

Quantification of Siltation / Sedimentation and Soil Erosion Values with the Help of Satellite Imagery: A Case Study of Harike Wetland, Punjab

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Abstract: According to globally estimates, over 50% of the world's wetlands may have been altered or lost in the last 50 years. Consequently, wetland conservation is a necessity and it requires an overview on their distribution and status. Harike, one of the largest wetlands of India, was declared a Reserve in 1987 by the Ministry of Environment and Forests, Government of India. Harike came into existence in 1952 due to the formation of a barrage at the confluence of river Sutlej and Beas at Hari-ke-Pattan. With the barrage comes the issue of sedimentation, siltation and soil erosion of the ponding and the nearby areas. To know about the cascading effect on the health of the wetland, the issue needs to be addressed and thus there is a requirement of data and imagery and support of Geographic Information System (GIS). In addition to the river flow and cross-sectional data, satellite-based data were obtained from United States Geological Survey (USGS) sites including with high-resolution satellite imageries, of EO-1, Landsat 7, and LISS-3 datasets. A digital elevation model (DEM) was created by integrating ASTER imagery, bathymetric survey data, and detailed river survey information. Siltation and soil erosion has reduced the pond area from 4100 ha. to 2800 ha. The storage capacity of this lake has considerably reduced from 8381 ha meter in 1952 to 1820 ha meter in 1990. Normalized Difference Water Index (NDWI) and the surveyed data were used to calculate the present grievous state of silt deposit at Harike. Moreover, the erosion prone area is identified using GIS and USLE model. The soil hazard map helps us to suggest the remedial measure and land use planning. Average benefit-cost ratio of 1.6 suggests that desilting operations are not only economically viable but also have additional benefits like environmental protection, increased soil microbial bio-diversity, improved soil quality and increased water storage.

Keywords: Wetland, Sedimentation, Siltation, Geographic Information System, bathymetry, Storage Capacity, Soil Hazard Map, NDWI, USLE model, NDWI, Imagery

1.Introduction

A great amount of sediment is carried annually by the Indian rivers down to the reservoirs, lakes, estuaries, bays, and oceans. Soil is eroded due to rainfall and winds, resulting in tremendous sediment movement into water courses by flood and storm waters. The impact of sediment erosion, transport and deposition is widespread. Deposition of coarse sediments reduces the reservoir storage and channel conveyance for water supply, irrigation, and navigation and cause extensive disturbance to streams. Suspended sediments reduce water clarity and sunlight penetration, thereby affecting the biotic life. As the sediment settles to the bottom of water bodies, it buries and kills vegetation and changes the ecosystem. The size and quantum of silt has major impact on the operation of water resources projects in terms of siltation of reservoirs and serious damage to equipment. Water users downstream of areas of heavy soil run-off may have to remove suspended sediment from their water supplies or may suffer a reduction in the quantity of water available because of reservoir siltation. The rapid reduction in the storage capacity of reservoirs due to siltation is a major sediment-related problem world-wide. Moreover, the availability of water for irrigation from the reservoir leads to more intensive land use and increased soil erosion. These effects may also be exacerbated by desertification (impoverishment of vegetative cover and loss of soil structure and fertility), whether anthropogenic or climatic in origin. The emergence of silt-conscious design is an engineering challenge.

During transport in a water body, sediment particles become separated into three categories:

Suspended material which includes silt + clay + sand; the coarser, relatively inactive bedload and the saltation load. Suspended load comprise sand + silt + clay-sized particles that are held in suspension because of the turbulence of the water. The suspended load is further divided into the wash load which is generally considered to be the silt + clay-sized material (< 62 µm in particle diameter) and is often referred to as "fine-grained sediment".

Bedload is stony material, such as gravel and cobbles, that moves by rolling along the bed of a river because it is too heavy to be lifted into suspension by the current of the river. Bedload is especially important during periods of extremely high discharge and in landscapes of large topographical relief, where the river gradient is steep (such as in mountains). It is rarely important in low-lying areas.

1.1.1 Effects of siltation

Silt deposition has very severe bad effects on the reservoir and wetland biodiversity. Some of them are as under;

- It reduces the reservoir storage capacity.
- It causes extensive disturbance to channel conveyance for water supply, irrigation, and navigation
- It reduces water clarity and sunlight penetration, thereby affecting the biotic life.
- It buries and kills vegetation and changes the ecosystem.

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Major impact on the operation of water resources projects in terms of siltation of reservoirs and serious damage to equipment.

Gradual enrichment of reservoir waters with nutrients.

1.2 Computation of reservoir capacity and sediment volume

The volume of deposited sediment was proposed to be worked out using the following different methods:

- Contour area interval method
- Modified Prismoidal method
- Grid method

1.2.1 Contour area interval method

Prepare contour map to a scale of 1 cm = 100 m. The successive areas enclosed by the contours, count the full and partial squares. Calculate the capacity by taking the average contour areas and multiplying by unit height i.e., contour interval. From the successive cumulative volume starting from the lowest elevation, the elevation capacity relationship was established up to the full reservoir level. The difference between the original and present capacity was the total volume of sediment deposited for intervening period.

1.2.2 Modified prismoidal method

In this method, the volume below the lowest contour was worked out by end area method. Using the following formula, for each succeeding higher contours, the volumes were worked out as

$$V_x = \left[\frac{2H}{6} \right] [A + 4B + C] - V_y \quad (1.1)$$



where,

V_x – volume between contour B&C

H – contour interval

B – area of mid surface

A – area of Bottom surface

C – area of top surface

V_y – volume between contours A and B previously determined

1.2.3 Grid method

In this method, the accuracy of the result depends on the size of the grid. As far as possible, smaller the size of grids, greater the accuracy This method is widely followed for the following advantages:

The coordinates of range pillars can be worked out more accurately and quickly.

Only by this method details of location of silt and scour can be marked in the map while by other methods, the net effect only can be obtained.

1.3 Case study

1.3.1 Sukhana lake desilting method (Shramdan)

During April-July 1188 a unique ‘peoples’ effort ‘Shramdan’ was mounted exhorting people of Chandigarh to render voluntary help in the removal of silt from the lake bed through manual labour (Figure 1.1). In this effort all sections of society participated with great enthusiasm. In addition, excavation of silt was also carried out through mechanical measures.



Figure 1.1: Local residents were involved to clean the lake

The Voluntary work for silt removal continued in the subsequent years till 1113 except for 1110 when no sharamdan was undertaken. The total silt so far removed

from the lake bed comes to 10, 18, 800 m^3 . Table 1 gives the data for annual silt removal.

