



Risk modeling of soil erosion under different land use and rainfall conditions in Soan river basin, sub-Himalayan region and mitigation options

Arshad Ashraf¹

Received: 25 September 2019 / Accepted: 1 November 2019 / Published online: 14 November 2019
© Springer Nature Switzerland AG 2019

Abstract

Soil erosion is a serious environmental problem impacting soil and water resources of the Himalayan region. To sustain food and fibres requirements of ever increasing population, there is need to rehabilitate erosion affected areas. In the present study, risk of soil erosion was assessed in the Soan river basin of sub-Himalayan region of Pakistan using Revised Universal Soil Loss Equation coupled with geo-informatic techniques. The influential factors leading to higher erosion rates were studied under variable scenarios of environmental change. The study revealed an average soil loss of about 8.4 tons/ha/year in the study area. The intensity of erosion was predicted around 15 tons/ha/year in the open soil and 10.3 tons/ha/year in the agriculture land. The rate of erosion was found maximum over 5°–15° slope, i.e., about 19 tons/ha/year. At steeper slopes (i.e., > 15°), the lower values of erosion rates were observed likely because of presence of exposed rocks lacking extensive soil cover. High risk of erosion was predicted in scenarios of increase in rainfall and conversion of rangeland and scrub forest into agriculture land in the basin. The menace of soil erosion can be controlled through adopting integrated land use planning and soil conservation approach at micro to macro level in this part of the Himalayan region.

Keywords Soil erosion · Risk management · Land degradation · Soan river · Himalayan region

Introduction

Soil erosion is a serious problem especially in South America, Africa and Asia averaging 30–40 t/ha annually (Ananda and Herath 2003; Jie et al. 2002; Pimentel et al. 1995) and is estimated to be severe in south Asia region (Iqbal et al. 2012). Climate change is affecting soil and agricultural productivity of semi-arid and arid agro-ecologies through exaggerating rate of land degradation (Alam et al. 2007; Ahmad 2013). The soil degradation rate in Soan basin lying in the Himalayan region of Pakistan is alarming, as because of undulating features of Soan the rainfall–run-off takes place quickly causing soil erosion. Erosion can remove the most fertile topsoil, causing soil productivity to decline. Soil erosion modeling is important for investigating

soil loss processes and assessment of soil erosion risk for future soil conservation, management and planning land-use activities (Parveen and Kumar 2012; Ashiagbor et al. 2013; Serpa et al. 2015). An approach of erosion risk modeling coupled with regular field investigations can provide reliable decision support useful for effective management of soil erosion risk (Ashraf et al. 2017; Abuzar et al. 2018; Jiu et al. 2019). Much effort has been put into predicting soil loss through developing empirical and process-based models world-wide (Russell and William 2001; Merritt et al. 2003; Ighodaro et al. 2013; Koirala et al. 2019). Efforts have been mostly focused on large scale appraisal of soil erosion risk (Chris and Jon 2002; David and David 2003; Yesuph and Dagne 2019). At regional scale, soil erosion modeling was undertaken following process based approach by Habib-Ur-Rehman et al. (2003). Among various models developed globally, Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) is mostly used for soil loss estimation. Its later version known as ‘Revised Universal Soil Loss Equation’ (RUSLE) is being used to assess annual soil loss at watershed level (Renard et al. 1997; Angima et al. 2003). Assessment of erosion hazards has been effectively

✉ Arshad Ashraf
mashr22@yahoo.com

¹ Climate, Energy and Water Research Institute, National Agricultural Research Center, Park Road, Islamabad, Pakistan

performed through integration of remote sensing and Geographic information system (GIS) coupled with Digital elevation model (DEM) (Jain et al. 2001; Kouli et al. 2009; Ashraf et al. 2017).

The present study is focused on the assessment of soil loss rate in the Soan basin through geo-spatial modeling techniques under variable land use and climate change scenarios. Various factors of RUSLE, i.e., rainfall erosivity (*R*-factor), soil erodibility (*K*-factor), cover management (*C*-factor), slope length and steepness (*LS*-factor) and support practice (*P*-factor) were determined and integrated to map intensity of soil erosion in the basin. Finally risk management strategies were suggested for effective conservation of land and water resources in the target areas in future.

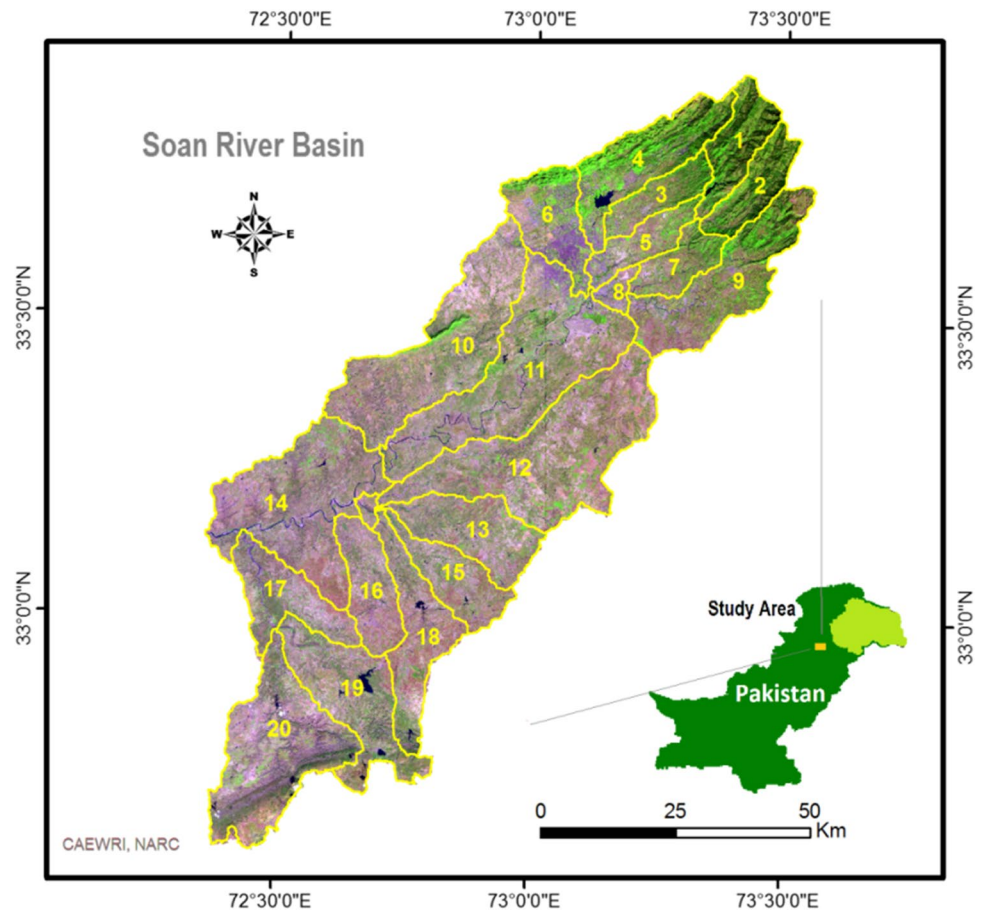
Study area

Soan basin stretches over an area of 6475 km² within elevation range of 293–2255 m in sub-Himalayan region of Pakistan (Fig. 1). About 52% area is flat to gentle (< 5° slope) while 22% area has medium slope (5°–15°). Steep (15°–30°) and very steep slopes (> 30°) cover about 19% and 7% areas, respectively. Soils are mostly moderately calcareous, deep

