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Soil erosion estimation of Soan river catchment using remote sensing and geographic information system

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Abstract

Soil erosion is a serious threat to agricultural and water resources projects. The environmental problems are also enhanced due to sever soil erosion at the catchment as well as the agricultural lands. Geographic Information System (GIS) and Remote Sensing (RS) are efficient tools for assessment and management of soil erosion for larger catchments. In this study, Morgan approach was integrated with GIS and RS for estimation of soil loss of Soan river basin. The GIS maps were generated for the rainfall intensity, kinetic energy, overland flow and soil erosion. The results showed that annual average soil loss for Soan river basin was 3541 tons km^{-2} $year^{-1}$. The barren land had the highest value of soil loss i.e. 6341 tons km^{-2} $year^{-1}$ whereas the cropped land had the lowest soil loss of 1876 tons km^{-2} $year^{-1}$.

Key words: Soil erosion, landuse, digital elevation model, integrated land water information system

Introduction

Soil erosion is universally recognized as a serious threat to land resources. It has geomorphological, pedological, ecological, social, and economical impacts. The soil is a nonrenewable natural resource while soil erosion is one of the major causes of its degradation. The loss of the regional soil resource is insidious, and the resource once lost is lost forever. The recent GLASOD (Global Assessment of Soil Degradation) survey (Oldeman *et al.*, 1991) has indicated that more than ten billions (10^9) hectares of the land surface of the earth is currently experiencing serious soil degradation as a result of water erosion. Worldwide up to 75 billion tons of topsoils are eroded every year by wind and water and 85% of world's agricultural soils are affected by erosion (Thompson *et al.*, 1991).

The consequences of soil erosion are both on and off-site. On site effects are particularly important for agricultural lands. The removal of organic matter and nutrients result in a reduction of cultivable soil depth and decline in soil fertility. The net effect is a loss of productivity. Off-site problems due to soil erosion are more severe which reduces the capacity of the rivers, enhance the risk of flooding, blocks irrigation canals and shortens the life of reservoirs (Morgan, 1986).

The situation in Pakistan is also alarming with reference to soil erosion and desertification. The climate of the country comprises arid and semi-arid with extreme variation in temperature. Watersheds in upper Indus and its tributaries suffer from unfavorable soil and moisture regimes. The detail data regarding soil erosion in different provinces and Northern Area (NA) of Pakistan is given in Table 1.

Accelerated surface erosion due to deforestation in the catchments reduces the useful life of a reservoir. The worst example can be cited of Wasrsak dam that was build in 1960 on river Kabul and it was completely filled with sediments in three year. Similarly other major reservoirs like Tarbela and Mangla are also facing severe problems due to soil erosion in the catchments. Indus River is 2737 km long, and it has a drainage area of 966,000 km^2. Tarbella Dam stores 13.5 km^3 and Manchar lake stores about 0.7 km^3. In 1981 and 1983, the Indus carried 53.4 and 57.9 km^3 of water and 91.9 and 37.2 million tons of sediments respectively (Milliman and Meade, 1983). It is therefore important to minimize soil erosion by different conservation measures. The soil conservation planning may seem difficult for larger areas, particularly the hilly areas, which are inaccessible in most of the cases. The remote sensing and geographic information system (GIS) are efficient tools to assess the erosion risks and to evaluate various alternatives spatially optimize conservation measures. Remote Sensing technique makes it possible to measure hydrologic parameters on spatial scales. Taking the advantages of the remote sensing and geographic information techniques, this study was planned for assessment of soil erosion of Soan river catchment. The objectives of the study were analysis of landuse parameters including land cover, soil type, topography and vegetation cover. A soil erosion model was formulated for sediment yield estimation for the study area.