Table 1.1: Desiltation of Sukhana lake through Sharamdan

Year	Silt removed (m ³)
1188	11, 050
1181	3, 53, 750
1110	No sharamdan
1111	84, 100
1112	1, 18, 100
1113	2, 83, 000

1.3.2 Maithon: Quantitative reservoir sedimentation analysis remote sensing techniques

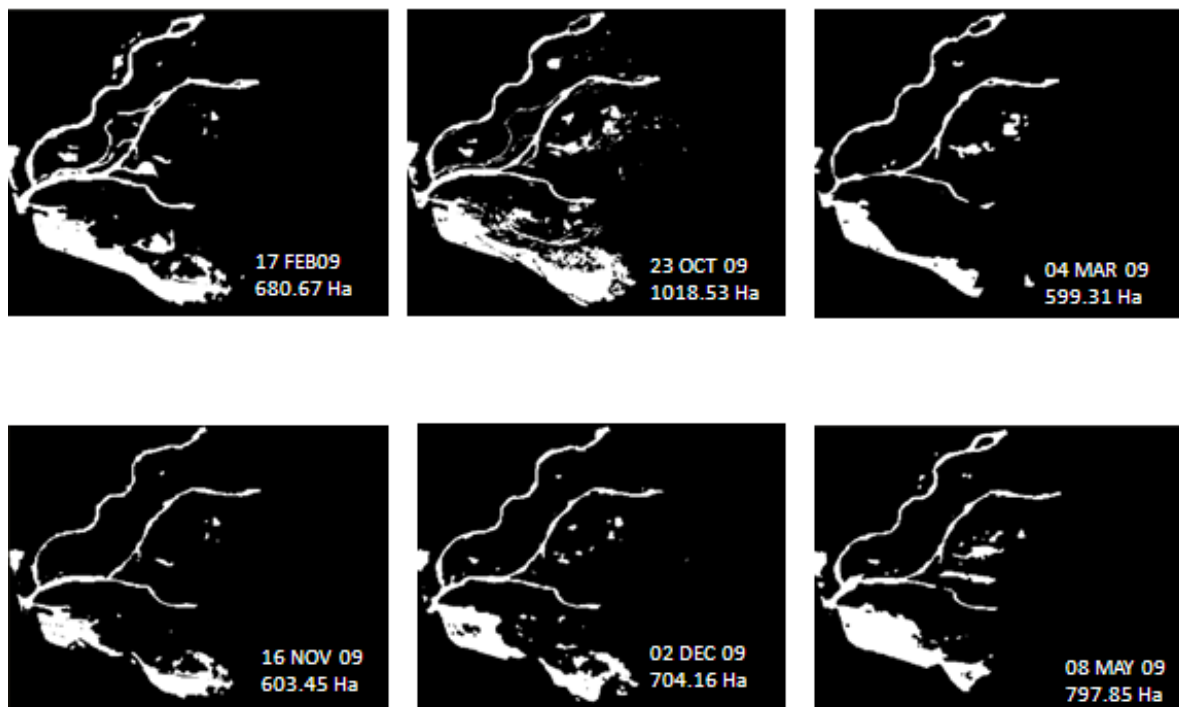
In this, study was carried out to correlate the digital number (DN) of satellite images with the sediment concentration of the reservoir water. It was physically monitored at the time of satellite pass and the image was correlated with corresponding DN values within the reservoir. Regression techniques was used for the same and once the relationship between sediment concentration and DN values are established, sediment concentration in the reservoir may be quantified.

In same case a second type of study in which sediment concentrations are not directly measured rather the change in the physical shape of the water body due to sedimentation is taken into account. It is obvious that due to sediment deposition within the reservoir water spread area at a particular elevation will reduce gradually over a period of time. Water spread area can be very easily monitored and quantified through satellite and using Arc-GIS tools to quantify the area.

1.3.2.1 Methodology

In India, more than 80 % of the annual rainfall is received during the four monsoon months from June to September. Hence, depending on the amount of rainfall in a monsoon, water level in a reservoir can be expected to be at higher elevation after the monsoon season (September/October) before it gradually depletes to lower levels towards the onset of next monsoon (May/June). Revised contour areas, as they exist at different elevations, can be calculated and the revised elevation-area curve can be prepared and the original contour areas at different elevations and the original elevation-area-capacity curves at the dam site can be obtained from the original capacity surveys, which are carried out before the planning and construction of a dam. The reduction in reservoir capacity between consecutive contour levels is computed using the prismoidal formula. Water levels in the reservoir corresponding to the date of imagery and time of satellite pass can be obtained from the dam authorities.

Monthly water spread of Harike wetland for the year 2001 using the satellite imagery is used to identified the water spread area using NDWI. Refer the Figure 1.2

**Figure 1.2:** Temporal changes for water spread area

The volume of reservoir below the lowest observed level is assumed to be the same before and after the sedimentation since sediments deposited below the lowest observed level cannot be determined using remote sensing.

1.4 Data collection

As per the survey report of the Irrigation department, Ferozpur the silt deposition detail is as under: Table 1.2

Table 1.2: Average silt deposition

Year	1187	1115	2000	2005	2010	Total
Average Silt deposition(cm)	0	6	4.	3	4	17cm
Average depth (m)	2.10	2.04	2.0	1.17	1.13	

1.5 Water spread area

From the LANDSAT-7 imagery of different months for the year 2008-01 different months cloud- free imagery were

extracted and then with NDWI as done in the Fig 2. Average Inundated area as calculated for the area is 811.00 Ha. Refer Table 1.3.

Table 1.3: Water spread area for different months

S.No.	Date of Image	Area(Ha)
1	22 July 07	967.23
2	25 Aug08	1153.98
3	26 Sep08	910.98
4	23 Oct09	1018.53
5	16 nov 09	603.45
6	02 Dec09	704.16
7	11 Jan 07	754.20
8	17 Feb 09	680.67
9	04 Mar 09	599.31
10	08 may 09	797.85

1.6 Findings and analysis

In order to determine the useful life of a reservoir, it is essential to periodically assess the sedimentation rate in a reservoir. The average silt deposition is 17.0 centimeters. The storage capacity of this lake has considerably reduced from 8381 ha meter in 1152 to 1820 ha meter in 1110. From survey data storage capacity has further reduced to 1580 Ha meter in 2010.

Reduction in storage capacity leads to imbalance in the wetland biodiversity as well as the anthropogenic requirements since the Rajasthan Feeder canal which is the life line of Rajasthan State starts from here and any reduction in the ponding capacity will also reduce down their share of water. Immediate desilting methods have to be adopted for early solution to this problem.

1.7 Mechanical removal of silt

As per our site requirement out of various techniques available for desilting such as Flushing, Sluicing, Density Current Venting, Dredging, Trucking, Hydrosuction Removal System (HSRS), following methods will be best suited for our area.

Dredging: Dredging is the mechanical removal of accumulated sediment in the reservoir from a reservoir bed by pumping (traditional hydraulic dredging) or by mechanical equipment without emptying the reservoir and then dumping the dredged sediment at a suitable area

Trucking: Trucking is the excavation of the accumulated sediment from a reservoir like dredging but it requires the drawdown of the reservoir.



