RISK ASSESSMENT OF SOIL EROSION IN RAWAL WATERSHED USING GEOINFORMATICS TECHNIQUES

Bashir, S.[1], Baig, M. A.[2], Ashraf, M.[2], Anwar, M. M.[3], Bhalli, M. N.[4], Munawar, S.[5]

1. GIS Assistant, United Nations World Food Programme
2. IESE-NUST
3. Department of Geosciences and Geography, University of Gujrat, Pakistan
4. Department of Geography, University of the Punjab, Lahore-Pakistan
5. Department of Environmental Sciences, University of Gujrat, Pakistan

Corresponding author: nasarbhalli@yahoo.com

Abstract: *Soil erosion due to water is becoming a serious problem in rain fed areas of Pothwar region, Pakistan. Rawal lake, a major source of water supply for Islamabad and Rawalpindi has reduced in its storage capacity over the past few decades. This research aims to assess soil erosion risk in Rawal watershed using Coordination of Information on the Environment (CORINE) model which is based on soil, precipitation, temperature, slope and vegetation cover. Soil maps are used to extract soil texture, soil depth and stoniness data which are overlaid to generate soil erodibility map. Precipitation and temperature data of 18 years (1988-2005) is used to compute Modified Fournier Index (MFI) and Bagnouls-Gaussen aridity Index (BGI) that is overlaid to generate erosivity map. Slope is generated from DEM of 20m spatial resolution which is extracted from topographic sheet of scale 1:25,000. Soil erodibility, erosivity and slope maps are overlaid to produce potential soil erosion risk. Vegetation cover is generated by NDVI using SPOT-5 satellite image which is used to generate actual erosion risk map by overlay analysis with potential erosion risk map. Soil loss computed for both potential (28 tons/ha/yr) and actual erosion risks (24 tons/ha/yr) by CORINE model integrated with GIS and RS techniques proved efficient and inexpensive way to generate soil erosion risk maps*.

Keywords: CORINE, *Rawal watershed, risk maps, soil erosion, soil loss*

1. INTRODUCTION

Soil erosion, which has been occurring throughout the history of agriculture, is intensified in the recent years because of human activities, deforestation, and over-exploitation for fuel wood, overgrazing, agricultural activities and industrialization. Soil erosion rates are estimated to be highest in Asia, Africa and South America averaging 30-40 tons/ha/yr [1]. Pakistan is one of those countries of the world that are severely affected by soil erosion and it is prevailing in most parts of the country including mountainous regions, barani lands and deserts [2]. Out of the total geographical area of Pakistan, almost 15.9 Mha of land (20 per cent of total) is affected by soil erosion and out of this, 11.2 Mha (70 per cent) is affected by water erosion [3]. The sub mountainous region of Pothwar Plateau is a large barani (rain-fed) area comprising of 1.82 Mha, out of which 1.21 Mha is affected by gully erosion and only 0.61Mha is cultivated. Intensive precipitation, steep slopes and erodible soils without adequate protection have led to extensive soil erosion in the area and the consequences are devastating including loss of fertile soil and vegetation [4]. Rawal watershed is of prime importance in Pothwar region which is subject to serious problem of soil erosion. Soil erosion models are considered as a powerful tool to predict erosion on various scales. CORINE is an erosion prediction methodology based on GIS and RS techniques has been successfully used in various regions of the world to produce erosion risk maps for large watershed that can predict erosion prone areas efficiently and inexpensively. The research has used CORINE model to identify erosion prone areas, calculate soil loss and develop an erosion risk map for Rawal watershed.

1.1. Study Area Description:

The study area is Rawal watershed (Fig.1) that is located within an isolation section of Margalla Hills National Park. The drainage area is 268.69 km^2 while storage capacity of lake is 58.58 MCM, covers area of 6.35 km^2 and is located at an altitude of 675 m from sea level. The area lies in sub-humid transitional to humid sub-tropical continent with highest rainfall in northern part during monsoon season and annual rainfall is 950 – 2000 mm. Temperature ranges between 4.7 °C to 38.9 °C. The soil comprises of sandy loam and sandy clay loam with Haro basin in North, Soan River in South and Jehlum River in East of the study area. [5; 6; 7].