Description of the study area and data collection

Soan river is situated in Pothowar plateau hill torrent area, and is located between longitude 71°45′ to 73°35′ and

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latitude 32º45′ to 33º55′ and it lies in Rawalpindi, Attock and Jhelum districts. Soan river is one of the left bank tributaries of Indus river. Lai Nallah originates from Margala hills in Islamabad and outfalls into Soan river. The Soan river rises from the Southern slopes of the Shivalik range also known as Solasinghi range in the tract to east of the Beas gap across the Southern periphery of the Kangra valley. It joins the boundary of Himachal Pradesh and Punjab. It enters the plains near Chirah, up to Chirah it drains an area of about 255 km^{-2}. This varies in elevation from 670.5 m to 2286 m. In the plains Soan river flows in a southwest direction to join Indus River at about 16 km up stream of Kalabagh. It is fed by its major tributaries including Ling, Korang, Lai Nalah, Sil River and flows smoothly with a gentle gradient of about 1.14 m km^{-1}. The Soan river basin up to Dhok pathan has area 6549 km^2. The slopes of the Soan catchment vary from gentle to steep. In the summer the discharge drops drastically, while during monsoon it is in spate.

Soan river catchment of Indus Basin in Pakistan was selected for model application. Location of Soan catchment is shown in Figure 1. The study area is 6549 km^2. Topographical parameters were extracted by using the GTOPO30 (http://edcdacc.usgs.gov/gtopo30/gtopo30. html). GTOPO30 is digital elevation model (DEM) with horizontal grid spacing of 30 arc seconds (approximately 1 kilometer). The digital elevation data of the study area is shown in Figure 2.

The landuse data was obtained from USGS (United State Geographical Survey's) Earth Resources Observation System (EROS) Data Centre. The Geographic information System (GIS) data for soil texture and landuse were available for year 1996-97 (SWHP, 1998). The landuse and soil texture data are shown in Figure 3 and Figure 4, respectively. The rainfall runoff and the sediment discharge data were used for the same period. The rain, river flow and sediment discharge data were collected from Surface Water Hydrology Project (SWHP). The spatial data map of digital elevation model (DEM), landuse map and stream network maps were derived from the topographic data. These maps were derived using Integrated Land Water Information System (ILWIS) software developed by International Institute for Geo-Information Science and Earth Observation (ITC).

Methodology

Morgan *et al*. (1984) developed a model to predict annual soil loss from field-sized areas on hill slope. It considers detachment of soil particles by raindrop impact and transportations of those particles by overland flow. It is a process based model which means that it runs in two phases one being water phase and the other being sediment phase. The flow chart of the model is shown in Figure 5. The soil erosion by water comprise of prediction of soil detachment by rain drop splash. It requires data related to rainfall intensity, number of rainy days, and total amount of the rainfall. As the GIS techniques are based on the spatial data in forms of map, the map of each parameter is generated and all the mathematical formulas are applied on the maps. The following steps were performed for development of the soil erosion map of the study area.

Generation of rainfall and energy maps

Rain map of Soan catchment was created using following equation.

$$\text{Rain (mm)} = 1384.2 + 0.329 * \text{Elevation (m)} \quad (1)$$

Where Elevation is the topographic height derived from the digital elevation model (DEM). The kinetic energy of rainfall (E) in jm^{-2} is dependent on amount of rainfall(R) and rainfall intensity (I). It was derived from the following equation.

$$E = R * [11.9 + 8.7 * \log_{10} (I)] \quad (2)$$

Where E= Energy map, R= Rainfall map, and I= 25 mm hr^{-1} and * = Multiplication sign

The soil detachment is a function of soil detachability index defined as weight of soil detached from the soil mass per unit of rainfall energy. It was computed from the following equation.

$$F = K * (E * e^{(-0.058A)}) * 1.0 * 10^{-3} \quad (3)$$

F= Rate of soil detachment in kg m^{-2}, K= Soil detachment index, A = Interception

