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Assessment of Soil Erosion using USLE Model in the Kandi Area of Punjab

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ABSTRACT

The Kandi Area lying in the Punjab state is characterized by steep slopes having highly dendritic drainage pattern and is infested with rivulets having narrow ridges between drainage catchments. Erosion is generally not so severe below the hills but there are some areas along their foot where the piedmont deposits are being cut by active gully erosion. In the upper watersheds, sheet erosion from the hillsides is a well-known feature. Also widespread is the severe bank erosion that is taking place along the major tributaries. To assess the sediment deposition it is necessary to characterize the erosion process on the watersheds and to highlight the areas most affected. The present study aims to describe the implementation of the Universal Soil Loss Equation (USLE) for the mapping and quantification of the potential soil erosion in this area. The USLE model, commonly used to calculate average annual soil loss per unit land area resulting from sheet and rill erosion. In the present study an estimation of soil erosion is done for different catchment areas of Kandi region and the results are compared with the observed values of soil erosion. A positive correlation has been found between the observed and calculated values of soil erosion. Various empirical approaches recommended by various researchers were tried; however these gave results highly divergent from the actual siltation rates observed from the capacity survey studies of the reservoirs in the study area using latest techniques.

Keywords

Erosion, Universal Soil Loss Equation (USLE), Kandi Area, Watershed

INTRODUCTION

Erosion is a process of detachment and transport of soil particles by erosive agents. Soil erosion is a naturally occurring process that affects all landforms.

In agriculture, soil erosion refers to the wearing away of a field's topsoil by the natural physical forces of water and wind or through forces associated with farming activities such as tillage.

Erosion, whether it is by water, wind or tillage, involves three distinct actions – soil detachment, movement and deposition. Topsoil, which is high in organic matter, fertility and soil life, is relocated elsewhere "on-site" where it builds up over time or is carried "off-site" where it fills in drainage channels. Soil erosion reduces cropland productivity and contributes to the pollution of adjacent watercourses, wetlands and lakes.

Soil erosion can be a slow process that continues relatively unnoticed or can occur at an alarming rate, causing serious loss of topsoil. Soil compaction, low organic matter, loss of soil structure, poor internal drainage, salinization and soil acidity problems are other serious soil degradation conditions that can accelerate the soil erosion process.

STUDY AREA

The area along the Shivalik Foothills on the eastern side of Pathankot- Chandigarh road falling mainly in districts of Hoshiarpur, Mohali, Nawanshahar, Ropar, and Mohali of Punjab State is known as Kandi Area. It covers an area of 4600 km^2 which is about 9% of the state area and 6% of the state population. The location map of the kandi area is shown in fig.1

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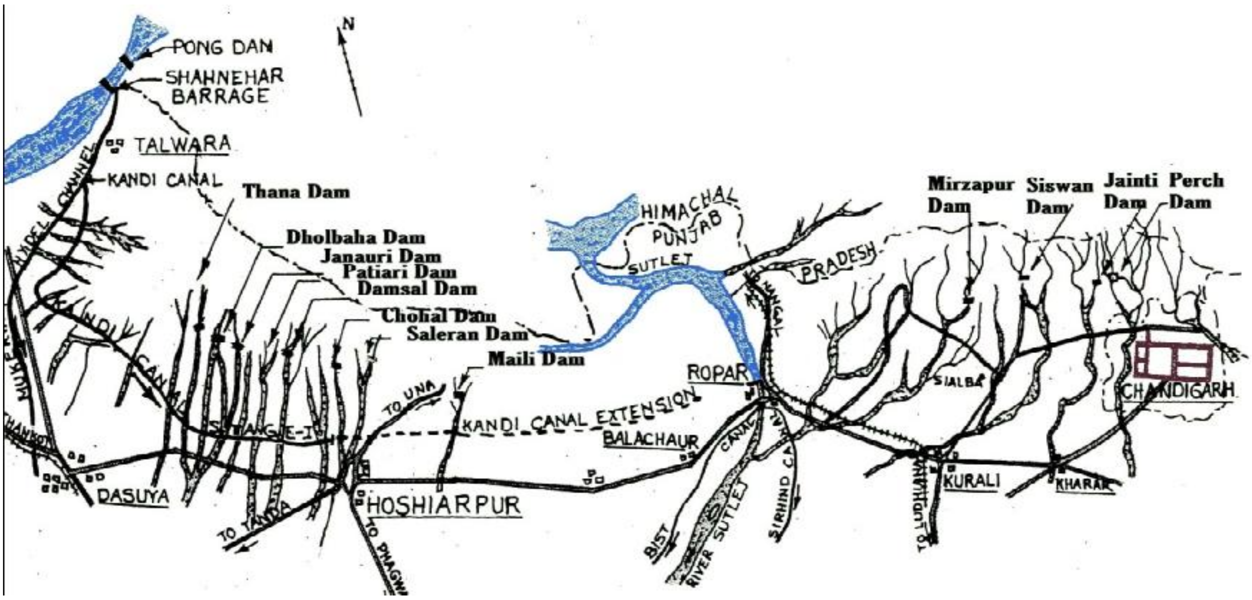