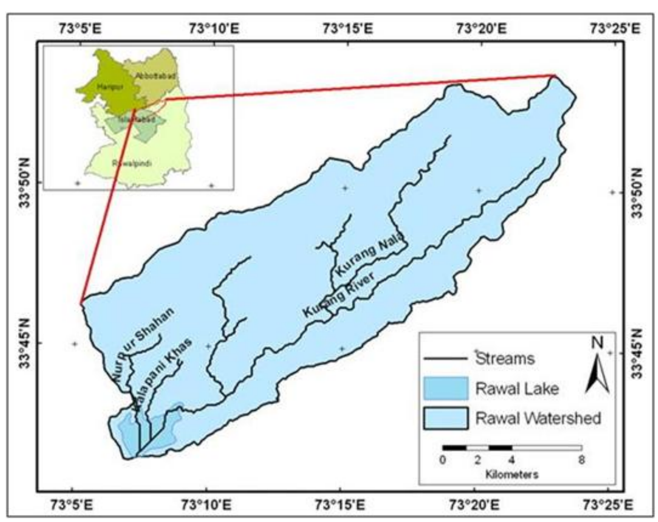

Fig. 1: Study area - Rawal watershed
Source: [8].

2. MATERIALS AND METHODS

2.1. Datasets Used: CORINE model based on soil, climate, topography (slope) and land cover parameters. Soil data is obtained from Soil Survey Reports by Soil Survey of Pakistan (SSP) of Rawalpindi, Murree-Kahuta and Haro Basin were used. Climate data comprising of monthly, annual rainfall and mean temperature for 18 years (1988-2005) is obtained from Pakistan Meteorological Department (PMD), National Agriculture Research Center (NARC), Satra Meel and Murree weather stations. Topographic sheet (1:25,000) is obtained from Survey of Pakistan (SOP) in order to generate 20 meters digital elevation model (DEM). SPOT-5 multispectral image with 2.5 m spatial resolution is purchased from Space and Upper Atmospheric Research Commission (SUPARCO), Islamabad, to calculate NDVI.

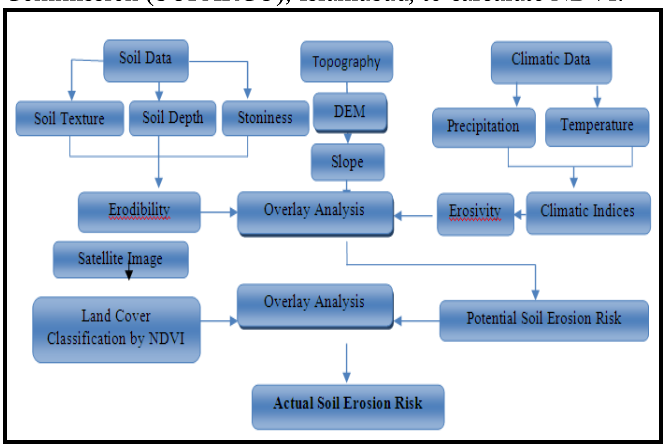

Fig. 2: Flow chart of CORINE model adopted in the present study
Source: [8].

2.2. Methodology: The data sets are used to map actual soil erosion risk according to the flow chart shown in Fig. 2. Soil erodibility is calculated by overlay analysis of soil texture, soil depth and stoniness. Soil texture is classified into three classes ranging from slight (clay, sandy clay, silty clay) to moderate (sandy clay loam, clay loam, silt clay loam, loamy sand) and high (loam, silt loand, sandy loam) erodibility. Soil depth of Rawal watershed ranged from 0-190 cm and classified into three classes i.e., low (above 75 cm depth), moderate (25-75 cm depth) and high (below 25 cm depth). Stoniness is defined as the percentage surface cover of soil with stones having diameter greater than 20 mm; study area is classified into two classes; fully protected soil (above 10% stoniness) and not fully protected soil (below 10% stoniness). Finally, soil erodibility index is classified into low (0-3 index value), moderate (3-6 index value) and high (above 6 index value) classes.