Generation of overland flow map

Overland flow (Q) is dependent on moisture storage capacity (MS) of surface soil which can be derived from field capacity. It is also dependent on the soil bulk density (BD). Moreover it is dependent on rooting depth (RD) of various cover types, the ratio of actual to potential evapo-transpiration (Et/Eo), the amount of annual rain (R) and the number of rainy days (Rn). It can be expressed by the following equations:

$$Q = R * \exp(-Rc/Ro) \quad (4)$$

Where R is annual rain (mm)

$$Rc = 1000 * MS * BD * RD * (Et/Eo)^{0.5} \quad (5)$$

$$Ro = R/Rn \quad (6)$$

Where Rc and Ro are variables which are used to split the equation (4)

Table 1. Soil erosion in different provinces of Pakistan

DEGREE OF EROSION	PUNJAB	SINDH	NWFP	BALOCH	N.A
		(Thousand hectares)			
Slight					
(sheet and rill erosion)	61.2	-----	156.3	-------	110.5
Moderate					
(sheet and rill erosion)	896.8	-----	853.8	1858.6	25.8
Severe					
(rill, gully, steam bank)	588.1	58.9	1765.1	2724.4	504.2
Very severe					
(rill, gully, pipe and pinnacle erosion)	357.9	------	1517.0	-----	1571.6
Total	1904.0	58.9	4292.2	4583.0	2212.1

Source: Shah and Arshad (2006)