Figure 1: Location Map of the study area

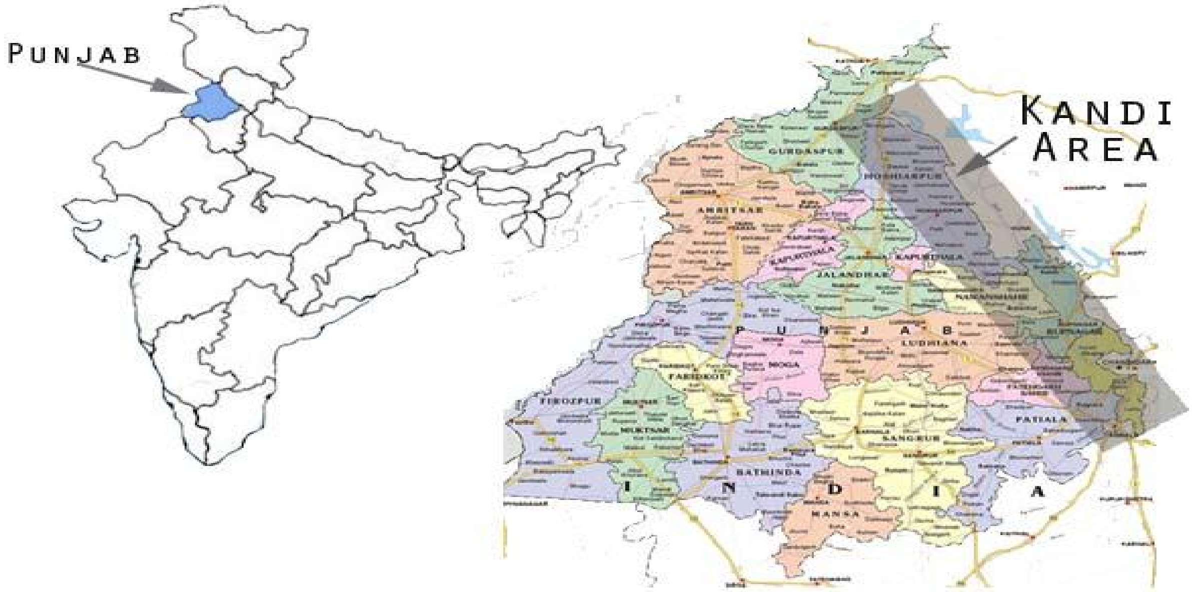

Figure 2: Map of the study area

Punjab Govt. with the help of World Bank prepared an ambitious programme to develop the Kandi Area by harnessing the choes for flood protection and to provide irrigation in the area which was mostly dependent on rains. For attenuation of floods and conservation of surface run-off, 31 prospective sites were identified for construction of earthen dams in the upper reaches; 12 of these have already been built, namely: Maili, Dholbaha, Janauri, Damsal, Perch, Chohal, Saleran, Mirzapur, Siswan, Jainti, Patiari and Thana dams as shown in Figure 2. Beyond their command, the Kandi Canal is being constructed for irrigation development of the hilly terrain having higher elevations in southwest.