Figure 1.3: Dredging



Figure 1.4: Trucking

1.8 De-silting cost

Currently, dredging costs about Rs 125-150 per cu. m for maintenance and Rs 250-300 per cu. m for capital dredging according to an executive with the state-owned Dredging Corp. of India Ltd. Cost for de-silting will be Rs 75 crores.

1.9 Recovery of desilting cost

1.9.1 Irrigation Charges

Table 1.4: Irrigation charges (Rs / hectare)

	1170-71	1170-81	1181-11	1111-2001	2001-05	2004-05
Haryana	101.60	116.46	370.12	101.74	1, 811.86	1, 106.11
Madhya Pradesh	2.33	31.40	242.48	717.61	1, 660.86	1, 161.51
Punjab	71.15	101.16	171.56	321.80	431.33	461.72
Rajasthan		251.81	452.34	1, 145.42	2, 647.53	2, 381.44
Uttar Pradesh	88.10	151.52	311.42	131.16	2005.66	2, 630.44

Source: Raghavan, 2008

The rates are also low because of heavily subsidized water and electric charges for irrigation since Punjab avails the credit under the Accelerated Irrigation Benefit Programme or Rural Infrastructure Development Fund scheme, both initiated in the mid-1110s, are being forced to raise irrigation.

1.9.2 Water Requirement of Crops

The various definitions for water requirement for crops are as under:

- The Water Requirement (WR) of crops depends upon retention and transmissivity of water in soil, absorption and transmission within plant, transpiration, effective rainfall, vapour pressure, and energy. WR is that quantity of water regardless of its sources required by a crop in a given period of time for its maturity. It includes losses due to evapotranspiration plus the losses during the application of irrigation water which may be unavoidable.
- Irrigation requirement (IR) of a farm is the sum total of irrigation need for an individual crop in a specified time plus the losses occurring in field distribution such as

The cost of irrigation is dependent on the sources of irrigation, like surface water, wells, tube-wells, tanks and so on. It also depends on prices of pump sets, low speed diesel oil, electricity tariffs, canal irrigation rates, etc. In terms of importance, there are two major irrigation sources. Water from wells and tube-wells drawn with electricity and diesel pump sets work out to around 70 per cent of all sources in Haryana and Uttar Pradesh and as high as 17 per cent in Punjab. The reasons being over exploitation of groundwater and the depth of ground water recedes to average 15 to 20 meters to what it use to be 10 years back.

The next major source of irrigation is surface water from rivers, springs or canals. Compared to pump irrigation, the share of flow irrigation is rather insignificant, except in Madhya Pradesh, where it comes to about one-fourth of all sources of irrigation. The average irrigation charges work out to 17 per cent of the operational costs of cultivation at present, compared to 10 per cent in the 1180s. In states like Punjab and Haryana, this share is not only very low, but also has remained stagnant for a long period (Table 1.4). Government is encouraging farmers to use the surface water irrigation by reducing the charges so that farmers again go back to old method of irrigation system and thus it will also reduce the salinity of the soil (State of environment Punjab, 2007) and which is prevailing mostly towards the southern west part of Punjab

seepage, percolation etc. Similarly, IR for a command area will constitute the sum of water needs for individual farms plus the loss taking place in the distribution system in that area.

- Net irrigation requirement (NIR) is the depth of irrigation water, exclusive of precipitation, carry-over soil moisture or ground water contribution which is required for plant growth. It is that amount of irrigation water which is required to bring the soil moisture of the effective root zone to field capacity (FC). Thus, it is the difference between FC and soil moisture content in the root zone before irrigation.

We are basically concern about the IR since we will be discussing about the total amount of revenue generated because of the area irrigated with the increase in ponding capacity of the reservoir.

1.9.3 Crop season and water requirement

In India there are two primarily two seasons for crops i.e Kharif and Rabbi. Still in some States there are third season primarily for vegetable growing (Table 1.5)

Table 1.5: Crop Seasons

Season	Period From- To	Base Period (days)	Common crops
Kharif	15 th June- 14 th Oct	123	Rice, Jowar, Cotton, etc.
Rabbi	15 th Oct-14 th Feb	122	Wheat, Linsheed, Gram, etc.
Hot weather	15 th Feb-14 th June	120	Crops like vegetable
Eight monthly	15 th June-14 th Feb	245	Tobacco, cotton, groundnut, etc.
Annual	15 th June-14 th June (next year)	365	Sugarcane, Orchards, etc.

Total water requirement for irrigation differs from state to state with di climatic conditions for example the water requirement for Wheat is 306 mm for Ludhiana, Punjab and 405 mm for Rajasthan.

Irrigation requirement for different crops under various climatic conditions and soil types are given in Table 1.6.

Table 1.6: Irrigation requirement for different crops

Sl. No	Crop	Place	Soil type	Season	Irrigation Requirement(water)s	
					Number	Amt (mm)
1.	Wheat	Jobner (Rajasthan)	Loam sand	Rabi	6	405
		Ludhiana (Punjab)	Sandy loam	Rabi	5	360
3	Rice	Ludhiana (Punjab)	Sandy loam	Kharif	12	1240
		Ganganagar (Rajasthan)	Loam sand	kharif	112	1400
4	Bajra	Hissar (Haryana)	Sandy loam	Kharif	3	200
		Delhi	Sandy loam	Kharif	2	150
5	Groundnut	Chittorgarh (Rajasthan)	Loam sand	July-Oct	4	300

1.9.4 Revenue generation

Calculation of water

Total silt to be excavated - 240, 000 Ha mm

Increase in ponding capacity of water / year (240, 000 * 365)
- 87, 600, 000 Ha mm

Water share for Rajasthan (60%) - 52, 560, 000 Ha mm

Share for Punjab is (40 %) - 35, 040, 000 Ha mm

Assuming, **Crops requirement** (consider only two seasons)

Punjab - Kharif + Rabi (Wheat+ Rice)

Rajasthan - Kharif + Rabi (Wheat +Groundnut)

Irrigation requirement (water requirement)

Punjab - 1600 mm (360+ 1240)

Rajasthan - 705 mm (405+300)

Area Irrigated

Rajasthan - 40, 000 ha (taking 20 % canal losses)

Punjab - 21, 500 ha (taking 10 % canal losses)

Revenue generated annually refer Table 1.4

Punjab - Rs 13, 620, 740 (@ Rs 461.72 / ha)

Rajasthan - Rs 15, 577, 600 (@ Rs 2381.44 /ha)

Total saving -Rs 101, 118, 340

say **10 Crores/ year**

This additional revenue of Rs 10 crores/ year would be generated due to enhanced storage, achieved by desilting the pond area of the barrage. 2.4 M m³ of silt deposite at the annual average rate of 0.1 M m³has been computed. Assuming the proposed de-silting continue to provide additional storage for 1/3rd of siltation period, i.e. ~ 8 years, total revenue from additional supply of water to two states would be 8x 10 Crore = 80 Crore.