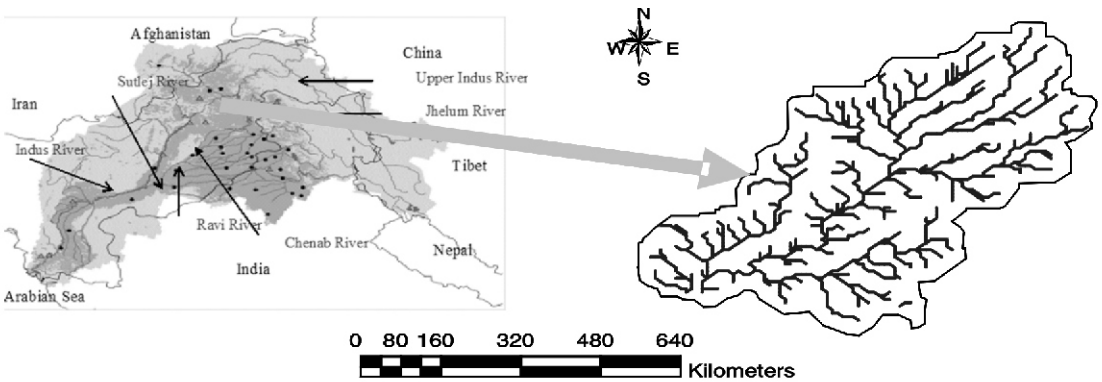

Figure 1. Location of the Soan River Basin

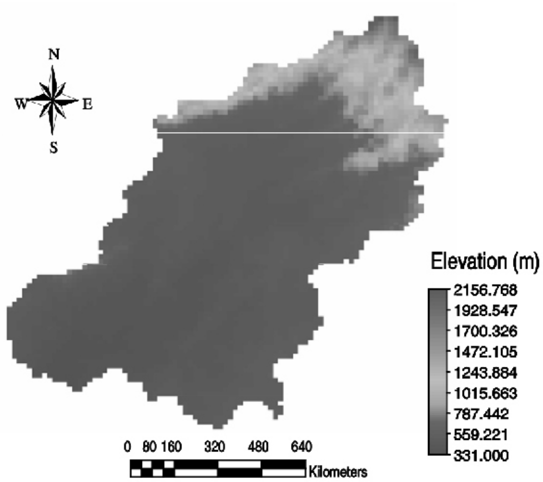

Figure 2. Digital Elevation Model (DEM) of the study area

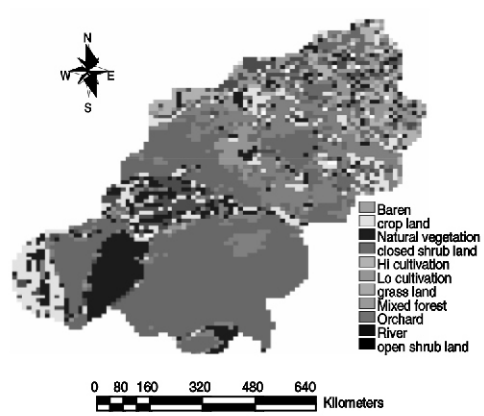

Figure 3. Landuse[1] classifications of the study area
[1]Hi cultivation mean High cultivation
Lo cultivation mean Low cultivation

