.80	0.22	10985.45	109854.55
	20	A70	42.6382	42.6767	0.04	38.50	3850.00	0.66	2541.00	0.22	11550.00	115500.00
	25	A54	41.5737	41.5991	0.03	25.40	2540.00	0.76	1930.40	0.22	8774.55	87745.45
	30	M15	40.0084	40.0348	0.03	26.40	2640.00	0.85	2244.00	0.22	10200.00	102000.00
			Total soil loss				23030.00	3.25	74847.50	0.22	340215.91	3402159.09
Gypsume-2	5	A55	41.8971	41.9536	0.06	56.50	5650.00	0.17	960.50	0.22	4365.91	43659.09
	10	46	76.3847	76.4397	0.06	55.00	5500.00	0.38	2090.00	0.22	9500.00	95000.00
	15	A57	43.3131	43.3676	0.05	54.50	5450.00	0.62	3379.00	0.22	15359.09	153590.91
	20	A85	41.7558	41.8092	0.0534	53.40	5340	0.75	4005	0.22	18204.55	182045.45
	25	M9	40.7732	40.8147	0.0415	41.50	4150	0.8	3320	0.22	15090.91	150909.09
	30	A51	42.5297	42.5677	0.038	38.00	3800	0.83	3154	0.22	14336.36	143363.64
			Total soil loss				29890	3.55	106109.5	0.22	482315.91	4823159.09

Particle size distribution of soil

Sample	Plate no.	Plate mass (g)	Plate + particle (g)	Particle (g)	Coarse (0.2 - 2 mm)	Gravel (g)
Farmlands	MM69	90.82	91.45	0.63	0.62	0.01
	MM26	136.78	137.29	0.51	0.51	0.00
	MM17	136.17	137.07	0.9	0.86	0.04
Governmental farm	CC74	109.89	110.44	0.55	0.47	0.08
	MM57	136.89	137.61	0.72	0.54	0.18
	MM57	136.89	137.47	0.58	0.41	0.17
Orchards	N28	120.55	120.88	0.33	0.33	0.00
	CC206	37.03	37.36	0.33	0.33	0.00
	N1	121.89	122.28	0.39	0.33	0.06
Uncultivated lands	MM26	136.78	138.12	1.34	1.32	0.02
	CC74	109.89	111.1	1.21	1.11	0.10
	N28	120.55	121.76	1.21	1.17	0.04

Sample	Can no.	Can mass (g)	Can + particle (g)	Particle (g)	Silt (0.02 - 0.002 mm)
Farmlands	K7	40.8990	41.0420	6.3340	4.2150
	24	76.8936	77.0145	5.2290	3.4050
	10	75.6251	75.7593	5.8940	3.6200
Governmental farm	K1	41.0780	41.2018	5.3740	3.1900
	K17	39.7058	39.8278	5.2840	3.0200
	K26	41.4391	41.5658	5.5190	3.2150
Orchards	A50	38.6642	38.7937	5.6590	3.5250
	M9	40.7985	40.9216	5.3390	3.0750
	A77	40.4582	40.5774	5.1440	3.1000
Uncultivated lands	M1	40.2623	40.3458	3.3590	2.2050
	M13	41.1523	41.2308	3.1090	1.9900
	K19	39.9112	39.9878	3.0140	1.9750
Sample	**Can no.**	**Can mass (g)**	**Can + particle (g)**	**Particle (g)**	**Clay (<0.002 mm)**
Farmlands	A56	41.6753	41.7340	2.119	2.119
	28	77.4165	77.4693	1.824	1.824
	31	77.0870	77.1488	2.274	2.274
Governmental farm	42	76.7834	76.8434	2.184	2.184
	A28	39.7613	39.8229	2.264	2.264
	49	77.1182	77.1806	2.304	2.304
Orchards	40	76.7487	76.8077	2.134	2.134
	6	76.5861	76.6477	2.264	2.264
	A60	41.9379	41.9951	2.044	2.044
Uncultivated lands	11	76.3245	76.3639	1.154	1.154
	M6	40.6797	40.7184	1.119	1.119
	A66	42.6251	42.6622	1.039	1.039
Sample		**Plate no.**	**Plate mass (g)**	**Plate + particle (g)**	**Find sand (0.02-0.2 mm)**
Farmlands		5	82.92	86.16	3.24
		10	79.43	82.14	2.71
		3	80.65	83.15	2.50
Governmental farm		9	82.93	85.72	2.79
		MM69	90.81	93.43	2.62
		6	73.92	76.71	2.79
Orchards		8	82.49	85.01	2.52
		7	80.22	82.27	2.05
		11	74.33	77.04	2.71
Uncultivated lands		N28	120.54	125.76	5.22
		N1	121.83	127.20	5.37
		2	82.60	88.27	5.67