and varied in type, i.e. clay loam to silty clay loam with good drainage. The gravel and rock outcrops are exposed at various locations on the western side of the study area close to the drain of the Rawal lake. Most of the area is covered by alluvium but at places rocks belonging to Miocene Murree Formation are exposed. Agriculture is dependent on the rainfall, springs, wells and perennial flows stored through small/mini dams. The cultivated area lies mainly in plains and terraced slopes along the river banks and hilly terrain. The major crops grown under rainfed condition are wheat, chickpea, groundnut, millets, sorghum, oilseeds and fodders. Vegetables and orchards like of guava, citrus, loquat and pears are grown where irrigation water from dams, dug wells/tube wells and springs are available.

The climate is continental, subtropical with hot summers and fairly cold winters. Annual rainfall is about 1172 mm, about two-third of which occurs during the monsoon period (July–September). Monthly rainfall in lowlands and highlands is shown as minimum and maximum curves in Fig. 2, respectively. Mean annual rainfall ranges between 1147 in the plains to about 1811 mm in the mountainous terrain. Mean temperature low is 9 °C in December and high is 31 °C in June. The major causes of soil erosion in the Soan basin are human induced, i.e., growth in urban development

Fig. 1 Location of study area with major watersheds in Landsat 8 image [FCC 6, 5, 4 (RGB) in background]



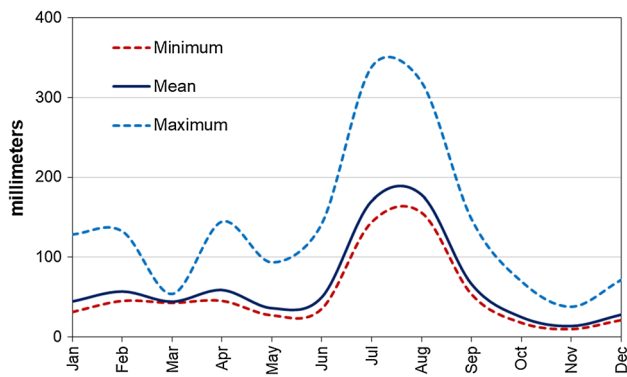


Fig. 2 Minimum, mean and maximum monthly rainfall in the basin area

and deforestation. There is also rapid unplanned urban development and deforestation in the hilly and valley areas that add up to the severity of erosion problem. Land sliding in the mountainous terrain (Fig. 3a) and rill erosion due to cutting of scrub forest for agriculture and urban development (Fig. 3b) are common causes of removal of top soil in the area.

Materials and methods

Data used

The remote sensing data of Landsat-8 OLI (Operational Land Imager) image data (Path-Row: 150-037) of October 2013 was used as primary data for land cover mapping and land degradation analysis. Topographic map of 1:50,000 scale, land use, soil texture, geology and climate data were also collected from source departments like Survey of Pakistan, Soil Survey and Geological Survey of Pakistan. Digital Elevation Model (DEM) of Shuttle Radar Topography Mission (SRTM) 30 m resolution was used for the preparation of input data for RUSLE model. The historical rainfall data of five meteorological stations lying in the basin, i.e.,

Murree, Satrameel, NARC (National Agricultural Research Center), Islamabad (Airport) and Islamabad (H-8) available of 1988–2012 period was used for the estimation of erosivity factor. The rainfall data were linked with DEM data through regression model for mapping spatial variability of rainfall. Field surveys were carried to collect ground control points using Global positioning system (GPS) for validation of land use and degraded areas in the basin.

Soil erosion estimation

The RUSLE equation consists of five data variables: rainfall erosivity, soil erodibility, cover management, slope-length and support practices. Some of these factors change over space and time and depend on secondary parameters. Rainfall erosivity was calculated using the verifiable month to month precipitation data of Murree and Islamabad meteorological stations. As the precipitation data is most accessible at month to month level, subsequently Arnoldous (1980) method was utilized which gives answer for inaccessibility of precipitation attributes data:

$$\text{Log } R = 1.93 \log \sum pi^2/P^2 - 1.52, \quad (1)$$

where ‘ pi ’ is monthly precipitation and ‘ P ’ annual precipitation.

The erosivity (R -factor) values were estimated within the range of 160–767 MJ/ha mm/year in the basin. The higher values of erosivity were observed mainly in the northeastern part of the basin (Fig. 4). The erodibility— K Factor is a key component for assessing silt loss through soil erosion modeling. Auerswald (1987) had made use of erodibility of the soil (K -factor) in the USLE and its revised versions. The basin soils have high detachment potential due to which top soil is lost and runoff is generated at high rates. Among 9 soil units, 1 belong to Mountain valley system, 2 and 4 to weathered bed rock, 3 and 6 to miscellaneous areas, 5 to alluvium basin, 7 & 8 to loess deposits and 9 to ridge trough. The degree of erodibility (K) varied from 0.07 to 0.35 in the basin (Table 1 and Fig. 4).

Fig. 3 Land sliding is common in the mountains during the rainy season (a); Rill erosion over lowland cleared of scrub and rangeland for urban development (b)