Two climate indices i.e., Modified Fournier Index (MFI) and Bagnouls-Gaussen aridity Index (BGI) are combined to map erosivity for Rawal watershed.MFI, for each climate station, is calculated by considering total monthly precipitation, Pi (mm) and mean annual precipitation, P and number of years, b using Eq. 1.

MFI= $\frac{1}{b}\sum_{i=1}^{12}\frac{P_i^2}{P}$ ……………………………………. Eq.1

Source: [9].

MFI value is spatially interpolated using Inverse Difference Weighted (IDW) algorithm to determine spatial distribution of index for the watershed which is classified into five classes according to CORINE model (Table 1).

Table 1: Classification of MFI for Rawal watershed

Class	MFI (mm)	Description
1	< 60	Very Low
2	60 – 90	Low
3	90 – 120	Moderate
4	120 – 160	High
5	> 160	Very High

Source: [9].

BGI is generally defined as dry or arid month in which monthly precipitation, P (mm) is less than twice mean monthly temperature, T (°C) [10]. To evaluate the number of dry months for Rawal watershed, precipitation and temperature data are plotted on the same graph known as ombrothermic graph while doubling the values on precipitation scale. Dry months are with mean temperature curve higher than the precipitation curve [11]. Bagnouls-Gaussen aridity index was then calculated using Eq. 2 where, it is the mean monthly temperature, pi is the average monthly precipitation , ki is a coefficient indicating the number of months, in which 2ti > pi or 2ti - pi > 0.

BGI = $\sum_{i=1}^{12}(2t_i - p_i)k_i$ ……………………………..q.2

Source: [12].

BG aridity index value for each climate station is interpolated using IDW technique in order to generate BGI surface which is classified into four classes as per CORINE requirements (Table 2).

Table 2: Climate classification based on BGI

Class	BGI Value	Climate Type
1	0	Humid
2	0 – 50	Moist
3	50 – 130	Dry
4	> 130	Very Dry

Source: [12].

Erosivity map is prepared by multiplying MFI and BGI maps using Raster Calculator and classified into low (index < 4), moderate (4-6 index) and high (index above 6).

DEM of 20 m resolution is used for slope angle generation which is classified into four classes: gentle to flat (slope < 5%), flat (5%-15%), steep (15%-30%) and very steep (above 30% slope). Finally, for potential soil erosion risk map overlay analysis is performed on erodibility, erosivity and slope which is classified into low (0-5 index), moderate (5-11 index) and high (above 11 index) erosion risk areas.

Vegetation cover is calculated by NDVI using SPOT-5 multispectral image and classified in to two classes of fully protected soil and not fully protected soil. Finally actual soil erosion risk map of study area is computed by overlay analysis of vegetation cover and potential soil erosion risk map and classified into low, moderate and high erosion risk area. CORINE is a qualitative erosion risk model that shows the severity of soil erosion in a specific area by classifying it into low, moderate and high risk. In order to calculate soil loss from CORINE erosion index values, Eq. 3 is used.

$$y = 0.0085\,x^3 - 0.0433\,x^2 + 0.785\,x \qquad \text{……Eq.3}$$

Where, y = soil loss (ton/ha), x = CORINE erosion value

Source: [13].

3. RESULTS & DISCUSSIONS

Soil erodibility map for Rawal watershed is produced by overlay analysis of soil texture, depth and stoniness. The map (Fig. 3) shows that 45 per cent (121 km^2) area is highly erodible soils found in south-west and some patches in the north. The area comprises loam, sandy loam and silty loam soils with soil depth less than 25 cm. The soil is not protected with stones which increases the risk of soil erosion. Moderately erodible soils (23 per cent, 61 km^2) have soil texture classified as sandy clay loam, clay loam and silty clay loam. The depth of these soils range between 25-75 cm and are located in a continuous pattern in north and north-east part of study area. Low erodible soils (32 per cent, 88 km^2) have clay, sandy clay and silty clay texture with soil depth greater than 75 cm and are located in south-east part. Highly erodible soils are found in Islamabad and some of the Abbottabad district. Furthermore, moderately erodible soils fall in Abbottabad and Rawalpindi district while low erodible soils fall in Rawalpindi district.