Nitrogen and Phosphorus in soil

Sample	Soil (g)	R (mg/L)	N (g/g)	×10^-5 g/g	Avg. N	N (mg/kg)	Soil (g)	R (mg/L)	P (g/g)	×10^-5 g/g	Avg. P	mg/kg
	0.0243	0.25	0.00061728	61.73			0.0260	0.17	0.000392	39.23		
	0.0243	0.19	0.00046914	46.91	55.97	559.67	0.0260	0.17	0.000392	39.23	39.23	392.31
	0.0243	0.24	0.00059259	59.26			0.0260	0.17	0.000392	39.23		
	0.0281	0.24	0.00051246	51.25			0.0202	0.20	0.000594	59.41		
Farmlands	0.0281	0.33	0.00070463	70.46	60.50	604.98	0.0202	0.20	0.000594	59.41	59.41	594.06
	0.0281	0.28	0.00059786	59.79			0.0202	0.20	0.000594	59.41		
	0.0289	0.32	0.00066436	66.44			0.0230	0.27	0.000704	70.43		
	0.0289	0.3	0.00062284	62.28	72.66	726.64	0.0230	0.25	0.000652	65.22	66.09	660.87
	0.0289	0.43	0.00089273	89.27			0.0230	0.24	0.000626	62.61		
	0.0231	0.16	0.00041558	41.56			0.0256	0.21	0.000492	49.22		
	0.0231	0.15	0.00038961	38.96	40.69	406.93	0.0256	0.21	0.000492	49.22	48.44	484.38
	0.0231	0.16	0.00041558	41.56			0.0256	0.20	0.000469	46.88		
	0.0253	0.18	0.00042688	42.69			0.0235	0.21	0.000536	53.62		
Governmental farm	0.0253	0.19	0.00045059	45.06	43.48	434.78	0.0235	0.22	0.000562	56.17	55.32	553.19
	0.0253	0.18	0.00042688	42.69			0.0235	0.22	0.000562	56.17		
	0.0212	0.17	0.00048113	48.11			0.0241	0.18	0.000448	44.81		
	0.0212	0.17	0.00048113	48.11	46.23	462.26	0.0241	0.18	0.000448	44.81	44.81	448.13
	0.0212	0.15	0.00042453	42.45			0.0241	0.18	0.000448	44.81		
	0.0203	0.24	0.00070936	70.94			0.0223	0.19	0.000511	51.12		
	0.0203	0.26	0.00076847	76.85	72.91	729.06	0.0223	0.18	0.000484	48.43	49.33	493.27
	0.0203	0.24	0.00070936	70.94			0.0223	0.18	0.000484	48.43		
	0.0256	0.28	0.00065625	65.63			0.0252	0.21	0.000500	50.00		
Orchards	0.0256	0.28	0.00065625	65.63	68.75	687.50	0.0252	0.22	0.000524	52.38	50.79	507.94
	0.0256	0.32	0.00075	75.00			0.0252	0.21	0.000500	50.00		
	0.0266	0.52	0.00117293	117.29			0.0274	0.25	0.000547	54.74		
	0.0266	0.52	0.00117293	117.29	128.57	1285.71	0.0274	0.25	0.000547	54.74	54.74	547.45
	0.0266	0.67	0.00151128	151.13			0.0274	0.25	0.000547	54.74		
	0.0282	0.21	0.00044681	44.68			0.0243	0.12	0.000296	29.63		
	0.0282	0.16	0.00034043	34.04	36.17	361.70	0.0243	0.12	0.000296	29.63	30.45	304.53
	0.0282	0.14	0.00029787	29.79			0.0243	0.13	0.000321	32.10		
	0.0267	0.14	0.00031461	31.46			0.0203	0.10	0.000296	29.56		
Uncultivated lands	0.0267	0.16	0.00035955	35.96	36.70	367.04	0.0203	0.09	0.000266	26.60	29.56	295.57
	0.0267	0.19	0.00042697	42.70			0.0203	0.11	0.000325	32.51		
	0.0251	0.15	0.00035857	35.86			0.0219	0.10	0.000274	27.40		
	0.0251	0.20	0.00047809	47.81	42.23	422.31	0.0219	0.10	0.000274	27.40	26.48	264.84
	0.0251	0.18	0.00043028	43.03			0.0219	0.09	0.000247	24.66		