We have to phase the fund demand and clearance procedure for 8-year plan. The Cost Benefit analysis for the same has been calculated in next paragraph.

1.9.5 Cost benefit analysis for siltation

Detail cost benefit analysis has been done to see for the viability for desilting such a huge quantity as it may be nuisance for the locals and huge area have to pre identified for its systematic disposal. We have to access the tangible and intangible benefits from this

1.9.5.1 Some of the primary benefits of desiltation

Increased rainwater storage,

Groundwater recharge,

Water availability for irrigation of additional area.

Restoration of biological activity return of high value organic “C” to fields for improving crop productivity.

1.9.5.2 Some addition benefits are

Sediments back to the agricultural lands not only return back the nutrient-rich fine fractions with high C values.

Restores the soil microbial biodiversity in the system.

1.9.5.3 Organic carbon

The overall mean organic C value is assumed to be 11.64 g C /kg sediment, indicating that by desilting the lake and adding the sediment to farms would return 335232 tonnes of organic C. This will be recycled for increasing agricultural productivity through C mineralization and the release of plant nutrients. The improved plant growth in turn would fix more C through increased photosynthesis resulting in increased productivity of farms and reduced CO₂ concentration in the atmosphere. This large amount of carbon in tank sediment would otherwise have been released to atmosphere, resulting in increased concentration of atmospheric CO₂. Organic C plays an important role in plant nutrition and the application of sediment with higher values

would give increased benefits to the agricultural system by improving the soil quality and productivity.

1.9.5.4 Microbial population

A higher microbial population gives an indirect inference of higher moisture retention capacity in the substrate sediment as well as better nutrient availability. Maximum microbial population is found in region where soils have high moisture retention capacity, which is optimum for the microbial activity.

This wide variability in microbial population could be attributed to the nutrient status of tank sediment, farm cropping and soil history which have a direct influence on the quality of the tank sediment. Loss of microbial diversity from fields is one of the important causes of land degradation through erosion.

Returning of lake sediments rich in biological counts would help in improving the microbial diversity and biological activity in farm soils thereby improving soil quality and crop production.

1.9.5.5 Nitrogen and phosphorus content in the sediment

Fertilizer usage details provided by the state district officials reveal that mostly nitrogen (N) and phosphorus (P) are applied through diammonium phosphate (DAP) fertilizer and only nitrogen was applied through urea fertilizer. Nitrogen and P are the most important nutrients that contribute towards higher crop yields. The sediment samples were analysed for N and P contents.

The total N and P content in the lake is assumed with an average of 711 mg/kg and 321 mg/kg (Padmaja et al, 2008).

In total, 2.88 M tonnes of sediment contained 21024 tonnes of nitrogen and 10281 tonnes of phosphorus.

1.9.5.6 Relationship between nutrients and microbial population

Nutrients such as N and P are required for synthesis of amino acids, proteins, purine, pyrimidine nucleotides and certain vitamins, which are important for microbial growth. The nitrogen occurs in nature in a variety of oxidation states, each of which can be utilized by different microorganisms. It was found that sediment samples, which were high in N content, also had a higher microbial population.

Phosphorus occurs in living organisms chiefly as sugar phosphates in nucleotide and nucleic acids. Hence phosphorus, usually as inorganic phosphate, needs to be provided in considerable amount for the growth of microorganisms. A similar positive relationship was found between P content in the sediment and the microbial population. When a comparison of the bacterial population and N and P content in the sediment samples was made, where the bacterial population was high, the N and P contents were low. This indicates that the nutrients could possibly be utilized for microbial assimilation or used for restoring the soil health. The nutrients in the tank sediment that were washed off from the fields are directly related to the agricultural practices adopted. Hence, a direct positive

relationship can be established between microbial population and nutrient (N, P) content.

1.9.5.7 Economics of removal of sediment from the Lake

A direct positive correlation was found between amounts of sediment deposited in the lake to the rainfall received as per USLE model. In Harike the total silt deposition is found out to be 240-hectare meter or 2.4 M m^3 . As the quantities of sediment deposited in the lake is huge, an economic feasibility for the desiltation process was required to be undertaken.

The total quantity of sediment from the lake is about 2.88 M tons. The total cost incurred in removal of this sediment from tanks amounted to be Rs 75 Crores (Refer para 1.1.4) including disposal to the required area within 5 Km range.

1.9.5.8 Calculation for revenue generated from the use of silt

Total silt -----240 ha meter or $2.4 \times 10^6 \text{ m}^3$

Density of silt is 1.2 (Source: Neeru-Meeru' program in Andhra Pradesh)

Total weighs- 2.88 M tonnes

The overall mean N, P and organic C content in the sediments was calculated to (Padmaja et al, 2008).

N to be 730 mg /kg sediment

P to be, 357 mg /kg sediment

C to be 11.64 g C /kg sediment.

Total N, P and organic C assumed to produce same amount as in Andhra Pradesh (Padmaja et al, 2006).

21024 tonnes of N

10281 tonnes of P

335232 tonnes of C

Cost of fertilizer equivalents produced from the silt deposition are

Rs 221036128 of N or 23 Crores

Rs 111210150 of P or 11 Crores

Total cost retrieved - Rs 42 Crores.

Cost benefit calculation

Cost incurred for desiltation – Rs 75 Crores

Benefit from fertilizer equivalent – Rs 42 Crores

Benefits from extra irrigation area for 8 years as mentioned in para. 1.1.4 is

$8 \times 10 = \text{Rs } 80 \text{ Crores}$

Benefit to cost ratio- $122/75 = 1.6$

1.9.5.1 Benefit-cost ratio

In order to check whether the task of sediment removal and their recommendations to apply to fields and irrigation makes sense, the economic feasibility of such investment costs were estimated. The quantity of sediment removed from lake is 2.88 M tons. The total cost incurred in removal of this sediment amounted to Rs75 Crores. The value of sediment was quantified in terms of fertilizer equivalent costs and the extra area irrigated both in Punjab and Rajasthan. . The nutrient content in terms of N and P retrieved from the sediment and the area irrigated was considered to be the profit (benefit) as against the expenditure (cost) incurred in removing the sediment from the lakes (see para 11.6). Additionally, the process of sediment application to farm lands that is rich in organic C

will result in C mineralization and higher nutrient availability thereby helping plant growth and greater fixation of C through photosynthesis. The benefit-cost ratio averaged to 1.6.

Average benefit-cost ratio of 1.6 suggests that desilting operations are not only economically viable but also have additional benefits like environmental protection, increased soil microbial bio-diversity, improved soil quality and increased water storage. If indirect additional environmental benefits are also estimated in the benefit component, then there would be compounded benefit. Application of sediment back to the agricultural fields forms an improved agricultural management system that enhances and protects the soil quality resulting in improved production capacity of soil and reversing the process of land degradation.