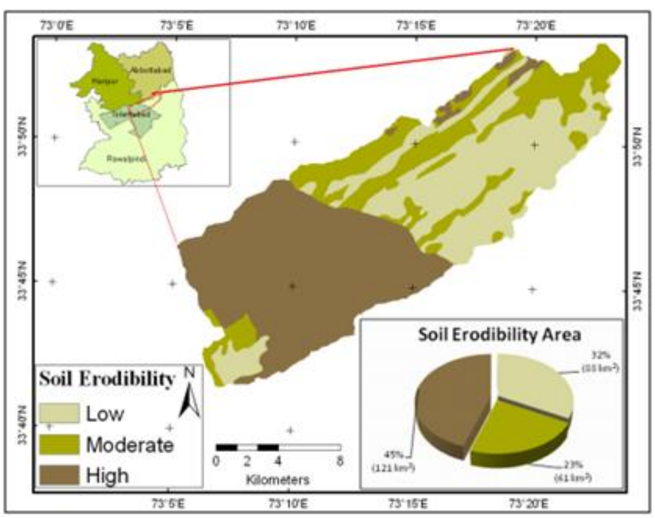

Fig. 3: Map showing the Soil Erodibility Area
Source: [8]

MFI value classified the total study area in high class because total annual rainfall in the study area is greater than 1000 mm. MFI value indicate that high precipitation causes higher runoff which is associated with erosion and classified the climate into humid, moist, dry and very dry (Table 2) by determining dry months of the year with the help of ombrothermic graph. High amount of precipitation and low temperature generate low BGI values and the index value for study area ranged between 0-21, indicating that climate of the area is sub-humid to humid. The humid climate comprises 1 per cent of the study area while sub-humid climate comprises 99 per cent including Abbottabad, Haripur, Rawalpindi and Islamabad (Fig. 4).

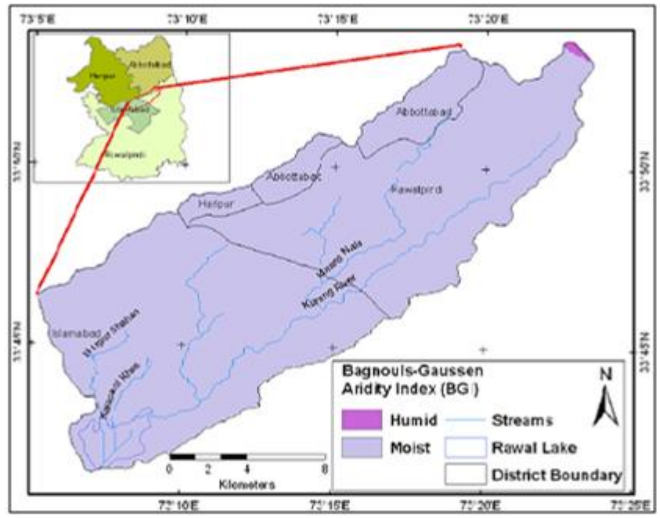

Fig. 4: Bagnouls-Gaussen aridity Index
Source: [8].

Erosivity is based on the amount and intensity of rainfall and it is determined by combining two climatic indices i.e., MFI and BGI. Erosivity map is generated by overlay analysis of these climatic indices. The moist climate contributes to erosivity and hence the area is more prone to erosion. The combined effect of indices indicates that the Rawal watershed lies in moderate erosivity (Fig. 5).

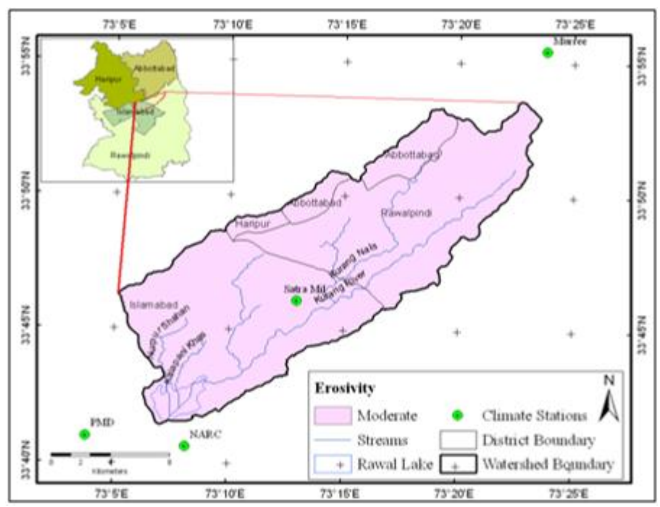

Fig. 5: Map showing the Erosivity Area
Source: [8]