Calculated table of permeability experiment

Sample	Core no.	Cross section area of core (A)	Cross section area of pipe	Upper water level (H1)	Lower water level (H2)	Length of core	Time (second)	Permeability (cm/sec)	Average	Permeability cm/sec	Permeability mm/hr
Farmlands		19.63	0.5	18.5	15.5	3	440	3.0693E-05			
	N12	19.63	0.5	18.5	15.5	3	457	2.95509E-05	2.87E-05		
		19.63	0.5	18.5	15.5	3	521	2.59208E-05			
		19.63	0.5	18.5	15.5	3	282	4.78892E-05			
	N25	19.63	0.5	18.5	15.5	3	286	4.72194E-05	4.72E-05	3.42E-05	1.23
		19.63	0.5	18.5	15.5	3	291	4.64081E-05			
		19.63	0.5	18.5	15.5	3	495	2.72823E-05			
	N30	19.63	0.5	18.5	15.5	3	500	2.70095E-05	2.67E-05		
		19.63	0.5	18.5	15.5	3	525	2.57233E-05			
Governmental farm		19.63	0.5	18.5	15.5	3	754	1.79108E-05			
	A60	19.63	0.5	18.5	15.5	3	800	1.68809E-05	1.67E-05		
		19.63	0.5	18.5	15.5	3	878	1.53813E-05			
		19.63	0.5	18.5	15.5	3	880	1.53463E-05			
	A12	19.63	0.5	18.5	15.5	3	895	1.50891E-05	1.51E-05	1.51E-05	0.54
		19.63	0.5	18.5	15.5	3	905	1.49224E-05			
		19.63	0.5	18.5	15.5	3	972	1.38938E-05			
	A14	19.63	0.5	18.5	15.5	3	1000	1.35047E-05	1.34E-05		
		19.63	0.5	18.5	15.5	3	1063	1.27044E-05			
Orchards		19.63	0.5	18.5	15.5	3	400	3.37619E-05			
	A9	19.63	0.5	18.5	15.5	3	371	3.64009E-05	3.46E-05		
		19.63	0.5	18.5	15.5	3	400	3.37619E-05			
		19.63	0.5	18.5	15.5	3	222	6.08322E-05			
	N23	19.63	0.5	18.5	15.5	3	245	5.51214E-05	5.69E-05	4.25E-05	1.53
		19.63	0.5	18.5	15.5	3	247	5.46751E-05			
		19.63	0.5	18.5	15.5	3	355	3.80415E-05			
	N2	19.63	0.5	18.5	15.5	3	370	3.64993E-05	3.61E-05		
		19.63	0.5	18.5	15.5	3	400	3.37619E-05			
Uncultivated lands		19.63	0.5	18.5	15.5	3	115	0.000117433			
	N14	19.63	0.5	18.5	15.5	3	126	0.00010718	1.09E-04		
		19.63	0.5	18.5	15.5	3	133	0.000101539			
		19.63	0.5	18.5	15.5	3	51	0.000264799			
	N9	19.63	0.5	18.5	15.5	3	52	0.000259707	2.61E-04	1.93E-04	6.93
		19.63	0.5	18.5	15.5	3	52	0.000259707			
		19.63	0.5	18.5	15.5	3	60	0.000225079			
	N7	19.63	0.5	18.5	15.5	3	66	0.000204617	2.08E-04		
		19.63	0.5	18.5	15.5	3	70	0.000192925			

Cation concentration in surface runoff (surface runoff experiment)

	Gypsum-treated loamy soil texture									Control loamy soil texture								
Time	Ca (mg/L)			Mg (mg/L)			Na (mg/L)			Ca (mg/L)			Mg (mg/L)			Na (mg/L)		
5	400	400	420	15	16	23	23	22	21	96	102	100	27	20	10	30	33	31
10	400	380	400	10	13	20	21	22	23	140	100	104	21	21	12	23	30	29
15	385	375	370	13	10	20	20	20	20	93	95	125	20	22	11	25	27	30
20	377	350	338	10	12	19	20	19	21	179	140	85	22	19	9	23	26	24
25	365	345	240	12	8	20	20	19	20	117	80	110	19	21	7	21	24	23
30	334	333	200	9	9	21	20	21	22	94	85	90	15	18	5	20	26	25
	Gypsum- treated sandy loam soil texture									Control sandy loam soil texture								
Time	Ca (mg/L)			Mg (mg/L)			Na (mg/L)			Ca (mg/L)			Mg (mg/L)			Na (mg/L)		
5	400	400	490	32	33	26	30	25	24	92	90	100	12	12	10	34.66	33	31
10	400	400	400	28	24	24	25	25.3	24	70	85	85	10	9	12	28	30	29
15	400	400	375	25	24	25	25	25	26	73	70	80	14	10	11	27	27	30
20	386	400	380	25	26	25	25	26	23	56	70	80	10	11	9	26	26	24
25	351	398	360	27	26	23	25	23	24	67	60	60	12	10	7	25	24	23
30	315	375	330	27	25	22	25	23	22	87	58	45	7	6	5	25	26	25