1.10 Water- Erosion

1.10.1 Mechanics

There are three steps to accelerated erosion by water:

- Detachment** or **loosening** of soil particles caused by flowing water, freezing and thawing of the topsoil, and/or the impact of falling raindrops.
- Transportation** of soil particles by floating, rolling, dragging, and/or splashing.
- Deposition** of transported particles at some place lower in elevation.

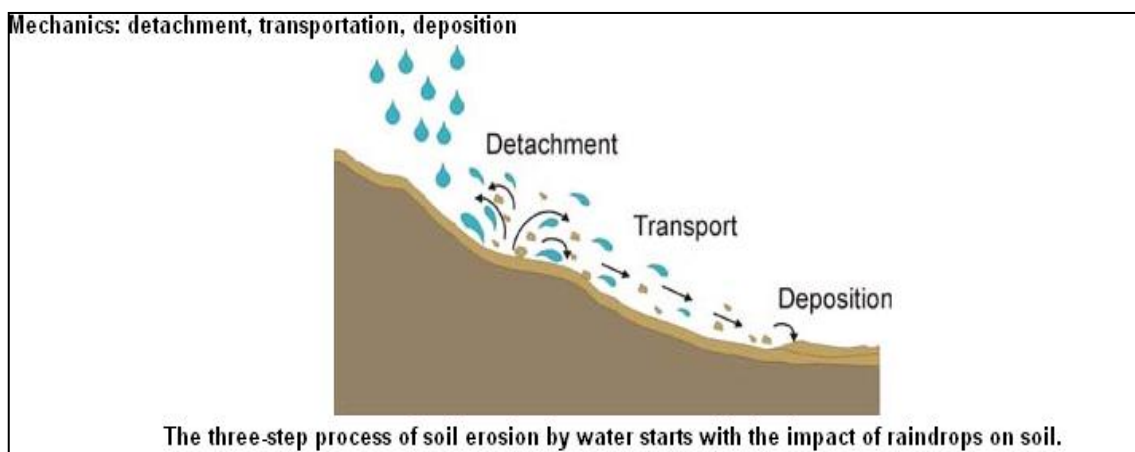


Figure 1.5: Process of soil erosion by water (Source: Lesley Dampier)

1.10.2 Soil Erosion Models

Soil erosion and sedimentation by water involves the processes of detachment, transportation, and deposition of sediment by raindrop impact and flowing water (Foster and Meyer, 1177; Wischmeier and Smith, 1178; Julien, 1118). The major forces originate from raindrop impact and flowing water. Figure 6. shows the mechanisms of soil erosion, in which water from sheet flow areas runs together under certain conditions and forms small rills. The rills make small channels. When the flow is concentrated, it can cause some erosion and much material can be transported within these small channels. A few soils are very susceptible to rill erosion. Rills gradually join together to form progressively larger channels, with the flow eventually proceeding to some established streambed. Some of this flow becomes great enough to create gullies. Soil erosion may be unnoticed on exposed soil surfaces even though raindrops are eroding large quantities of sediment, but erosion can be dramatic where concentrated flow creates extensive rill and gully systems.

1.10.3 Universal Soil Loss Equation (USLE)

The USLE (Universal Soil Loss Equation) is an erosion prediction model, for estimating soil losses from a specified land in a specified cropping and management system. The equation predicts only the losses from sheet and rill erosion under specified condition. It computes the soil loss for a given site, as a product of six major factors, whose most

likely values at a particular location can be expressed numerically (Wischmeier and Smith, 1178) as:

$$A=R*K*L*S*C*P \quad (1.2)$$

where,

A = the computed soil loss per unit area, expressed in the units selected for K and for the period selected for R. In practice, these are usually so selected that they compute A in metric ton per ha per year, but other units can be selected.

R = The rainfall erosivity factor

K = The soil erodibility factor

L = The slope length factor

S = The slope steepness factor

C = The crop management factor

P = The conservation practice factor.

It is an equation that estimates average annual soil loss by sheet and rill erosion on those portions where erosion, but not deposition, is occurring. It neither estimates deposition at the toe of concave slope, nor the sediment yield at downstream location. Also, it does not include ephemeral gully erosion.

1.10.4 Rainfall erosivity factor (R)

The rainfall erosivity factor (R) is calculated as the product of the kinetic energy of the storm and the 30-minute maximum rainfall intensity occurring during the storm. This

product is known as the erosion index (EI) value. It has been established that this value gives very good correlation for estimation of soil loss, and is the most reliable estimate of potential rainfall erosivity. The highest rainfall intensity in any 30-minute period during the storm was computed using the rainfall data of automatic weather station. For computing rainfall erosion index, storms having total rainfall values more than 12.5 mm and separated from another storm by six hours were selected (Hardaha *et al.*, 1116; Satpathi *et al.*, 1111). Therefore, EI₃₀ can be expressed as

$$EI_{30} = K.E. * I_{30} (1.3)$$

Wischmeier and Smith (1178) gave the following equation for the calculation of K.E.

$$E = 0.111 + 0.0873 \log_{10} I \text{ for } I < 76 (1.4)$$

$$E = 0.283 \text{ for } I > 76$$

Where E = K.E. in megajoules / hectare mm,

I = rainfall intensity in mm/hr

This EI₃₀ value gives the measure of rainfall erosivity factor and in order to obtain daily, weekly, monthly, seasonally and yearly values, the storm EI₃₀ values for that length of period are summed up.

In our case, being very small area, we have assumed that there will be uniform rainfall in the entire area, it's a comparative assessment of the area and we have to identify and priorities th problems.

1.10.5 Soil Erodibility Factor (K)

The soil erodibility factor, K, is the rate of soil loss per unit of R or EI for a specified soil as measured on a unit plot, which is a 22.1 m length of uniform 1 percent slope continuously in cleaned tilled fallow. Therefore, K has units of soil loss per unit of area per erosivity unit. In SI system unit its unit is t h MJ⁻¹ mm⁻¹.

The standard plot size considered in the above discussion was result of the sizes that were adopted for runoff plot studies. Runoff plots were earlier made to be of 1/100 acre that is plots of 6 ft. wide and 72.6 (nearly 22.1 m) long. Thus, the standard conditions assumed have no special significance but a historical accident.

A nomograph can be used to determine the value of K or it can be calculated by the following regression equation (Foster *et al.*, 1181)

$$K = 2.8 * 10^{-7} * M^{1.14} (12-a) + 4.3 * 10^{-3} (b-2) + 3.3 * 10^{-3} (c-3) (1.5)$$

Where,

M = particle size parameter (% silt + % very fine sand) (100 - % clay)

a = organic matter content

b = soil structure code

c = profile permeability class

1.10.6 Erodibility and organic matter

Organic matter has a variable influence on the soil, affecting both its chemical and physical properties. The effect of organic matter on physical properties relates largely to its

availability to bind soil particles together. By virtue of its binding action, organic matter helps stabilize loose soil against erosion. Soils with less than 3.5 % organic content can be considered erodible. Some studies suggested that soil erodibility decreases linearly with increasing organic content over a range of zero to 10% whereas soil detachment by raindrop impact decreased exponentially with increasing organic content over a range of zero to 12%.