Slope is an important factor in determining soil erosion, since steep slopes contribute to higher runoff rate and eventually cause high soil erosion. Slope is classified into five classes and the map shows that 23 per cent of the area has very steep slope (more than 30% gradient) and

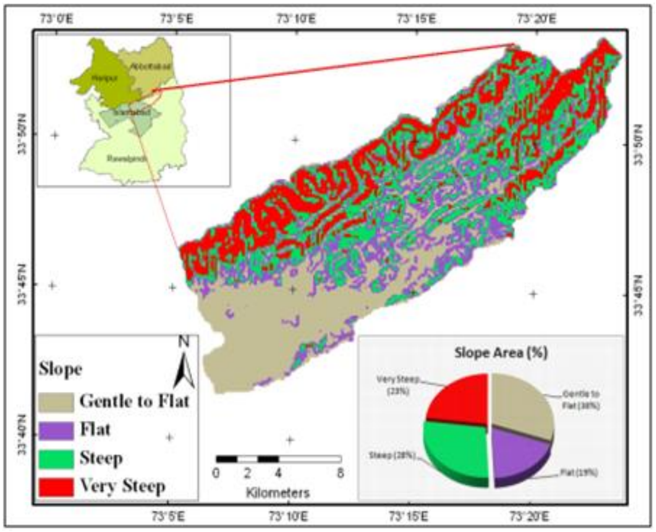

Fig. 6: Map showing the Slope area
Source: [7]

28 per cent has steep slope (15-30% gradient) which is located in a zig-zag pattern in north, north-west and south-east part (Figure 6). Flat slope (5-15% gradient) is located in central-southern part making up 19 per cent and gentle slope (less than 5% gradient) is found in south-west part making 30 per cent of area. The study area lies in a mountainous region with varying slope and high elevation range. Very steep and steep slope is distributed in upper and central parts of the study area whereas gentle slope of less than 5% is mainly located in Islamabad district.

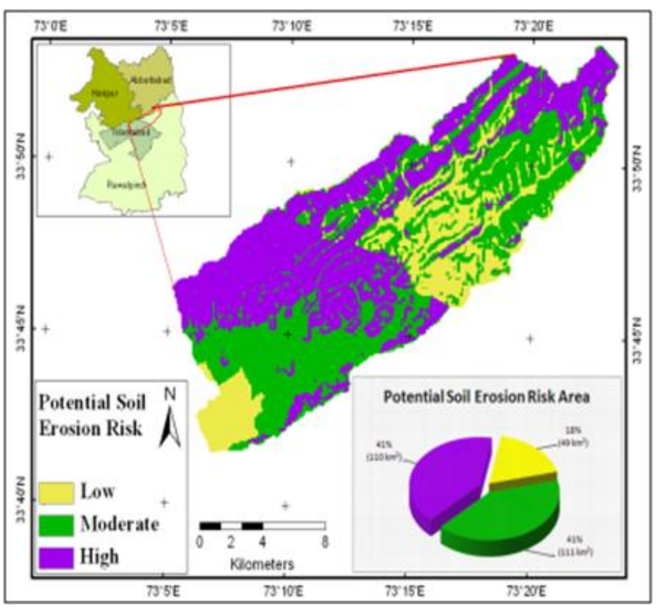

Fig. 7: Potential Soil Erosion Risk map
Source: [8].

Figure 7 indicates that 40 per cent (108 km^2) area has high erosion risk that comprises moderate to high soil erodibility and steep to very steep slopes. The area is mostly located in the western, northern and north-east part of study area falling in urban area of Islamabad, Abbottabad and Murree. Moderate erosion risk area is 41 per cent (111 km^2) and it constitutes high and low soil erodibility while slope is gentle to flat. This is located in the central part of Rawalpindi district and south-west part of Islamabad district. The low erosion risk area, 18 per cent (49 km^2) includes low soil erodibility while slope is gentle in this area. Low erosion risk is found along Kurang River and in south-east part of study area. The erosivity index is moderate in whole of the watershed.