Comparisons of observed erosion pins results with USLE/GIS

Average difference (m)	Area (m^2)	Volume (m^3)	pd (kg/m^3)	Soil loss (kg)	Soil loss (t)	Soil loss (t/ha)	R/r	A/a
0.004	0.09	0.00036	1490	0.5364	0.0005364	59.6	2.33	0.84
0.00175	0.09	0.0001575	1490	0.234675	0.000234675	26.075	2.33	1.92
0.00025	0.09	0.0000225	1490	0.033525	0.000033525	3.725	2.33	13.42
0.00125	0.09	0.0001125	1490	0.167625	0.000167625	18.625	2.33	2.68
-0.0015	0.09	-0.000135	1490	-0.20115	-0.00020115	-22.35	2.33	-2.24
-0.00175	0.09	-0.0001575	1490	-0.234675	-0.000234675	-26.075	2.33	-1.92
0.00175	0.09	0.0001575	1490	0.234675	0.000234675	26.075	2.33	1.92
0.00375	0.09	0.0003375	1490	0.502875	0.000502875	55.875	2.33	0.89
0.00375	0.09	0.0003375	1490	0.502875	0.000502875	55.875	2.33	0.89
0.00225	0.09	0.0002025	1490	0.301725	0.000301725	33.525	2.33	1.49
0.00075	0.09	0.0000675	1490	0.100575	0.000100575	11.175	2.33	4.47
-0.0025	0.09	-0.000225	1490	-0.33525	-0.00033525	-37.25	2.33	-1.34
-0.001	0.09	-0.00009	1490	-0.1341	-0.0001341	-14.9	2.33	-3.36
0.00225	0.09	0.0002025	1490	0.301725	0.000301725	33.525	2.33	1.49
0.00025	0.09	0.0000225	1490	0.033525	0.000033525	3.725	2.33	13.42
-0.00025	0.09	-0.0000225	1490	-0.033525	-0.000033525	-3.725	2.33	-13.42
-0.001	0.09	-0.00009	1490	-0.1341	-0.0001341	-14.9	2.33	-3.36
-0.00325	0.09	-0.0002925	1490	-0.435825	-0.000435825	-48.425	2.33	-1.03
-0.00225	0.09	-0.0002025	1490	-0.301725	-0.000301725	-33.525	2.33	-1.49
-0.0015	0.09	-0.000135	1490	-0.20115	-0.00020115	-22.35	2.33	-2.24
-0.00175	0.09	-0.0001575	1490	-0.234675	-0.000234675	-26.075	2.33	-1.92
0.00075	0.09	0.0000675	1490	0.100575	0.000100575	11.175	2.33	4.47
-0.00075	0.09	-0.0000675	1490	-0.100575	-0.000100575	-11.175	2.33	-4.47
-0.00225	0.09	-0.0002025	1490	-0.301725	-0.000301725	-33.525	2.33	-1.49
-0.00275	0.09	-0.0002475	1490	-0.368775	-0.000368775	-40.975	2.33	-1.22
0.00025	0.09	0.0000225	1490	0.033525	0.000033525	3.725	2.33	13.42
-0.00025	0.09	-0.0000225	1490	-0.033525	-0.000033525	-3.725	2.33	-13.42
-0.0025	0.09	-0.000225	1490	-0.33525	-0.00033525	-37.25	2.33	-1.34
0	0.09	0	1490	0	0	0	0	0
-0.00125	0.09	-0.0001125	1490	-0.167625	-0.000167625	-18.625	2.33	-2.68
-0.00125	0.09	-0.0001125	1490	-0.167625	-0.000167625	-18.625	2.33	-2.68
-0.00175	0.09	-0.0001575	1490	-0.234675	-0.000234675	-26.075	2.33	-1.92
0.00025	0.09	0.0000225	1490	0.033525	0.000033525	3.725	2.33	13.42
0.00075	0.09	0.0000675	1490	0.100575	0.000100575	11.175	2.33	4.47
-0.00175	0.09	-0.0001575	1490	-0.234675	-0.000234675	-26.075	2.33	-1.92