1.10.7 Erodibility and structure

The soil structure is defined as the manner in which soil particles are assembled in aggregate form. Aggregation in soils depends primarily on the cohesive nature of the finer particles and on natural forces that organize and retain them in specific structural units, or peds, of definable shape and size. Structure may be designated as blocky, prismatic, platy, granular and structure less. Very fine granular structure is stable; does not break down cultivation and high infiltration capacity. Blocky and platy structure are more erodible.

Table 1.7: Structure code for different types of soil

Code	Structure	Size, mm
1	Very fine granular	<1
2	Fine granular	1-2
3	Medium or coarse granular	2-10
4	Blocky, platy or massive	>10

1.10.8 Erodibility and permeability

Water intake of soil is at a maximum when soil is fairly dry, for after water is added, the pore space becomes full. Then collides swell, and the rate of entry of additional water declines to a low but uniform level. Wischmeier *et al.* (1171) presented the integrated effect of the various factors influencing infiltration rate by a single factor of permeability to determine erodibility of soils.

Table 1.8: Permeability code for different types of soil

Code	Description	Rate, mm/h
1	Rapid	>130
2	Moderate to rapid	60-130
3	Moderate	20-60
4	Slow to moderate	5-20
5	Slow	1-5
6	Very slow	<1

In our study, to know the different values of the factor we have first procured the soil map of Punjab from NBSS (land use planning), Nagpur. The Map was Geo-referenced and then the area of interest was extracted giving the different class, texture and structure of soil. The values assigned to different class of soil incorporated in our study was taken from the study conducted by Jawahar Sehgal, 1174 Astt prof Soils, PAU, Ludhiana.

1.10.1 Slope length factor (L) and slope steepness factor (S)

The effects of slope length and gradient are represented in the USLE as L and S, respectively. However, they are often evaluated as single topographic factor, LS. The L and S factor can be calculated from the following equation,

1.10.13 Development of Model Database for USLE

1.10.13.1 Delineation of wetland area

The boundary of the watershed was manually digitized in polygon mode using ARC-GIS software also the reference

of Punjab remote sensing departments boundary map and GPS was used to delineate the required area and the buffer area of approx. 10 Km. The total area considered is of 8600 Hectares, whereas the core area is of 4200 Hectares, which is also considered as the Bird Sanctuary area. The boundaries of different sub watersheds were also digitized.

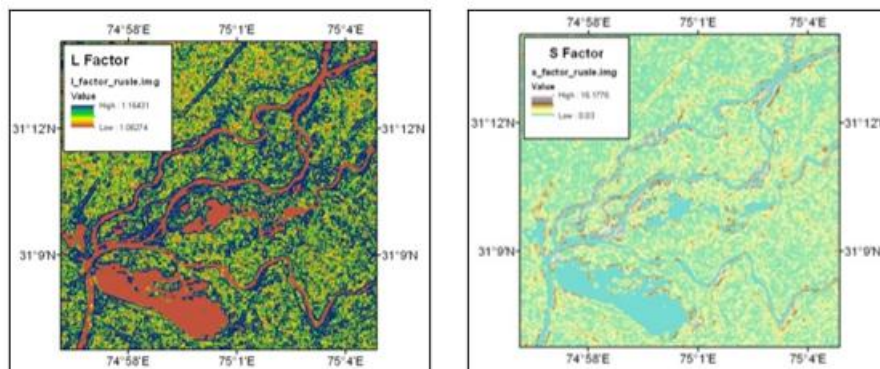


Figure 1.7: L and S factor Map

1.10.13.2 Generation of slope coverage

The ARC-GIS software was used for generating the slope coverage. Based on the literature survey, in the present study, cell size of 30×30 m was considered as basic operational unit for the erosion analysis. Therefore, for generating slope of the study area, DEM was generated for the study area by interpolating the digitized contours at 10 m interval and spot height into 30×30 m cell-size. Thus, elevation has been obtained for each of the grid element of 30 m resolution (Figure. 1.8.).

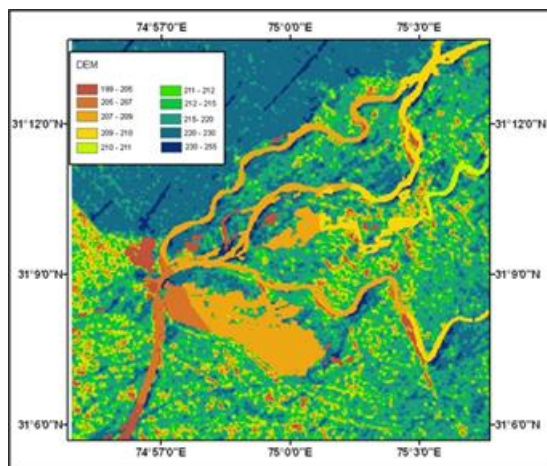


Figure 1.8: Digital Elevation Model (DEM) of Harike Wetland

1.10.13.3 Topographic factor (LS)

Determination of slope steepness and length factor is an integral part of most soil erosion prediction models. Using field surveys, Horton (1145) was one of the first to quantify the effects of the slope steepness and length. He demonstrated that erosion increases on longer slopes and steeper slopes because of the increase of shearing forces on the soil surface. Such a relationship between the slope length and soil loss was further used as a basis for the slope length (LS) factor of the USLE.

A $30 \text{ m} \times 30 \text{ m}$ cell size Digital Elevation Model (DEM) was generated which is shown in Fig. 1.8. A DEM derived slope map was used to generate slope length (L) and slope gradient (S) maps. GIS based module was created to generate a combined L and S map. The spatial distribution of topographic factor (LS) is shown in Fig 1.9. The majority of area has LS value less than 0.70, the range of LS values varied between 0.03 and 18.0. The mean LS value derived from LS factor map was 0.674.

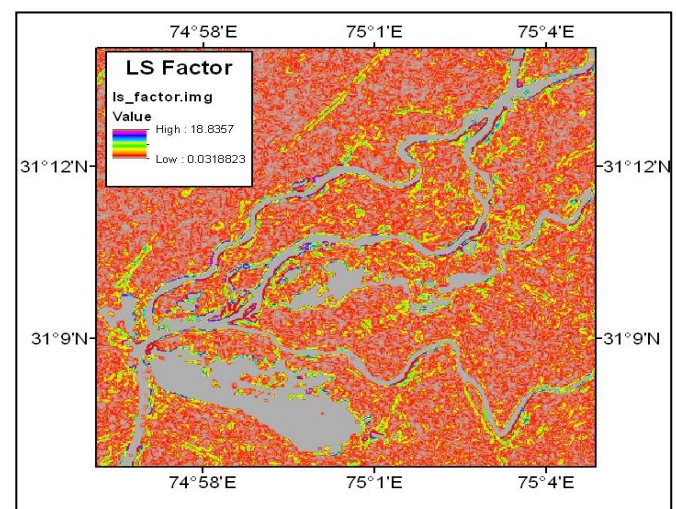


Figure 1.9: Length-Slope map of Harike wetland

1.10.13.4 Soil texture map

To know the different values of the factor we have first procured the soil map of Punjab from NBSS (land use planning), Nagpur. The Map was Geo-referenced and then the area of interest was extracted giving the different class, texture and structure of soil as per the study conducted by Jawahar L. Sehgal, associate professor soils (Pedology), Department of soils, Punjab agricultural University, Ludhiana and the values assigned to them were also incorporated in our study depending upon the type of soil.