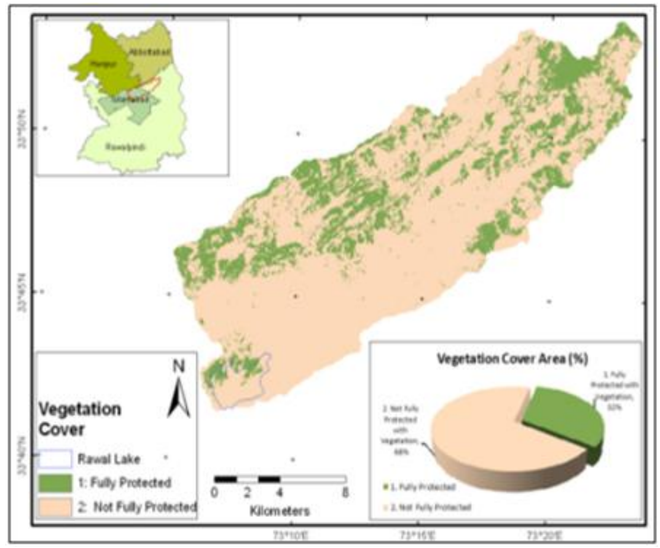

Fig. 8: Thematic map of vegetation cover
Source: [7].

The vegetation cover map (Fig. 8) was generated by applying NDVI on satellite image of Rawal watershed. Classification of this map shows that about 32 per cent of the area is fully protected with vegetation including thick forest, grass and sparse vegetation whereas, 68 per cent is classified as not fully protected with vegetation that includes road, crops, terrace fields, uncultivated terrace fields, bare land, urban land and rocks.

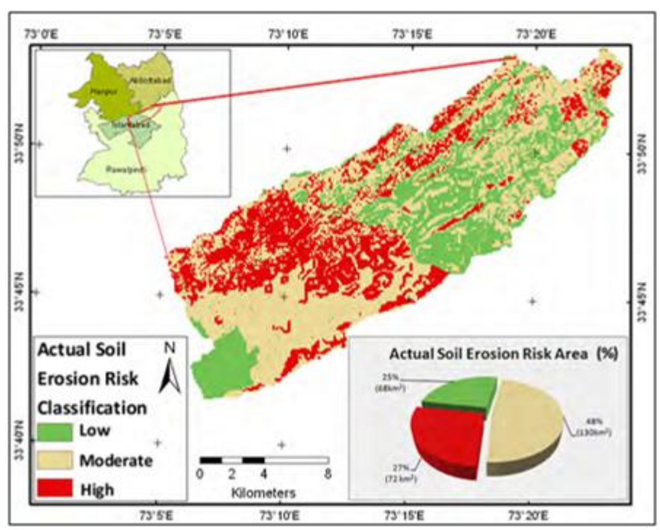

Fig. 9: Actual Soil Erosion Risk Map
Source: [8].

Finally, actual erosion risk map (Fig. 9) was generated by overlay analysis of vegetation cover map and potential erosion risk map. The map indicates spatial distribution of high, moderate and low erosion risk areas in Rawal watershed. The red color (Fig. 9) shows high erosion risk that is 26 per cent (71 km^2) of the study area. It is distributed in north-west and southern part while some of the area in north and north-east is also under high risk. These areas have highly erodible soil consisting of loam, silt loam and sandy loam. The erosivity index is also moderate with greater than 1000 mm total annual rainfall. The slope in most of the area is very steep with low vegetation cover. Moderate erosion which is 48 per cent (129 km^2), indicated by green color, can be found in the south, south-west and north-east part of study area (Figure 9). The area comprises moderately erodible soils with 5-15% slope in central region and a few very steep slopes in the northern region of study area. Sparse vegetation also exists in this area whereas low erosion area which accounts 26 per cent (69 km^2) is observed in the central part of study area. Here exists thick vegetation and the soil is slightly erodible, covered with stones thus protecting it from rain splash. The area consists of flat slopes which are fully protected with the vegetation.