Integrated development scheme of Low Dams and Kandi Canal will considerably increase crop production, prosperity and overall economy of the area. Development effects of the ongoing schemes are already reflected through increase of orchards, agricultural output and socio-economic prosperity of the people in the area. Apart from the main benefits of irrigation, flood prevention and silt control, the numerous other benefits of the project include development of fisheries, recharge of ground water, tourism, and recreation.

MATERIALS AND METHODS

Universal Soil Loss Equation (USLE)

The Universal Soil Loss Equation, later revised as the RUSLE Renard *et al* (1997), was developed by Wischmeier and Smith (1978). It's a mathematical and an empirical model used to describe soil erosion processes and based on many factors such as soil, topography, climate, land cover and human activities. The USLE predicts potential erosion and is widely used in the world. Potential erosion, representing by soil losses, has units of weight per unit area per year (ton/ha/yr). This equation is the product of six factors:

A = R x K x LX S x C x P

Where A is the average soil loss due to water erosion (ton/ha/yr), R the rainfall-runoff erosivity factor; K the soil erodibility factor, L, the slope length, S the slope steepness, C the land cover management factor and P the soil conservation practice factor. This model is derived from more than 10,000 plot-years of data collected on natural runoff plots and an estimated equivalent of 2,000 plot-years of data from rainfall simulators. Numerical values for each of the six factors of the equation were derived from analyses of the assembled research data and from National Weather Service precipitation records in USA. USLE only predicts the amount of soil loss that results from sheet or rill erosion on a single slope and does not account for additional soil losses that might occur from gully, wind or tillage erosion. Although originally developed for agricultural purpose, its use has been extended to watershed with other land uses.

Rainfall Erositivity Factor:-

The rainfall factor (R) in the Universal soil loss equation (USLE) is the number of rainfall erosion index units (EI_{30}) for a particular location. It is defined (Wischmeier, 1959) as one hundredth of the product of the kinetic energy of the storm (KE) and the 30 minute intensity (I_{30}) as the most reliable single estimate of rainfall erosion potential and termed as EI_{30}. Annual total of storm EI_{30} value is referred to as the rainfall erosion index. The location value of this index is the rainfall factor, R in the USLE. EI_{30} is expressed as

$$E_{3} = \frac{K * I_{3}}{1}$$

where,

EI_{30} = Erosion index

KE = Kinetic energy of storm

I_{30} = Maximum 30 minute rainfall intensity of the storm

The KE is expressed as (Wischmeier and Mannering, 1960)

$$KE = 210.3 + 89 \log I$$

Where

KE = Kinetic energy in metric tons per ha-cm

I = Rainfall Intensity (cm/hr)

Individual rainfall events equal to and more than 0.5 cm were taken into consideration for computing R. Events separated by more than 6 hours can be considered as separate storm.

The rainfall data for the entire kandi area has been acquired from Punjab Irrigation Department, Chandigarh for a period of 1983-1990 and this rainfall data is used to calculate the value of R for different catchment areas. The mean value of R factor is determined in Table 1.

The study area experiences extreme climatic conditions characterized by two distinct rainfall seasons, namely the months of June to September which brings intense storms accounting for 80% of the annual rainfall, which is of the order of 900-1000 mm, and the relatively dry non- monsoon period generating rainfall predominantly during the months of January to March.