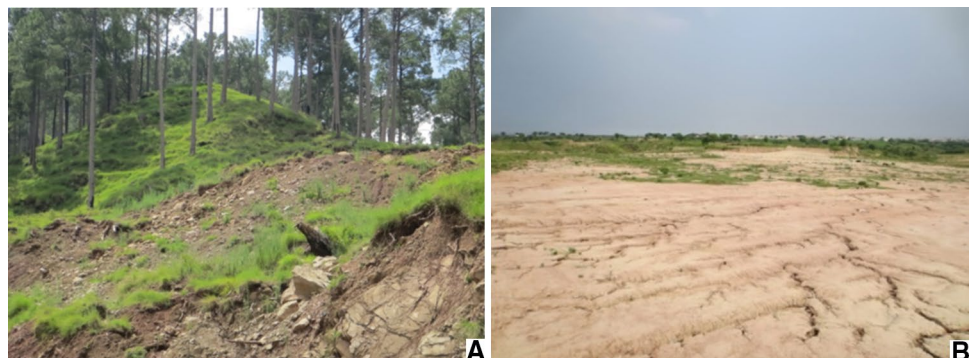


Fig. 4 Layers of RUSLE factors prepared using GIS and RS techniques

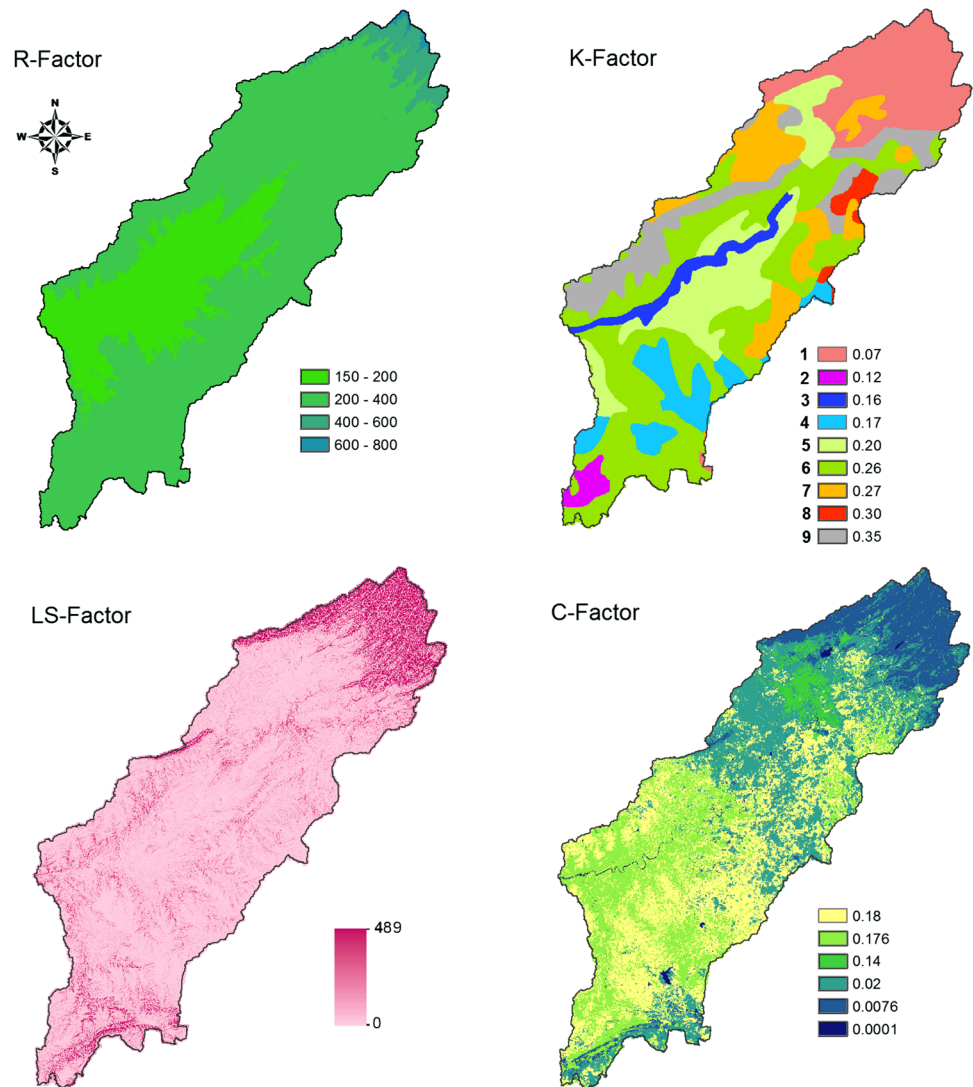


Table 1 K-factor values associated with soils and geomorphology of the study area

Geomorphology	No.	Soil class	K value
Mountain-valley system	1	Gravelly, medium to fine textured excessively drained soils	0.07
Weathered bedrock tract	2	Medium to coarse textured soils	0.12
	3	Mainly coarse textured, excessively drained soils	0.17
	4	Medium some coarse textured soils	0.27
Loess plateau	5	Gullied land consisting of a network of deep channels	0.30
	6	Frequent reworking area by a major river	0.35
Alluvial basins/valleys	7	Moderately fine/medium textured soils	0.20
Miscellaneous areas	8	Medium/moderately fine textured soils	0.16
	9	Medium textured, some excessively drained soils	0.26

Length slope factor (LS-factor) ranging in values from 0 to 489 was derived from the slope map of the basin. The higher values of LS-factor were concentrated mainly in the northern and northeastern parts, while lower values were observed in the valleys along the main streams because of

the presence of flat to gentle slopes here (Fig. 4). The soil loss is proportional to a given condition of slope steepness and slope length represented by L-S factor values. The L-S factor was mapped in ArcGIS software using Eq. 2 following Moore et al. (1993):

$$\text{Pow}([\text{flowacc}] \times \text{resolution} / 22.1, 0.4) \times \text{Pow}(\text{Sin}([\text{slope}] \times 0.01745) / 0.09, 1.4) \times 1.4 \quad (2)$$

The land use/land cover map of the area was used to derive *C*-factor values (Table 2 and Fig. 4). At a particular condition, *C*-factor indicates security to soil against its transportation, e.g. lower *C* factor values mean a stronger cover protection against soil loss (Erencin 2000). The land use of the basin is characterized by agriculture land over 33%, rangeland over 27%, open soil in about 23% area besides other classes, e.g. built-up land, forest cover and water in minor coverage (Ashraf et al. 2016). ICARDA calculated diverse vegetative cover types from the defensive impact of vegetation and additionally the cultivating practices impact that incorporate the turn and types of crops (Oweis and Ashraf 2012). Agriculture land was assigned a higher *C* value than others owing to farm practices resulting in unstable and fragile condition of the soil (Table 2). *P*-Factor (conservative practice) values are calculated as rates of soil loss brought on by a particular help practice separated by the soil loss caused by column cultivating all over the slope. For conservative soil loss estimation, it is assumed that there, so high the value of *P*-Factor was selected 1 assuming a least conservative practice followed in the area. The calculated values of *K*, *C*, *LS* and *R* layers were incorporated in the Eq. 3 in raster calculator to calculate rate of soil loss in the area. The flow of methodology adopted is shown in Fig. 5.

$$A = [K \text{ values}] \times [C \text{ values}] \times [LS \text{ value}] \times [R \text{ values}] \times [P \text{ value}]. \quad (3)$$

The basin was classified into five risk zones of soil erosion, i.e., very high (> 100 tons/ha/year), high (30–100 tons/ha/year), medium (10–30 tons/ha/year), low (1–10 tons/ha/year) and very low (< 1 ton/ha/year) following criteria defined by Almeida-Guerra et al. (2012). Intensity of the soil erosion was determined under various land use and slope classes, as well as under variable scenarios of land-use

Table 2 Major land-use types, associated *C*-factor values and predicted risk of erosion

Land use	Area (km ²)	Area (%)	<i>C</i> -factor value	Mean erosion (Tons/ha/year)
Conifer forest	268.1	4.1	0.0076	4.3
Scrub forest	532.7	8.2	0.0076	3.6
Rangeland	1776.5	27.4	0.02	2.8
Agriculture land	2169.2	33.5	0.181	10.3
Open soil	1491.2	23.0	0.176	15.0
Built-up land	203.5	3.1	0.14	5.2
Water	33.8	0.5	0.0001	1.2
Total	6475	100		

change and rainfall conditions. The implications of such conditions may be expected considering the rapid changes in the land use due to urbanization growth and climate conditions. Risk zones of soil erosion were developed and percentage coverage of erosion risk was determined for planning and decision making at watershed level. Relationship analysis of erosion risk and geomorphic factors was performed to study the risk response in 472 sub-watersheds delineated in the basin and influential factors leading to higher erosion rates were studied.