Soil map was scanned into raster format and boundaries of different soil texture were digitized. The soil texture map for Harike wetland shown in Figure 1.10. This soil map resamples in 30×30 m cell-sized. Different maps of soil properties such as percentage of sand, silt, clay, organic matter, soil's structure code and permeability classes were generated from ground truth information collected from study area. These maps were coded into the module which was developed in Arc Toolbox as raster files to generate the K factor layer using the regression equation.

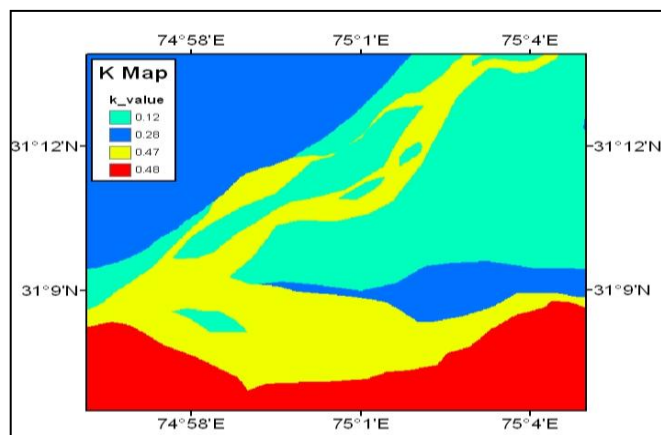


Figure 1.10: Soil Texture map of Harike Wetland

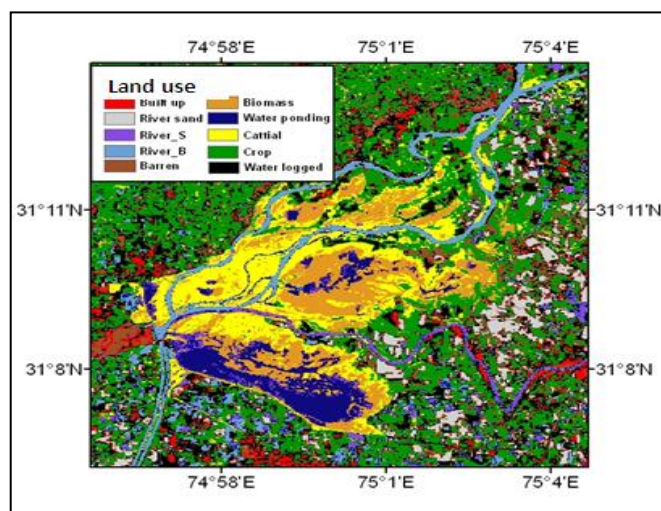


Figure 1.11: Landuse/ land cover classification of Harike wetland

1.10.13.5 Land Use/ Land Cover Classification

Earth Observation 1 satellite digital image of year 2010 (DOP: 10th October 2010) was classified using supervised classification. The classified images of harike wetland is presented in Fig.1.11. Further land use/land cover image was resampled into 30×30 m cell-size. The graphical representations of LU/LC statistics of Harike watershed and its sub-watershed is also given in

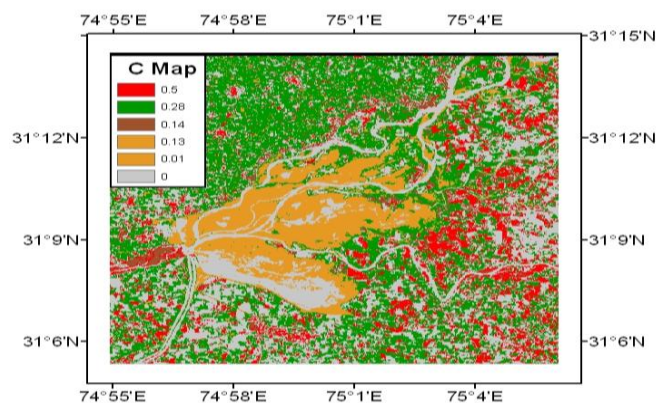


Figure 1.12: Crop Management map

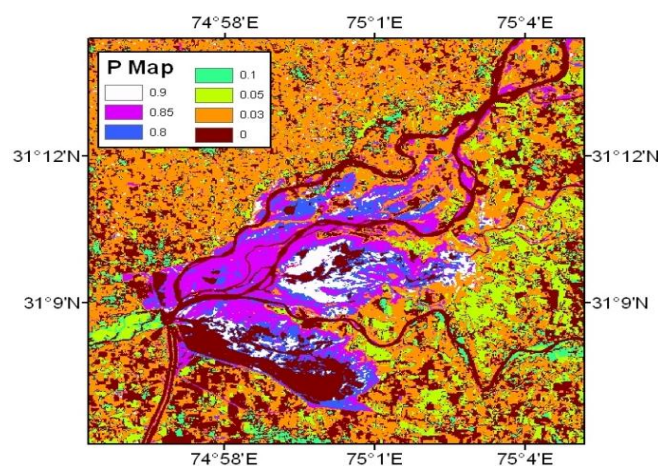


Figure 1.13: Conservative practice factor map

1.10.13.6 Computation of crop management (C) and conservation practice factor (P)

C factor map and P factor map was prepared from Land use/ land cover map, which was prepared from supervised classification of FCC of EO-1 image. The C and P values were chosen based on the research findings of Central Soil and Water Conservation Research and Training Institute, Dehradun and suggested by Rao (1181), Singh *et al.* (1181) and USDA-SCS handbook. The values are shown in the Table 1.9.

Table 1.9: Values of C and P factor for different Land use/Land cover

Land use/land cover	C value	P value
Dense forest	0.01	0.8
Open forest	0.02	0.85
Degraded forest	0.13	0.1
Water bodies	0	0
Paddy	0.28	0.03
Waste land	0.14	1
Plantation	0.13	0.8
Village / orchards	0.5	0.1
Fallow	0.28	0.03

Information on landuse permits a better understanding of the land utilization aspects on cropping pattern, fallow land, forest and wasteland and surface water bodies, which are vital for development planning/erosion studies. Land use/land cover map of study area is shown in Fig 5. Using Land use/ land cover map and procedure given in section

5.4.5 crop management factor (C) and conservation practice factor (P) maps were prepared. C values ranged from 0 to 0.5 and P values ranged from 0 to 1. The magnitude and spatial distribution of crop management factor (C) and conservation practice factor (P) are shown in Figure 1.12 and 1.13 respectively.