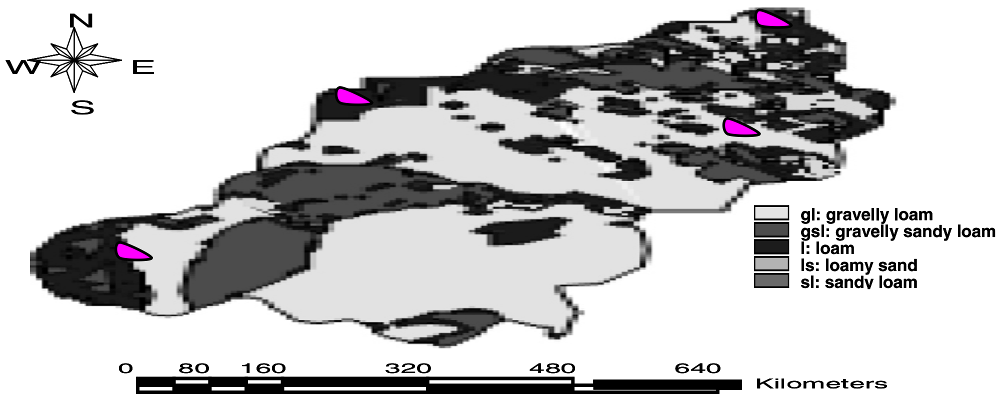

Figure 4. Soil textural classifications of the study area

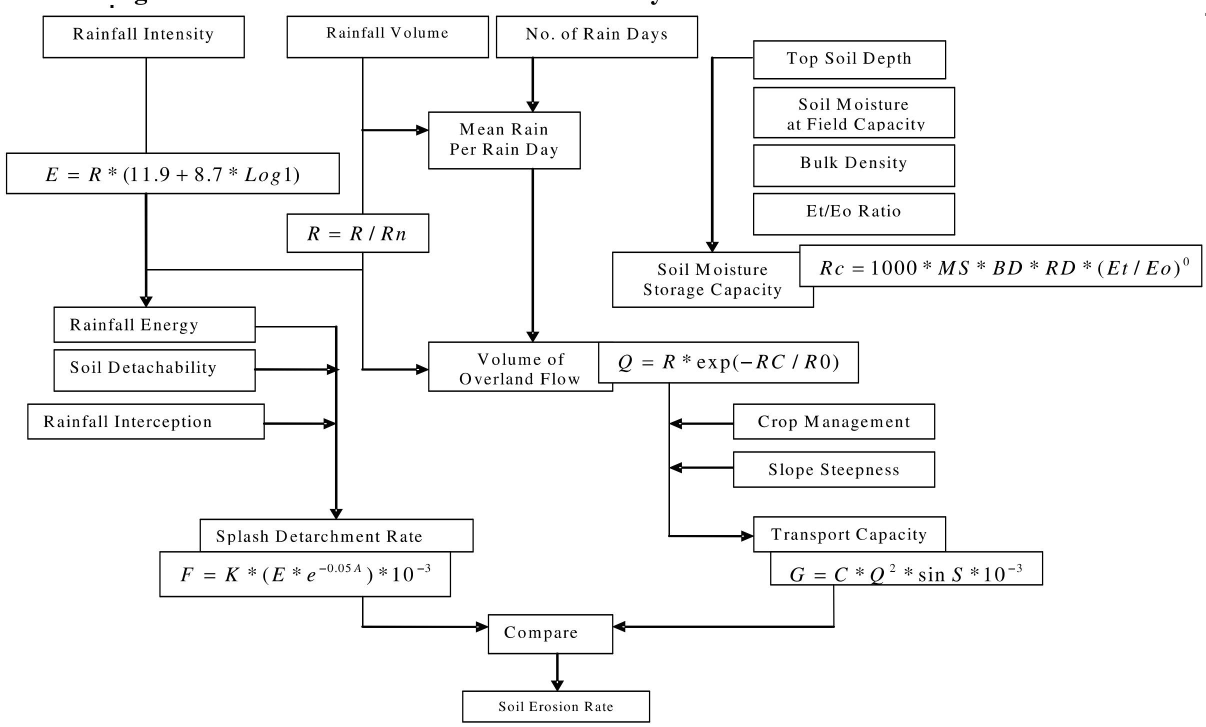

Figure 5. Flow chart of the model Morgan *et al.* (1984)

Table 2. Soil type Classification and Overland Flow of Soan catchment

Classes	Unit area (km^2)	Q (over land flow m^3 year^{-1})
Barren	0.80	44.06
Crop land	0.51	15.18
Natural vegetation	1.02	14.02
Closed shrub land	10.19	13.90
High cultivation	12.39	20.46
Low cultivation	14.80	27.96
Grass land	6.38	14.96
Mixed forest	3.01	15.13
Orchard	0.06	13.73
Open shrub land	0.03	30.62

Generation of transport capacity of overland flow

Transport capacity of overland flow (G) is dependent on the volume of overland flow (Q), crop cover management factor (C) and the topographic slope factor (S). It was calculated by the following equations:

$$G = C*(Q^2)*\sin(S*10^{-3}) \quad (7)$$

The soil detachment was calculated by the following equation.

$$F = K*(E*e^{-0.005A})*1*10^{-3} \quad (8)$$

Results and Discussion

Overland flow was calculated by flow map and crossing it with landuse and soil classes. The results are summarized in Table 2. It is apparent from this table that barren unit of landuse has the highest volume of overland flow (44.05 m^3 $year^{-1}$) due to low infiltration (0.7 mm h^{-1}) (Pit *et al.*, 1999 and high overland velocity of water on the other hand the orchard land has the lowest overland flow (13.73 $m^3 year^{-1}$) due to basin formation resulting in high infiltration rate (2.5 mm h^{-1})

For better visualization, data of Table 2 is plotted in Figure 6. It is clear from this figure that barren land and open shrub areas are most vulnerable to the soil erosion due to less infiltration and high overland flow. The barren has the smallest unit area (0.8 km^2) but overland flow is very high (44.06 m^3 $year^{-1}$) following the open shrub land which has unit area of (0.03 km^2) but its overland flow is 30.62 m^3 $year^{-1}$.

Estimation of soil erosion

The soil loss was calculated from the transport capacity of overland flow (G) and the estimated rate of soil detachment (F). When the transport capacity was higher than the rate of soil detachment, the soil detachment value was taken equal to soil loss. Similarly, when the rate of soil detachment was higher than the transport capacity of overland flow, the value of the transport capacity was set equal to the soil loss.

Different types of the vegetation covers have different resistance to the detachment and the movement of the soil particles. The soil erosion was estimated based on the vegetation cover, overland flow and kinetic energy of the rainfall. The soil erosion was estimated for eleven different types of landuses and the results are presented in Table 3. The soil loss on annual basis ranges from 1926 to 6341 tons km^{-2} $year^{-1}$. The rate of soil erosion mainly depends on the nature of vegetation cover, overland flow and texture of the soil. The kinetic energy of rainfall cause more erosion on the bare land as compared to the area covered by vegetation, as normally expected. The barren land area is 0.80 km^2 and the soil loss is 6341 tons km^{-2} $year^{-1}$ which is the highest value among all other types of landuses.