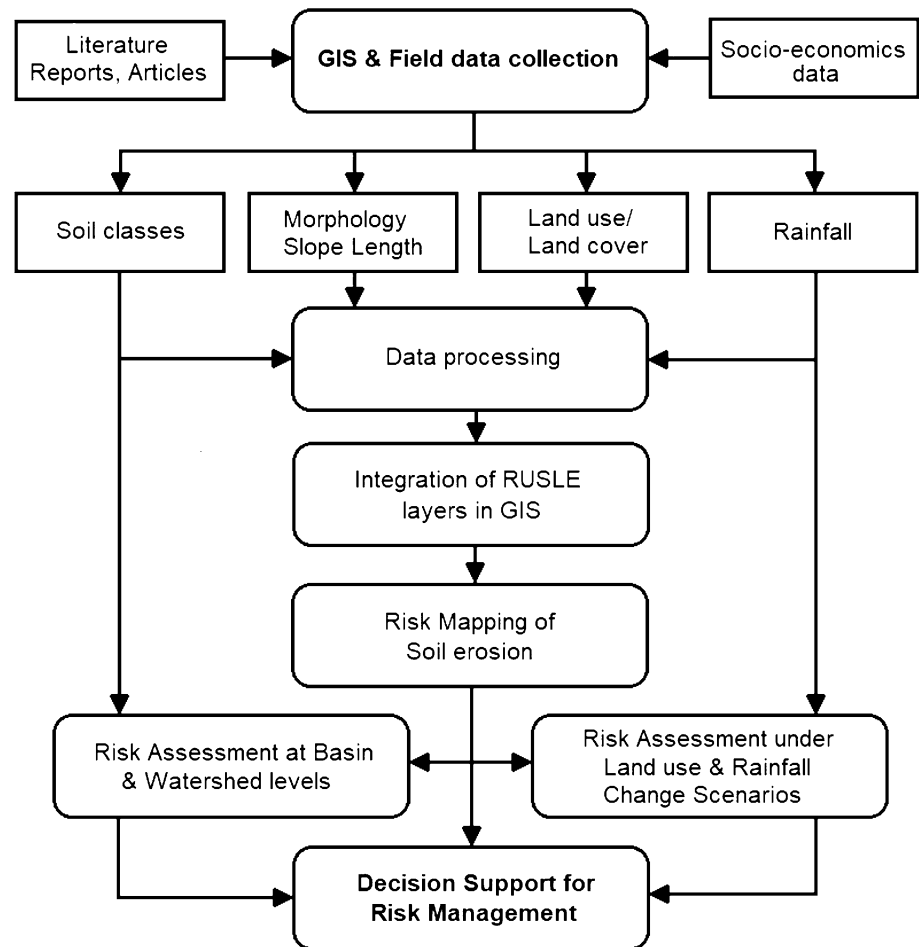
Results and discussion

Predicting risk of soil erosion

The intensity of soil erosion was predicted over 8.4 tons/ha/year in the river basin (Fig. 6). High to very high risk of soil erosion was observed in about 6.5% area and medium risk in 12.9% area of the basin (Table 2 and Fig. 7). In open soil/rocks class, erosion was assessed over 15 tons/ha/year followed by agriculture land at a rate of about 10.3 tons/ha/year. In flat areas (< 2°), the soil loss was estimated about 3.4 tons/ha/year and in flat to gentle sloppy area (< 5°) about 9.8 tons/ha/year. The rate of erosion was found maximum, i.e., about 19 tons/ha/year over 5°–15° sloppy area. These findings are in conformal with those of Nasir et al. (2006) and Rafiq et al. (2011), according to which 0.1 to 8 tons/ha/year of soil loss was predicted from flat to gentle slopes in one of the sub-catchment lying in the northeast of the basin.

The erosion was predicted within the range of 1.6–22.7 tons/ha/year in 20 watersheds of the basin, the percentage distribution of which is shown in Table 3. The watersheds were based on the existing perennial streams/tributaries of the Soan river, that were dammed at various locations for conserving excess runoff of rainy periods (e.g. of July to September monsoon) for irrigation and domestic purposes. For example, Soan and Korang are dammed at Simly and Rawal located in watersheds 1 and 4 for supplying water to Rawalpindi and Islamabad urban and rural areas. Higher intensity values were mostly observed in the low lying southwestern watersheds comprising of rainfed agriculture and open soil classes. Assessment of soil erosion based on discrete level is required for evolving appropriate set of planning and management strategies for controlling risk of soil erosion. Priority areas were identified at watershed as well as sub-watershed levels where resources for risk management could be diverted to sustain livelihood and socio-economic conditions (Fig. 8). Medium to high-risk zones, i.e., also be considered as priority areas for inducing controlling measures, are concentrated mostly in the southwest of the basin (Fig. 8b, c). High-risk zones can be clearly discretized at sub-watershed level (Fig. 8c). In fact,

Fig. 5 Flow chart of methodology followed in the present study



for resource planning and management, watershed scale is usually adopted as a workable scale, however, for development and implementation of management strategies, sub-watershed scale is generally preferred.

Scenarios of land use and rainfall change

Response of soil erosion was studied under variable scenarios of change in land use and rainfall conditions to plan and implement future risk mitigation strategies/measures. The first four scenarios belong to land use conditions, while the scenarios from 5 to 7 deal with changing rainfall conditions. The increase in rainfall scenarios (6 and 7) were developed in view of general trending of rise in rainfall particularly in the highlands of the basin. The increase in rainfall has two-fold impact in this rainfed region, e.g. on one hand it results in increasing surface runoff useful for water conservation perspective, and on the other hand it may eventually exaggerate the risk of soil erosion. In scenario 1, the conversion of all scrub forest into rangeland results in generating erosion at an average rate of 8.7 tons/ha/year, i.e., slightly higher than of the base condition (Table 4). Medium risk

zone dominates over lower watersheds in the south west of basin under this scenario (Fig. 9).