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Soil erodibility factor:-

The soil erodibility factor (K) represents the susceptibility of a soil type to erosion. The *K* factor reflects the ease with which the soil is detached by splash during rainfall and/or by surface flow, and therefore shows the change in the soil per unit of applied external force of energy. This factor is related to the integrated effect of rainfall, runoff, and infiltration and accounts for the influence of soil properties on soil loss during storm events on sloping areas. This factor is determined using inherent soil properties. A simpler method to predict K was presented by Wischmeier *et al.* (1971) which includes the particle size of the soil, organic matter content, soil structure and profile permeability. The soil erodibility factor K can be approximated from a monograph if this information is known. The USLE monograph estimates erodibility as:

The soil erodibility factor K is the average soil loss, in tons per acre per unit of the rainfall factor R. It can be computed by the formula

$$K = \frac{2.1(10^{-4})(12 - \%O\quad)M^{1.4} + 3.25(S\quad - 2) + 2.5(P\quad - 3)}{100}$$

M = (%MS + % VFS) (100 - %CL)

Where, M = function of primary particle size fractions

%MS = percentage silt (0.002-0.05 mm)

VFS = percentage of very fine sand (0.05-0.1 mm)

%CL = percentage clay (<0.002 mm)

%OM = percentage organic matter

SI = soil structure index

PI = permeability index

The soil structure index SI is assigned a value 1,2,3, or 4 indicating (1) very fine granular; (2) fine granular; (3) medium or coarse granular; (4) blocky, platy or massive.

PI is assigned a value of 1-6 as follows: (1) rapid, (2) moderate to rapid, (3) moderate, (4) slow to moderate, (5) slow, or (6) very slow.

The soil of the study area on the cultivated terraces ranges in appearance from a good dark brown coloured sandy loam to rather poorer fine loamy silty sand. The cultivated soils below the hills range from a dark brown deep sandy loam, moderately well drained through well drained deep yellowish brown sandy loam to excessively well drained deep yellowish brown loamy sand. Soil surveys reveal clayshale and sandstone formations at the surface with isolated bands of compact sandrock. The majority of the uncultivated land contiguous to the choe has very deep sandy soils which have low fertility. The value of the soil erodibility factor is taken from Kandi Watershed Design Directorate, Chandigarh.

Topographic Factors (LS)

In the USLE model, the effect of topography on erosion is accounted for by the slope length (L) and the slope steepness (S). The L factor is defined as the distance from the source of

runoff to the point where either deposition begins or runoff enters a well defined channel that may be part of a drainage network. S factor reflects the influence of slope steepness on

erosion (Wischmeier and Smith, 1978). The longer the slope length the greater the amount of cumulative runoff. Also the steeper the slope of the land the higher the velocities of the

runoff which contribute to erosion. But soil loss increases more rapidly with slope steepness than it does with slope length. The common equation used for Calculating LS factor provide by the USDA *Agricultural Handbook*[8]

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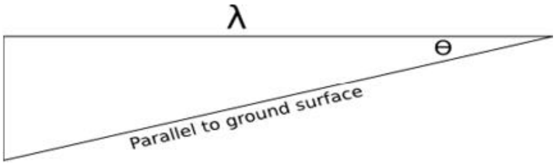

Figure 1: Illustration of the values used in the calculations of LS

$$L = \left(\frac{\lambda}{22.1}\right)^{m} (65.41 \sin^2\theta + 4.56 \sin\theta + 0.065)$$

Where λ is the horizontally measured plot length,

θ is the slope angle, and m is a variable plot exponent adjustable to match terrain and soil variants. $m$varies between 0.5 (slopes of 5% or more) and 0.2 (slopes of$< 1\%$). The value of LS factor is determined in Table-2.

Cover Management Factor

The C-factor measures the effects of all interrelated cover and management variables. C factor is measured as the ratio of soil loss from land cropped under specific conditions to the corresponding loss from tilled land under continuous fallow conditions. By definition, C equals 1 under standard fallow conditions. Cover Management factor C is a dimensionless ratio of soil loss from a certain combination of vegetative cover and management practice to the soil loss resulting from tilled, continuous fallow, which is assigned a C of 1.0. The value of C factor is determined in Table 3.

Support Cultivation Factor (P)

P is the support practice factor. It reflects the effects of practices that will reduce the amount and rate of the water runoff and thus reduce the amount of erosion. The P-factor is the ratio of soil loss with specific support practice to the corresponding loss with up and downslope tillage. These practices proportionally affect erosion by modifying the flow pattern, gradient, or direction of surface runoff and by reducing the amount and rate of runoff. The P values are between 0 and 1. This factor is assumed to be 1 because of a lack of information on practices conservation tillage.