1.10.13.7 Preparation of most vulnerable soil Loss map using USLE model

To determine the critical soil erosion zones in the watershed, cell-based USLE parameters were multiplied in specified 30 m × 30 m cells. The R factor was not computed as the area is very small and it was assumed that average rain fall is constant. The annual soil loss for sub-watersheds (SW) was calculated by yearly R factor and K, LS, C and P factors and the soil erosion rate (t/ha/yr) was estimated as total soil loss of a SW_i (t/yr) / total geographical area of SW_i (ha).

All the layers viz. K, LS, C and P were generated in GIS and the product was obtained by a module which was created in Arc Toolbox, which gives annual soil loss (A) for the study area. Then this soil loss map was overlayed with wetland map of Harike which contains 3 sub-watersheds to get sub-watershed wise soil loss.

The basic purpose of this study was to identify the critical erosion prone grids of Harike wetland with cell size of 30 m × 30 m. Therefore, average annual soil loss was estimated on a cell basis and all the grid cells of watershed was regrouped in the following scales of priority: Slight (0-5 t ha⁻¹ yr⁻¹), Moderate (5-10 t ha⁻¹ yr⁻¹), High (10-20 t ha⁻¹ yr⁻¹), Very high (20-40 t ha⁻¹ yr⁻¹), Severe (40-80 t ha⁻¹ yr⁻¹) and very severe (>80 t ha⁻¹ yr⁻¹) erosion classes on the basis of as per the guidelines suggested by Singh *et al.* (1112) for Indian conditions.

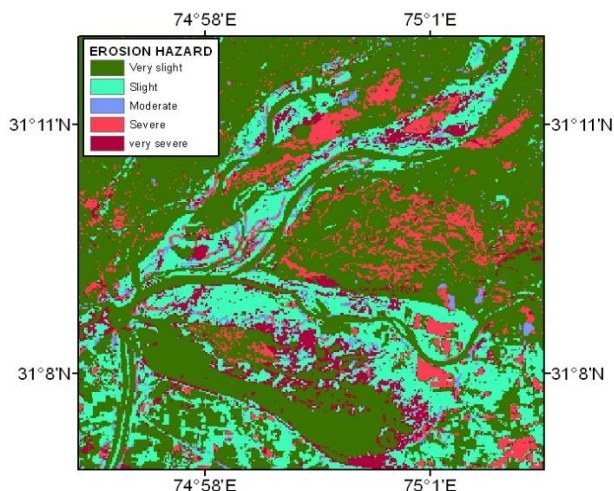


Figure 1.14: Spatial distribution of vulnerable soil loss zone of Harike wetland

The grids under very high and severe class of soil erosion consists barren land with high LS factor. Moderate and high class of soil erosion grids cover mostly the area where open and degraded forest is present and also has high LS factor which vary between 1 to 18. Slight class of soil erosion grids covers the area where forest and paddy fields are present. Soil loss may also increase due to the necessity of bringing more area under cultivation by felling of trees to meet the

demand of food for the growing population. Therefore, there is a need to take up soil conservation measures especially in the areas with severe and very severe zones.

1.11 Recommendation of Best Management Practices

Watershed approach for planning, development and management aims at harnessing all natural resources for sustainable development. Depending upon the priority levels of study-area and critical grids of soil erosion, treatment should be done with suitable vegetative and structural measures. For effective wetland planning, there must be a close coordination of vegetative and structural control measures.

Structural measures such as nala bunds and check dams and masonry drop structure can be taken up in the valley region which may help in improving the irrigation potential for the area which in turn can help to adopt double cropping system in the low land and agro-forestry areas. Nala bund structures may be constructed across nalas (streams) for checking velocity of runoff, increasing water percolation and improving soil moisture regime. The sites should be selected in relatively flatter nala reach, the slope of nala should not be more than 2 %. The nala bed should have soils with adequate permeability and fractured rocks to facilitate ground water recharge. Field leveling and grading of higher slope into bench terraces and collection of runoffs in small farm ponds (rainwater harvesting tanks) will help in recycling water for raising agri-horticulture crops.

It was observed from the average annual soil loss map (Figure 1.14) that, severe soil erosion grids have barren land and high LS factor. Therefore, to reduce length of slope farmer can adopt contour terrace technique. The main problem is barren land of these severe soil erosion grids, that can be reclaimed by using wasteland management strategies.

1.12 Wetland management strategies

Wastelands are broadly grouped into culturable and unculturable wastelands. Culturable wastelands have the potential for development of vegetative cover. However, they are not being used due to different constraints of varying degrees such as erosion, water logging, salinization etc. Most of these lands can be put to some productive use after proper treatment and reclamation measures. The lands that cannot be developed to vegetative cover are called unculturable wastelands. Barren rocky areas, snow-covered glacial areas are such type of land.

The selected area of the wasteland constituted mainly of coarse textured particles with gentle slope. It is susceptible to erosion. The soil is slightly acidic in reaction containing high level of N, P and K. The area receives an annual rainfall 700 mm. Such land has the potential to support many species of shrubs and trees besides some annual crop plants, with due soil conservation measures and agronomic management.

With the present scenario, the productivity of crops grown under above condition is stagnant. Adoption of appropriate agronomic practices with agro-ecologically suitable crops and cropping systems may be the only alternative to the

traditional rainfed agriculture for proper utilization of resources, maintaining soil fertility, improving land productivity and accruing maximum benefits. For resource poor farmers these practices are appropriate in as much as they guarantee a harvest and are borne of traditional wisdom.

1.13 Conclusion

This study demonstrated the effective use of remote sensing and GIS tools in quantifying siltation, sedimentation, and soil erosion processes within the Harike Wetland ecosystem of Punjab. The integration of satellite imagery with hydrological and field data revealed a substantial decline in both pond area and storage capacity, primarily due to continuous sediment inflow from the catchment. Through NDWI and USLE modeling, erosion-prone zones and critical sediment deposition areas were delineated, providing a scientific basis for prioritizing desiltation and conservation measures. The results show that excessive sedimentation has altered the wetland's hydrological balance, impacted biodiversity, and reduced water availability for irrigation in downstream regions.

The economic analysis supports that desiltation is both environmentally beneficial and financially viable, with a benefit–cost ratio of 1.6. Reuse of nutrient-rich sediments for agriculture can restore soil fertility, enhance microbial activity, and promote sustainable land productivity. The study underscores that integrated watershed management, combining structural and vegetative measures, is essential for long-term wetland conservation. Overall, this research highlights that maintaining Harike's ecological health is not only vital for biodiversity and habitat restoration but also for sustaining regional water resources and ensuring socio-economic resilience

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