In scenario 2, all the rangeland (about 27.4%) is assumed to be converted into agricultural land. The changes indicate soil erosion at rate of about 13.3 tons/ha/year in the basin (Fig. 10). The coverage of medium and high-risk zones of erosion increases to 17.3% and 8.4%, respectively. In scenario 3, all the rangeland of base condition is assumed to be transformed into built-up land and scrub forest into rangeland—the changes already going on in the region to expand urban developments to unused lands. This situation indicates an increase of erosion at a rate of about 12.4 tons/ha/year in the basin. In scenario 4, all the rangeland and open soil of base condition are assumed to be changed into scrub forest—representing an afforestation case. This scenario indicated erosion at an average rate of about 4.6 tons/ha/year in the basin (Fig. 10). In scenario 5, 20% decline in rainfall is assumed, i.e., representing a case of dry condition. Although, this situation indicates lesser risk of erosion, i.e., 3.5 tons/ha/year when compared with others, but it would not be favorable in terms of water conservation point of view. On the other hand, scenarios 6 and 7 dealing with 10%

Fig. 6 Intensity of soil erosion predicted under various water-sheds in the basin

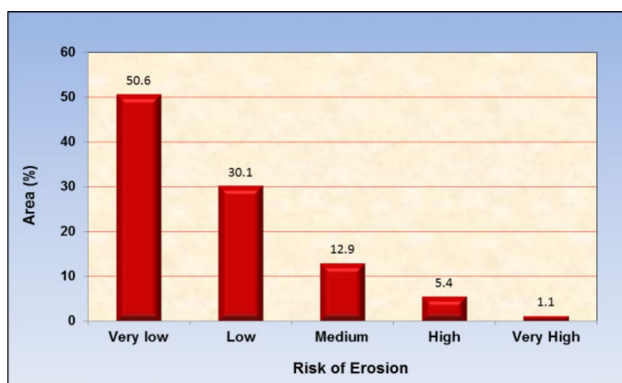
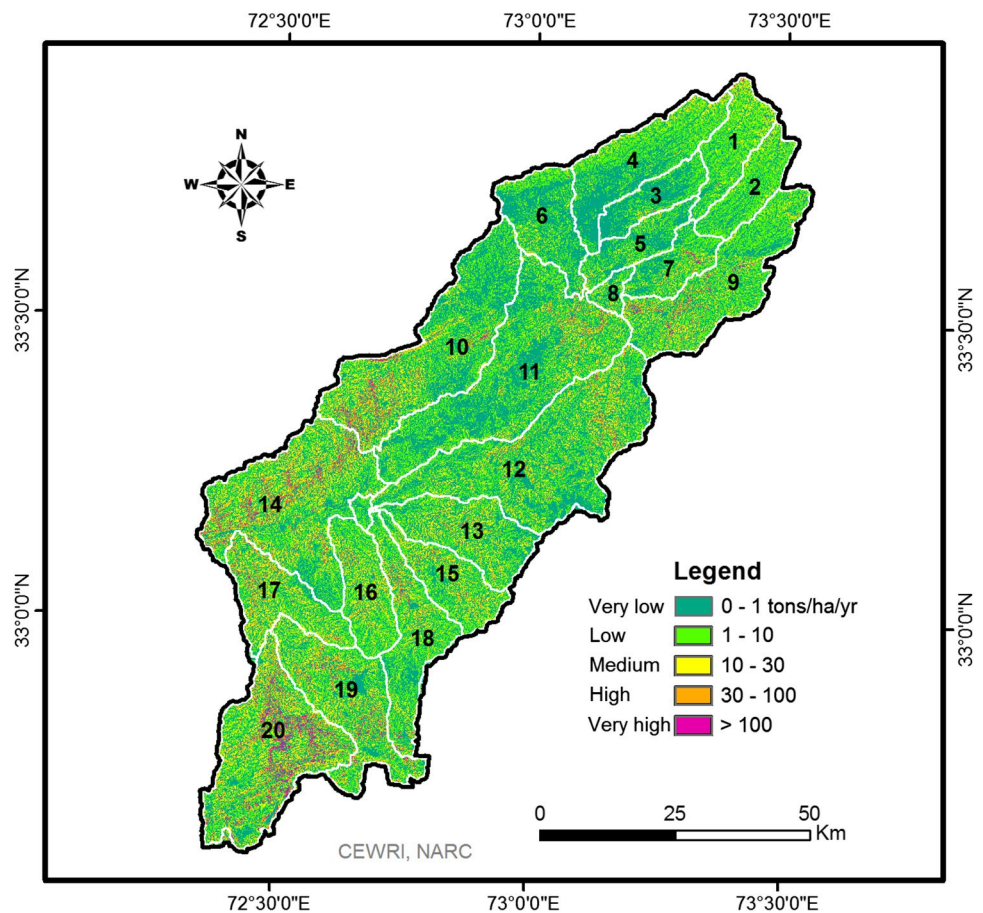


Fig. 7 Percentage coverage of various risk zones of soil erosion

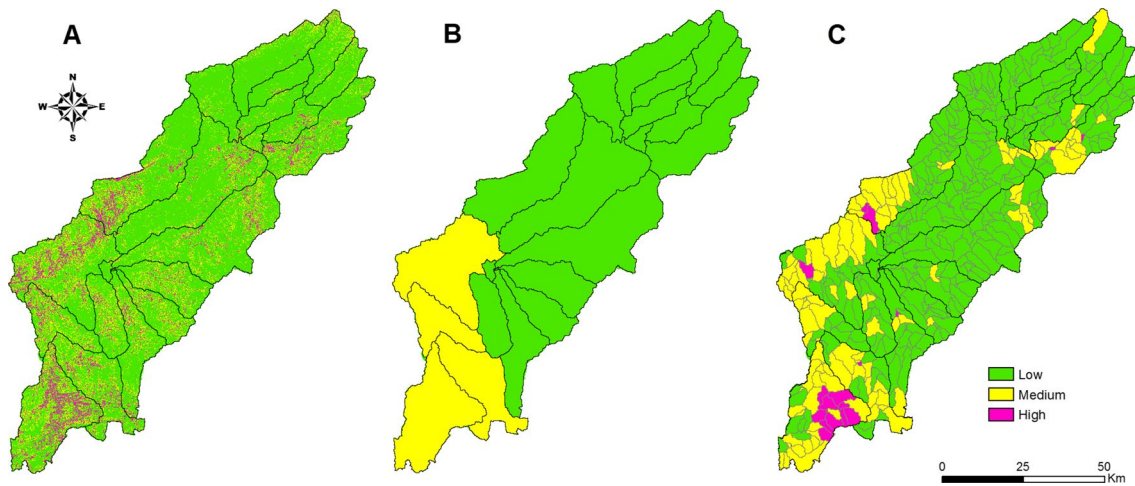
and 20% increase in rainfall (representing a wet condition) indicate exaggeration of erosion risk, i.e., at rates of about 12.1 tons/ha/year and 16.9 tons/ha/year, respectively, in the basin. The scenarios 1, 4, 5 and 6 exhibit lesser risk of erosion in the northeastern watersheds owing to presence of dense forest cover at elevated parts of the basin.