Empirical Equations

Many empirical equations and procedures have been developed for estimating sediment yield at the outlet of a watershed. A few of these in common use in India or developed by use of Indian data are given below. Sediment delivery ratio (SDR) is defined as the sediment yield from an area divided by the gross erosion of that same area. SDR is expressed as a percent and represents the efficiency of the watershed in moving soil particles from areas of erosion to the point where sediment yield is measured.

Khosla's Equation (1953)

The annual sediment yield on volume basis is related to catchment area as annual sediment yield rate (on volume basis)

$$q_s = \frac{0.0}{A^{0.2}} \text{ Mm}^3/\text{km}^2/\text{year}$$

Or Volume of sediment yield per year from the catchment is

$$Q_s = 0.00323\, A^{0.7} \text{ Mm}^3/\text{year}$$

Where A = area of catchment in km^2.

This equation is in common use in many parts of the country to estimate the annual sediment inflow into the reservoir. The observed data of Khosla had an upper average limit of 3.6ha.m/100km^2 and the absolute

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maximum limit of observed data was 4.3ha.m/100km^2. While this equation has been used in many of the reservoirs in the country up to about 1970, the observed data of actual sedimentation of many reservoirs indicate that the equation underestimates the sedimentation rate[6].

Joglekar's Equation (1960)

Based on data from reservoirs from India and abroad, Joglekar expressed the annual sediment yield rate as

$$q_s = \frac{0.0}{A^{0.2}} \quad Mm^3/km^2/year$$

Or volume of sediment yield per year from a catchment area is

$$Q_s = 0.00597A^{0.7} \quad Mm^3/year$$

In these equations A = area of catchment in km^2 [6].

Table 1 Mean Value of R factor

1983	1984	1985	1986	1987	1988	1989	1990	**Average**
330.79	314.60	331.36	327.69	331.76	386.62	346.18	325.87	**336.8**

Table 2 LS factor value for different catchment areas

Reservoir	Mean slope	L of main khad (km)	LS
Maili	1.31	7.9	5.27
Dholbaha	0.89	17.7	11.80
Janauri	0.95	2.5	1.67
Damsal	1.99	11.8	7.87
Perch	2.75	7.8	5.20
Chohal	1.14	14.9	9.93
Saleran	2.88	7.7	5.13
Mirzapur	2.02	8	5.33
Siswan	3.16	5.7	3.80
Jainti	0.94	7.5	5.00
Thana	1.36	12.77	8.51
Patiari	2.57	8.77	5.85

Table 3 C factor value for different catchment areas

Reservoir	CA sq. km.	Canopy Cover	C	Reservoir	CA sq. km.	Canopy Cover	C
Maili	17.5	0.65	0.36	**Mirzapur**	13.9	0.63	0.35
Dholbaha	56.14	0.72	0.40	**Siswan**	15.6	0.81	0.45
Janauri	6.1	0.64	0.35	**Jainti**	7.1	0.67	0.37
Damsal	21.6	0.7	0.39	**Thana**	12.64	0.56	0.31
Perch	5.6	0.42	0.23	**Patiari**	11.7	0.6	0.33
Chohal	16.1	0.66	0.36	**Saleran**	7.2	0.8	0.44