The result shows that soil loss estimation in low intensity agriculture i.e. in low cultivated area comprising 12.39 km^2, the estimated soil loss is 2589 tons km^{-2} $year^{-1}$, in open shrub land having area of 0.03 km^2, estimated soil loss is 5341 tons km^{-2} $year^{-1}$ which is higher as compared to high intensity agriculture i.e. high cultivation covering area of 1239.09 km^2 estimated soil loss 2589 tons km^{-2} $year^{-1}$ due to high detachability factor of soil having low agriculture intensity.

The area of each type of landuse was compared with the soil erosion on proportionate as shown in Figure 7. The high and low cultivated areas are 22 and 28%, respectively while the soil erosion area 7 and 9%, respectively. The barren land and open shrub have areas 0.045 and 1.44%, respectively whereas the soil erosion is 13.60 and 16.25%, respectively. It shows that barren land and open shrub areas are more vulnerable to soil degradation, thus these areas should be the first preference for soil conservation measures. One option is that more area should be brought under cultivation that will reduce the soil erosion and agricultural production will also increase. The grassland and mixed forest having areas of 11.53 and 5.4% but the soil loss is 11 and 4%, respectively. The development of range land and forest area may be the second option. This may increase the livestock production at low cost.

Conclusions

It is evident from the results of this study that this model is useful for qualitative as well as quantitative assessment of soil erosion. Multi-temporal, multi-sensor and multi-spectral remote sensing data have provided valuable and very important factors like crop cover management factor (C) and landuse type (P) for this study. Since, the crop cover is a useful option to reduce the direct impact of rainfall on soil particles therefore it is recommended that all barren lands in Soan river basin be converted to agricultural land or forest plantations through proper land management measures.

References

Milliman, J.D. and R.H. Meade. 1983. World-wide delivery of sediment to the oceans. *Journal of Geology* 91: 1-21.

Morgan, R.P.C., D.D.V. Morgan and H.J. Finney. 1984. A Predictive Model for the Assessment for the Soil

Table 3. Soil Loss over Landuse classification of Soan catchment

Landuse Classes	Unit area (km^{-2})	Soil Loss (tons km^{-2} year^{-1})
Barren	0.80	6341
Crop Land	0.51	876
Natural vegetation	1.02	2053
Closed Shrub land	10.19	3376
High Cultivation	12.39	2589
Low Cultivation	14.80	3691
Grass Land	6.38	4321
Mixed Forest	3.01	1926
Orchard	0.06	1972
Open Shrub land	0.03	5341
River	6.14	5522