Risk mitigation and land conservation strategies

Rainfed agriculture is highly vulnerable to soil erosion, moisture stress and soil fertility degradation. Sediment loss per year determined under various studies conducted in this region indicate high rates of soil loss in areas with depleted grass, open grazing and bare soil (Table 5). In order to control land degradation, the Government of Punjab established Soil and Water Conservation Research Institute (SAWCRI) based at Chakwal with its substations at Rawalpindi, Jhelum, and Hafizabad districts. SAWCRI is working well with the cooperation of farmers to reduce the risk of soil loss by establishing various types of erosion control structures. In fact, involvement of the local people in the planning and implementation of the programmes is the hall mark for the success of the development activities in the rainfed areas. The interventions introduced and developed by watershed management programme of Climate, Energy and Water Research Institute (CEWRI), National Agricultural Agricultural Research Center (NARC), Islamabad (Fig. 11b–d) are being adopted by the communities of Soan river basin for soil and water conservation. Creation of an effective extension service is considered helpful in propagating soil

Table 3 Percentage distribution of soil erosion risk at watershed level

No.	Area (km ²)	Elev. (m)	Mean erosion (ton/ha/year)	SD	V. low risk area (%)	Low risk area (%)	Medium risk area (%)	High risk area (%)	V. high risk area (%)
1	176.2	897	6.2	23.0	38.1	48.0	12.1	1.3	0.5
2	155.7	1055	4.7	16.8	40.2	50.8	7.9	0.7	0.4
3	132.5	553	1.6	5.4	70.5	26.8	2.0	0.6	0.0
4	318.0	642	3.4	9.7	55.5	36.2	7.1	1.1	0.1
5	135.8	512	3.0	8.7	62.6	29.7	6.1	1.6	0.1
6	227.6	539	2.5	7.6	63.1	31.1	4.9	0.9	0.1
7	134.1	569	6.1	23.7	52.4	35.0	8.9	2.8	0.9
8	39.5	439	4.1	8.3	56.1	30.0	11.7	2.2	0.0
9	406.1	566	8.2	27.3	44.5	37.2	12.1	5.1	1.1
10	602.8	482	9.2	27.9	53.0	26.8	11.9	6.9	1.3
11	715.7	446	4.5	12.6	58.0	30.3	8.5	2.9	0.2
12	720.7	464	5.7	15.2	53.8	29.9	12.2	3.8	0.3
13	267.3	433	6.4	14.0	50.1	29.5	16.1	4.0	0.3
14	608.5	329	12.9	34.3	46.5	22.8	19.0	10.1	1.7
15	210.8	426	6.8	14.6	46.6	33.0	15.9	4.1	0.4
16	202.4	393	7.6	15.9	43.4	33.3	17.9	5.0	0.3
17	235.6	371	10.1	18.8	43.8	26.4	20.5	8.5	0.7
18	285.0	481	7.1	21.3	47.8	34.1	13.2	4.2	0.7
19	371.0	569	10.9	28.7	46.1	27.7	16.8	7.9	1.5
20	529.7	502	22.7	61.8	43.0	20.3	18.3	13.1	5.3
	6475.0								

**Fig. 8** Risk of soil erosion at basin level (a), watershed level (b) and sub-watershed level (c)

conservation practices via motivating farmers to involve in various afforestation schemes and supplying necessary planting stock to them. The villagers are trained in activities like innovative farming practices, water harvesting techniques, raising of forest nurseries and improved grazing systems.

Based on the severity of the problem, mitigation and conservation measures can be adopted for soil and water conservation in various risk zones. High-risk zone mostly involves dismembered gully ranges where loss of vegetative cover is the major cause of erosion. Illegal wood cutting and grazing needs to be restricted to revive and conserve the existing

Table 4 Risk of erosion under various scenarios of land use and rainfall change (base value = 8.4 tons/ha/year)

Scenario	Description	Tons/ha/year
1	Scrub forest converted to rangeland	8.7
2	Rangeland converted to agricultural land	13.3
3	Rangeland converted to built-up land and scrub to rangeland	12.4
4	Rangeland and open soil converted to scrub forest	4.6
5	20% decrease in rainfall	3.5
6	10% increase in rainfall	12.1
7	20% increase in rainfall	16.9

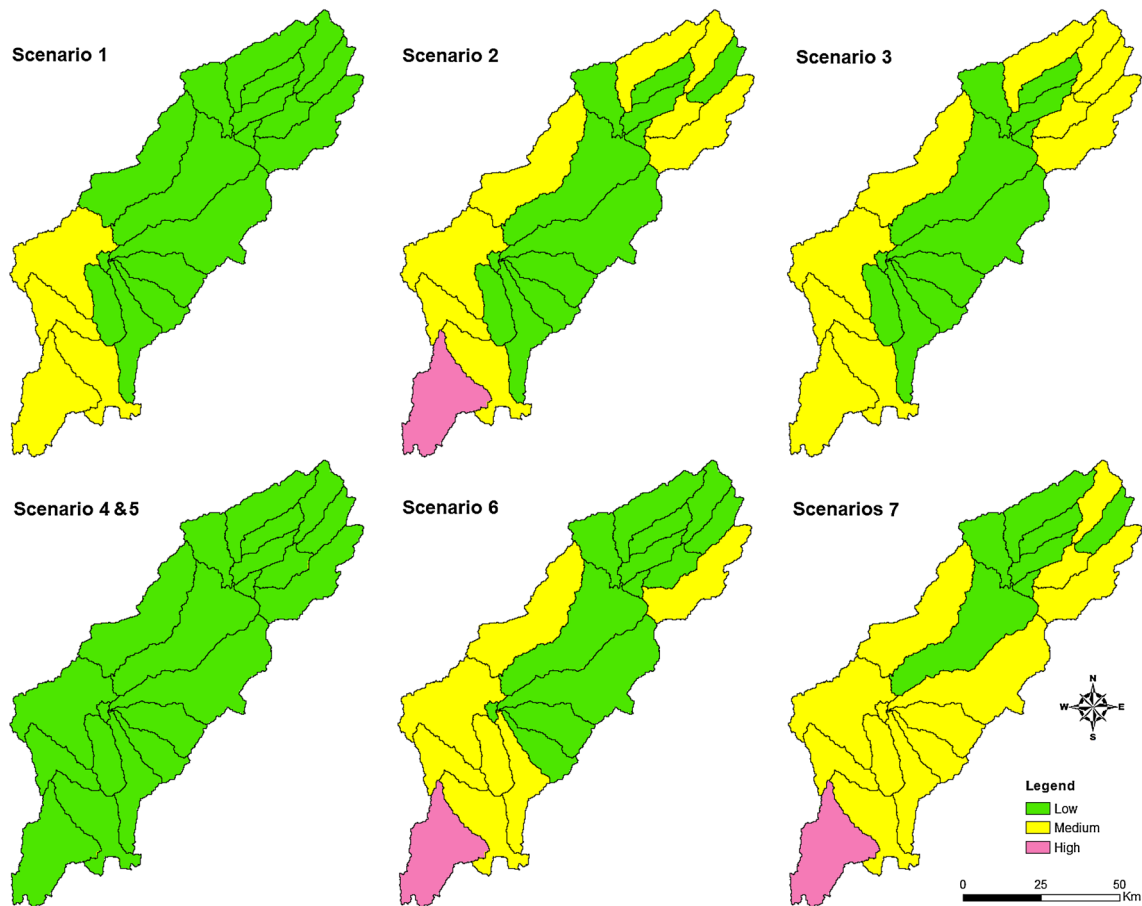


Fig. 9 Severity of soil erosion at watershed level under various scenarios of land use and climate change

vegetation cover. In this risk zone, practicable sediment control measures may include retaining walls, loose, cemented and gabion netted check dams (Fig. 11a and b) and inceptor drains. Such measures would help not only in reducing gully erosion and sedimentation in the degraded areas, but also provide fertile soil bed for raising woody plants and shrubs. The erosion control structure like sedimentation basin holds sediment below eroding areas and reduces sediment yields of reservoirs. A long-term monitoring program using remote sensing techniques and periodic field surveys is necessary to manage high risk of soil erosion in hot-spot areas. The

soil erosion risk maps generated from integration of RUSLE and GIS can provide base for planning land use, managing risk and developing future strategies for susceptible areas of soil erosion.