The CORINE erosion risk model is an estimation that provides a trend in soil erosion so that high, moderate and low erosion risk areas could be identified. In order to calculate soil loss from CORINE erosion index values for Rawal watershed, Eq. 3 is used. The correlation coefficient between erosion index value and soil loss (tons/ha) shows high correlation with R2 =1 (Figure 10).

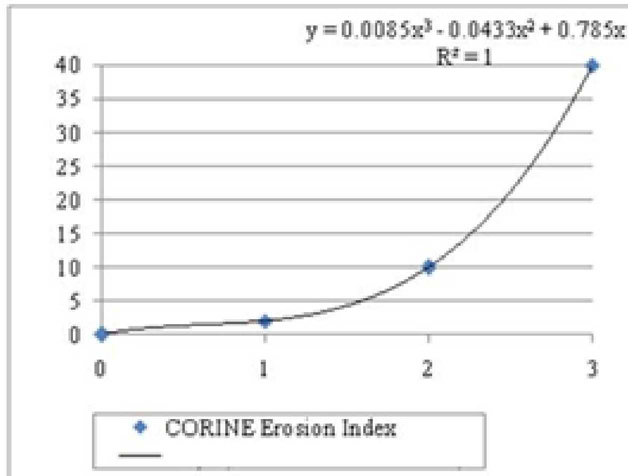

Fig. 10: Relationship between CORINE erosion index and soil loss (tons/ha) in study area

Source: [8].

After computing soil loss for two maps (potential and actual erosion risk), the area underlying various categories of erosion along with annual soil loss is shown in Table 3.

Table 3: CORINE erosion index and soil loss (tons/ha/yr) for the study area

CORINE Erosion Class	Soil Loss Range (tons/ha/yr)	Potential Soil Erosion Risk			Actual Soil Erosion Risk		
		Area (ha)	Area (%)	Soil Loss (tons)	Area (ha)	Area (%)	Soil Loss (tons)
Low	0 - 10	4930	18	24650	6828	25	34140
Moderate	10 – 40	11095	41	277375	12918	48	322950
High	> 40	10844	41	444604	7123	27	292043
Total		26869	100	746629	26869	100	649133
Soil Loss		**28 tons/ha/yr**			**24 tons/ha/yr**		

Source: [8].

It clearly indicates that the annual soil loss in potential soil erosion risk (28 tons/ha/yr) is higher than in actual soil erosion risk (24 tons/ha/yr). This is because the potential soil erosion does not consider vegetation cover and the soils in this region consist of loam, silt loam, clay loam or silty clay loam which has low water holding capacity. The slope is more than 30% gradient with high precipitation and low temperature values. Thus, all these factors collectively result in high runoff and soil erosion. From various studies it has been verified that the gentle slope (1-10% gradient) in Pothwar region can cause 17-41 tons/ha/yr of soil loss under fallow condition and steep slopes cause 28 tons/ha/yr of soil loss [14; 3]. The soil loss in actual erosion risk is lower because of vegetation that protects soil from erosion. However, in moderate erosion index, rate of soil loss has increased because of deforestation, inappropriate agricultural practices and urbanization. [14] estimated soil loss rate in this region to be 9-26 tons/ha/yr which coincides with the soil loss estimated in this research (i.e., 24 tons/ha/yr). Taking average soil loss of 24 tons/ha/yr and assuming that 100% of it is deposited in the Rawal lake, then the gross reservoir capacity of the lake would have been reduced from 58.26 MCM to 45.56 MCM (about 78%) during the last 50 years. Therefore, the watershed management activities should be carried out in the watershed of Rawal Lake to reduce the volume of sediment coming into the lake.

4. CONCLUSIONS

CORINE model integrated with GIS and RS techniques proved efficient and inexpensive in generating soil erosion risk maps for mountainous region of Pothwar region. These maps can be used for determination of discrete degrees of potential and actual risks, as well as of their distribution. The soils in the study area are highly erodible, intense rainfall and very steep slopes cause significant amount of soil loss contributing to high soil erosion risk. Vegetation helps in reducing soil erosion but with increase in population, urbanization and deforestation is a major phenomenon taking place in the vicinity of Rawal watershed. So, with the decrease in vegetation, soil erosion in Rawal watershed has been intensified. The estimated soil loss varies between 24-

28 tons/ha/yr with high erosion risk (26 per cent) at areas having very steep slopes and less vegetation cover. The soil erosion rate in these areas can be minimized by protecting soil with proper land management practices.