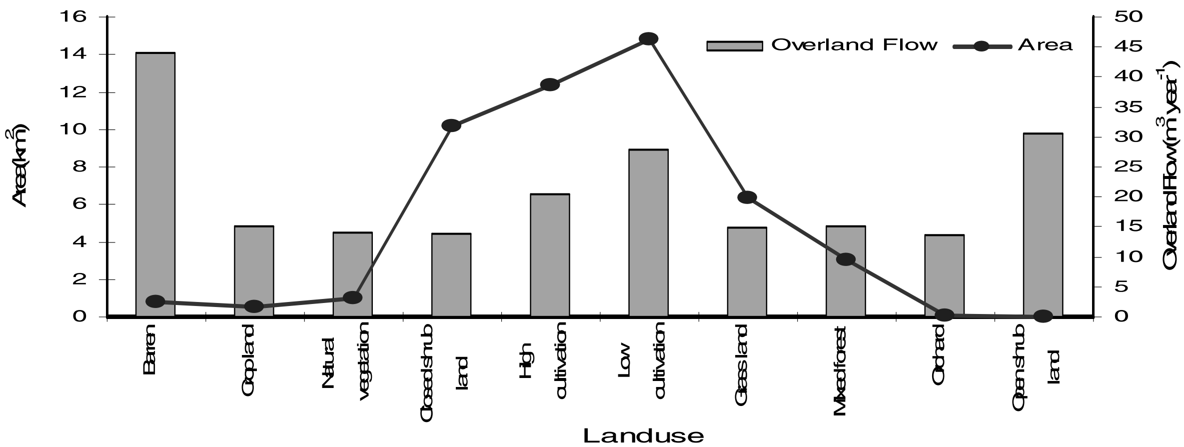

Figure 6. Visual comparison between different landuse and water yield of Soan River basin

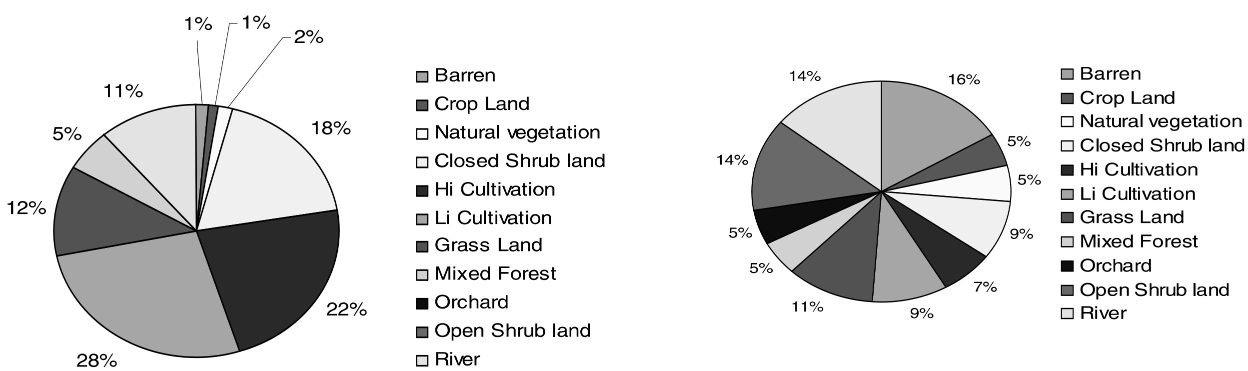

Figure 7. a) Percent of area under different landuse b) Percent of Soil erosion for different landuse

Erosion Risk, *Journal of Agriculture Engineering Research* 30: 254-253.

Morgan, R.P.C. 1986. Soil Erosion and Conservation. D.D.A. Essex (Ed.), England: Longman Scientific & Technical Co. Pub. John Wiley & Sons, Inc. New York. p. 63 -74.

Oldeman, L.R., R.T.A. Hakkeling and W.G. Sombroek. 1991. World Map of the Status of Human-Induced Soil Degradation, with Explanatory Note (second revised edition) - ISRIC, Wageningen, UNEP, Nairobi.

Pit, R., L. Janice, R. Harrison, C.L. Henry and D. Xue. 1999. Infiltration through disturbed urban soils and compost-amended soil effects on runoff quality and quantity. United States Environmental Protection Agency. Washington DC, USA.

Shah, Z.H. and M. Arshad. 2006**.** Land degradation in Pakistan: A serious threat to environments and economic sustainability online: http://www.eco-web.com/editorial/060715.html

SWHP. 1998. Sediment appraisal of Pakistan rivers, 1960 – 1990, Surface water hydrology project, SWHP publication no 48, WAPDA, Lahore, Pakistan.

Thompson, A.L., C.J. Gantzer and S.H. Anderson. 1991. Topsoil depth, fertility, water management and weather influences on yield. *Soil Science Society of America Journal* 55: 1085-1091.

Wischmeier, W.H. and D.D. Smith. 1978. Predicting Rainfall Erosion Losses: A Guide to Conservation Planning, USDA Handbook No. 537.