In Medium risk zone, speed of stream flows could be restricted through adjustment of the gullies during the rainy season. Protection measures like terracing shape binding and redirection channels can be adopted in the watersheds causing flashy streams flows to control gully erosion and provide extra dampness for raising crops/woody plants. Minor gullies may be changed into vegetated watercourses.

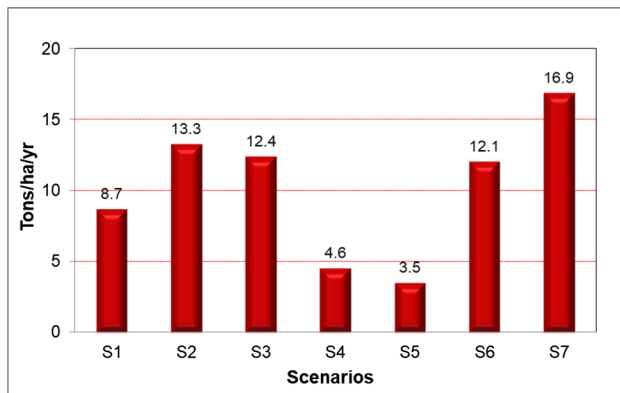


Fig. 10 Soil erosion predicted under various land use and climate change scenarios

Micro-catchments is another technique of water harvesting farming system where plants can be grown on runoff water concentrated in depression of small basins (Fig. 11).

In Low Risk zone, various types of management practices have been developed for the purposes of reducing erosion and increasing productivity. These measures may include proper tillage method, strip cropping, crop rotation, soil improvement, terracing practices, contour trenches beside other techniques. Also provision of soft loans particularly to the small farmers holding less than 2 ha of land may be encouraged by the government to facilitate the risk mitigation process.

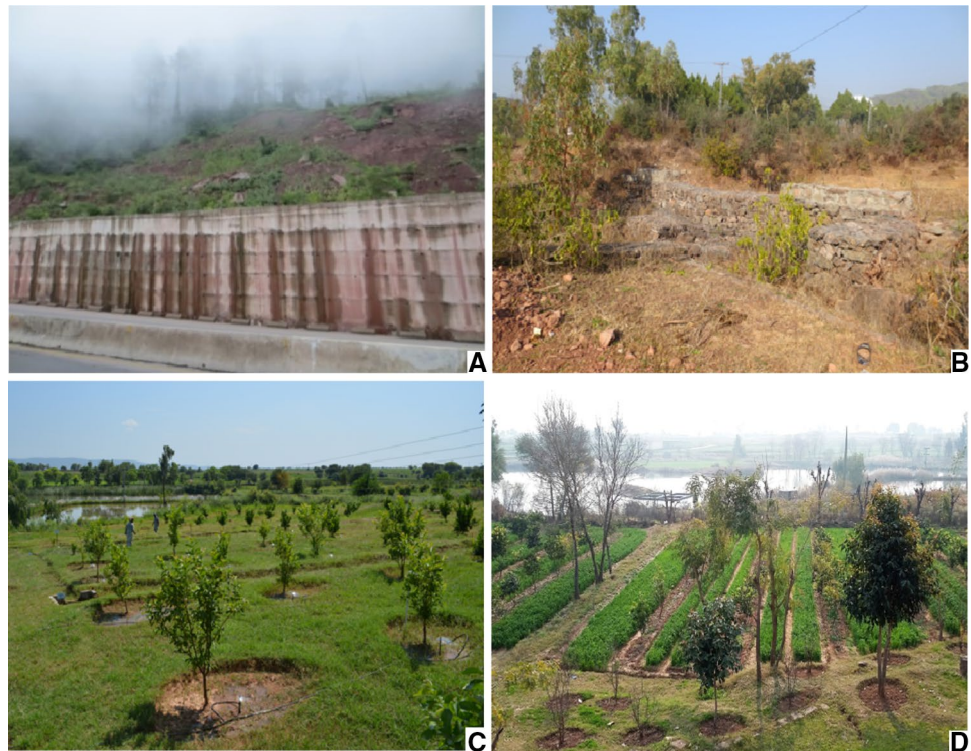
Table 5 Runoff and sediment loss per year estimated in different parts of this region (Source: Upland Degraded Watershed Forestry Sector Master Plan-Pakistan)

Research Site	Period of measurement	Treatment	Runoff (% of rainfall)	Sediment tones/ha-year
Missa (Gujar Khan) ^a	Average 12 year	Un treated, open low grazing	28	19.7
		40% gullied land treated and closed to grazing (planting, diversion channels, check dams, apron construction)	19	12.0
Ghoragali (Punjab) ^b	Average 2 $\frac{3}{4}$ Year	Pole crop of Chir pine	7	0.47
		Young Chir pine	18	1.81
		Fair grass (more than 70%)	17	4.24
		Depleted grass (less than 40%)	31	20.39
		Bare soil	46	72.00
Balakot (KPK) ^b	Average 5 $\frac{1}{2}$ Year	10 to 16 years Chir plus natural vegetation, closed to grazing	1.9	0.07
		Natural vegetation closed to grazing	3.2	0.10
		Natural vegetation, open to grazing	4.4	0.23
Batagram (KPK) ^b	Average 5 $\frac{1}{2}$ Year	2 to 8 year Robinia, plus natural vegetation, closed to grazing	3.9	0.16
		2 to 8 year Chir, plus natural vegetation, closed to grazing	4.6	0.18
		Natural vegetation, closed to grazing	4.9	0.23
		Natural vegetation, open to grazing	6.8	0.39
Tarbela Dam	N.A.	Under agriculture use	N.A	22.10
		Under range use	N.A	6.50
		Under forest use	N.A	0.65

^aResults based on 81 ha. sub-watersheds

^bResults based on 4 m² plots

Fig. 11 Retaining walls stabilized the mountain slopes along the roads (a). In gully areas, check dams should be developed to control soil loss from the area (b). Grass cover and fruit plants integration for managing soil erosion and livelihood improvement (c). Integration of microcatchments for fruit/forest plants and cereal crops on terraces for erosion control (d)