5. RECOMMENDATIONS

The CORINE model can be helpful in monitoring soil erosion & sedimentation rate of large dams annually by using satellite and climatic data. Better results can be obtained by having consistent dataset with same period of climatic data and satellite image of high resolution for small watersheds. Close spatial distribution of meteorological stations can be helpful in order to estimate soil erosion rate in mountainous regions. The relation of urban growth and soil erosion should also be incorporated in order to observe the rate of urbanization and its effect on soil erosion. Temporal analysis can also be performed to monitor soil erosion and change detection over past few years.

ACKNOWLEDGMENT: This paper is the part of 1st author MS thesis. I acknowledge IGIS-NUST for providing logistics and resources to carry out this research.

REFRENCES

1. Irshad, M., Inoue, M., Ashraf, M., Faridullah, Delower, K. M and Tsunekawa, A. Land desertification-an emerging threat to environment and food security of Pakistan. *Journal of Applied Sciences*, **7**(8), 1199-1205 (2007).
2. PARC. National Action Programme to Combat Desertification in Pakistan. *Pakistan Agricultural Research Council*. pp. 1-9 (2002).
3. Nasir, A., Uchida, K., and Ashraf M. Estimation of Soil Erosion by using RUSLE and GIS for Small Mountainous Watersheds in Pakistan. *Pakistan Journal of Water Resources*, **10**(1), 11-21 (2006).
4. Ashraf, M., Fayyaz-ul-Hassan, Saleem, A. and Iqbal, M., Soil Conservation and Management: A Prerequisite for Sustainable Agriculture in Pothwar. *Science, Technology & Development*, **21**(1), 25-31(2002).
5. SSP. Rawalpindi Area. Soil Survey Reconcience Report, Lahore (1967).
6. SSP. Haro Basin Area. Soil Survey Reconcience Report, Lahore (1976).
7. Rasheed, W., Ahmad, M., Akbar, G., Khan, M., Babar, K.N. and Qayyum, A., A Preliminary Study on the Vegetation of Rawal Experimental Sub-Catchment Area.*Pakistan Journal of Scientific and Industrial Research*, **31**(12). 848-851 (1988).
8. Bashir, S. Risk Assessment of Soil Erosion in Rawal Watershed using GIS & RS Techniques. Thesis unpublished, (MS). National University of Science and Technology (NUST), Islamabad; Pakistan (2010).
9. Bayramün, Ü.,Erpul, G., Erdogan, H. E. Use of CORINE Methodology to Assess Soil Erosion Risk in The Semi-Arid Area of Beypazarý, Ankara. *Turk Journal for Agriculture*, **30**(2005), 81-100 (2005).
10. Bienvenue, J.S., Ngardeta, M. and Mamadou, K. Land Evaluation in the Province of Thies, Senegal. 23rd Course Professional Master.Geomatics and Natural Resources Evaluation.IAO, Florence, Italy (2003).
11. Hernando, N. M. F., Assessment of Soil Erosion in Drylands of Colombia.International Centre for Physical Land Resources.MSC thesis, Ghent University, Krijgslaan (2006).
12. Yuksel, A., Gundogan, R. and Akay, A. E. Using the Remote Sensing and GIS Technology for Erosion Risk Mapping of Kartalkaya Dam Watershed in Kahramanmaras, Turkey. *Sensors*, **8**(2008): 4851-4865 (2008).
13. Zanolla, S., Barbieri, S., Michelutti, G. Cross-Border Pilot Area between Italy and Slovenia.Final Report.Ecological Soil Maps of the ALPS (2000).
14. Ahmad, S., Khan, M., Zaheer-ul-Ikram, M. Soil and Water Conservation and Integrated Land Use in Pothwar, Pakistan. Soil Physics: Applications under Stress Environments. Pakistan Agriculture Research Council, Islamabad. pp. 301-302 (1990).