References

- Abuzar MK, Shakir U, Ashraf A, Mukhtar R et al (2018) GIS based risk modeling of soil erosion under different scenarios of land use change in Simly watershed of Pakistan. *J Him Earth Sci* 51(2A):132–143
- Ahmad F (2013) Land degradation pattern using geo-information technology for Kot Addu, Punjab Province. *Pakistan. Glob J Hum Soc Sci* 13(1):1–6
- Alam S, Fatima A, Butt MS (2007) Sustainable development in Pakistan in the context of energy consumption demand and environmental degradation. *J Asian Econ* 18:825–837
- Almeida-Guerra P, Napolitano R and Feoli E (2012) Importance on soil erosion prevention for environmental risk alert by the application of remote sensing and GIS techniques. A case study in Santos (Brazil). <http://www.academia.edu/1586230/>. Accessed 14 Aug 2018
- Ananda J, Herath G (2003) Soil erosion in developing countries: a socio-economic appraisal. *J Environ Manage* 68:343–353
- Angima AD, Stott DE, O’Nell MK, Ong CK, Weesies GA (2003) Soil erosion prediction using RUSLE for Central Kenyan Highland Conditions. *Agr Ecosyst Environ* 97:295–308
- Arnoldous HML (1980) An approximation of rainfall factor in the universal soil loss equation. In: De Boodt M, Gabriels D (eds) *Assessment of erosion*. Wiley, Chichester, pp 127–132
- Ashigbor G, Forkuo E, Laari P, Aabeyir R (2013) Modeling soil erosion using RUSLE and GIS tools. *Int J Remote Sens Geosci* 2:7–17
- Ashraf A, Ahmad MM, Ahmad Z (2016) River basin management in the Himalayan Environment. A case of Soan River Basin, Pakistan. LAP LAMBERT Academic Publishing at <http://dnb.d-nb.de>. Accessed 25 Oct 2017
- Ashraf A, Abuzar MK, Ahmad B, Ahmad MM, Hussain Q (2017) Modeling risk of soil erosion in high and medium rainfall zones of Pothwar Region, Pakistan. *Proc Pak Acad Sci* 54(2):67–77
- Auerswald K (1987) Bestimmung der Bodengründigkeit aus dem Klassenbeschrieb der Reichsbodenschätzung zum Festlegen von tolerierbaren Bodenabträgen (T-Wert). [Estimating soil depth and soil loss tolerance for the classification units of the German soil productivity maps]. *J Agron Crop Sci* 158:132–139
- Chris SR, Jon H (2002) Soil erosion assessment tools from point to regional scales—the role of geomorphologists in land management. *Geomorphology* 47:189–209
- David PF, David RM (2003) Modelling large-scale fluvial erosion in geographic information systems. *Geomorphology* 53:147–164
- Ercin Z (2000) C-factor mapping using remote sensing and GIS. A case Study of Lom Sak/Lom Kao, Thailand. *Geographisches Institut der Justus-Liebig-Universität Giessen and Intern Inst. for Aerospace Survey and Earth Sci. (ITC), Enschede, The Netherlands*
- Habib-ur-Rehman S, Hamayun K, Saleem K, Nazir A, Bhatti WM (2003) Incidence and gross pathology of Salmonellosis in chicken in Hyderabad. *Jour Assoc Vet Adv* 2:581–584
- Ighodaro ID, Lategan FS, Yusuf SFG (2013) The impact of soil erosion on agricultural potential and performance of Sheshegu community farmers in the Eastern Cape of South Africa. *J Agric Sci* 5:140–147
- Iqbal MN, Oweis TY, Ashraf M, Hussain B, Majid A (2012) Impact of land-use practices on sediment yield in the Dhrabi watershed of Pakistan. *J Environ Sci Eng A* 1:406–420
- Jain SK, Kumar S, Varghese J (2001) Estimation of soil erosion for a Himalayan watershed using GIS technique. *Water Resour Manage* 15:41–54

- Jie C, Jing-zhang C, Man-zhi T, Zi-tong G (2002) Soil degradation: a global problem endangering sustainable development. *J Geogr Sci* 12:243–252
- Jiu J, Wu H, Li S (2019) The implication of land-use/land-cover change for the declining soil erosion risk in the three Gorges reservoir region, China. *Int J Environ Res Public Health* 16(10):1856. <https://doi.org/10.3390/ijerph16101856>
- Koirala P, Thakuri S, Joshi S, Chauhan R (2019) Estimation of soil erosion in Nepal using a RUSLE modeling and geospatial tool. *Geosciences* 9(4):147. <https://doi.org/10.3390/geosciences9040147>
- Kouli M, Soupios P, Vallianatos F (2009) Soil erosion prediction using the Revised Universal Soil Loss Equation (RUSLE) in a GIS framework, Chania, Northwestern Crete, Greece. *Environ Geol* 57:483–497
- Merritt WS, Letcher RA, Jakeman AJ (2003) A review of erosion and sediment transport models. *Environ Model Softw* 18:761–799. [https://doi.org/10.1016/s1364-8152\(03\)00078-1](https://doi.org/10.1016/s1364-8152(03)00078-1)
- Moore ID, Turner AK, Wilson JP, Jenson SK, Band LE (1993) GIS and land-surface-subsurface process modeling. In: Goodchild MF (ed) *Environmental modeling with GIS*. Oxford University Press, U.K., pp 196–230
- Nasir A, Uchida K, Ashraf M (2006) Estimation of soil erosion by using RUSLE and GIS for small mountainous watersheds in Pakistan. *Pak J Water Resour* 10(1):11–21
- Oweis T, Ashraf M (eds) (2012) *Assessment and options for improved productivity and sustainability of natural resources in Dhrabi watershed Pakistan*. ICARDA, Aleppo
- Parveen R, Kumar U (2012) Integrated approach of universal soil loss equation (USLE) and geographical information system (GIS) for soil loss risk assessment in upper south Koel Basin, Jharkhand. *J Geogr Inf Syst* 4:588–596
- Pimentel D, Harvey C, Resosudarmo P, Sinclair K, Kurz D, McNair M et al (1995) Environmental and economic costs of soil erosion and conservation benefits. *Science* 267:1117–1123
- Rafiq M, Ahmad M, Iqbal N, Tariq JA, Akram W, Shafiq M (2011) Assessment of soil losses from managed and unmanaged sites in a subcatchment of Rawal dam, Pakistan using fallout radionuclides, in impact of soil conservation measures on erosion control and soil quality, IAEA-TECDOC-1665, Vienna
- Renard KG, Foster GR, Weesies GA, McCool DK, Yoder DC (1997) *Predicting soil erosion by water: a guide to conservation planning with the revised universal soil loss equation (RUSLE)*. Agriculture Handbook, vol. 703US Department of Agriculture, Washington, DC, pp 1–251
- Russell SH, William WD (2001) *Landscape erosion and evolution modelling*. Kluwer Academic/Plenum, New York
- Serpa D, Nunes JP, Santos J et al (2015) Impacts of climate and land use changes on the hydrological and erosion processes of two contrasting Mediterranean catchments. *Sci Total Environ* 538:64–77
- Wischmeier WH, Smith DD (1978) *Predicting rainfall erosion losses—a guide to conservation*. Agricultural Handbook no. 537, United States Department of Agriculture, Washington, DC, p 58
- Yesuph AY, Dagne AB (2019) Soil erosion mapping and severity analysis based on RUSLE model and local perception in the Beshillo Catchment of the Blue Nile Basin, Ethiopia. *Environ Syst Res* 8:17. <https://doi.org/10.1186/s40068-019-0145-1>

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.