Table 4: Soil erosion calculations for different catchment areas

Reservoir	Mean slope	R	K	LS	C	P	Annual Soil Loss tons/acre	Delivery Ratio	Sediment Yield ton/acre/yr
Maili	1.31	336.8	0.35	5.27	0.36	1	221.95	0.17	38.56
Dholbaha	0.89	336.8	0.28	11.80	0.40	1	440.66	0.12	53.96
Janauri	0.95	336.8	0.31	1.67	0.35	1	61.25	0.24	14.60
Damsal	1.99	336.8	0.33	7.87	0.39	1	336.62	0.16	54.90
Perch	2.75	336.8	0.34	5.20	0.23	1	137.55	0.24	33.64
Chohal	1.14	336.8	0.3	9.93	0.36	1	364.33	0.18	64.90
Saleran	2.88	336.8	0.35	5.13	0.44	1	266.25	0.23	60.38
Mirzapur	2.02	336.8	0.32	5.33	0.35	1	199.17	0.19	37.08
Siswan	3.16	336.8	0.33	3.80	0.45	1	188.16	0.18	33.83
Jainti	0.94	336.8	0.35	5.00	0.37	1	217.19	0.23	49.46
Thana	1.36	336.8	0.2	8.51	0.31	1	176.63	0.19	33.83
Patiari	2.57	336.8	0.28	5.85	0.33	1	181.95	0.20	35.67

Table 5: Values of Soil erosion by different empirical equations

Watershed	CA km^2	Mean slope	L of main khad (km)	Observed Silting Rate	Joglekar	Khosla
Maili	17.5	1.31	7.9	0.51	0.297	0.145
Dholbaha	56.14	0.89	17.7	0.63	0.224	0.105
Janauri	6.1	0.95	2.5	0.3	0.382	0.195
Damsal	21.6	1.99	11.8	0.77	0.282	0.137
Perch	5.6	2.75	7.8	0.52	0.390	0.199
Chohal	16.1	1.14	14.9	0.81	0.303	0.148
Saleran	7.2	2.88	7.7	0.8	0.367	0.186
Mirzapur	13.9	2.02	8	0.52	0.314	0.155
Siswan	15.6	3.16	5.7	0.48	0.305	0.150
Jainti	7.1	0.94	7.5	0.55	0.369	0.187
Thana	12.64	2.2	12.8	0.44	0.321	0.159
Patiari	11.71	2.5	10	0.72	0.327	0.162

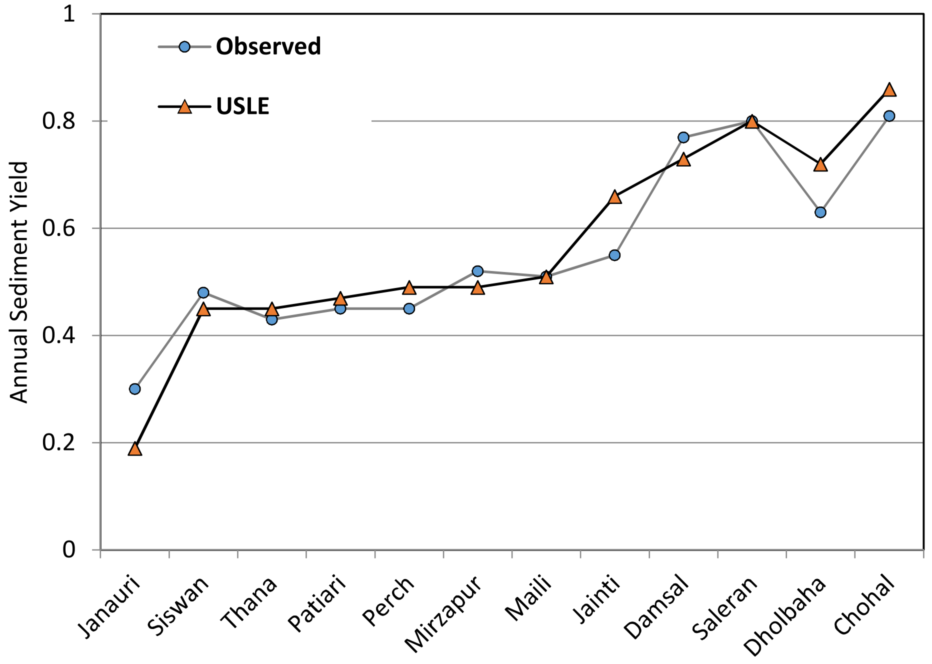

Figure 4: Observed and predicted values of soil erosion

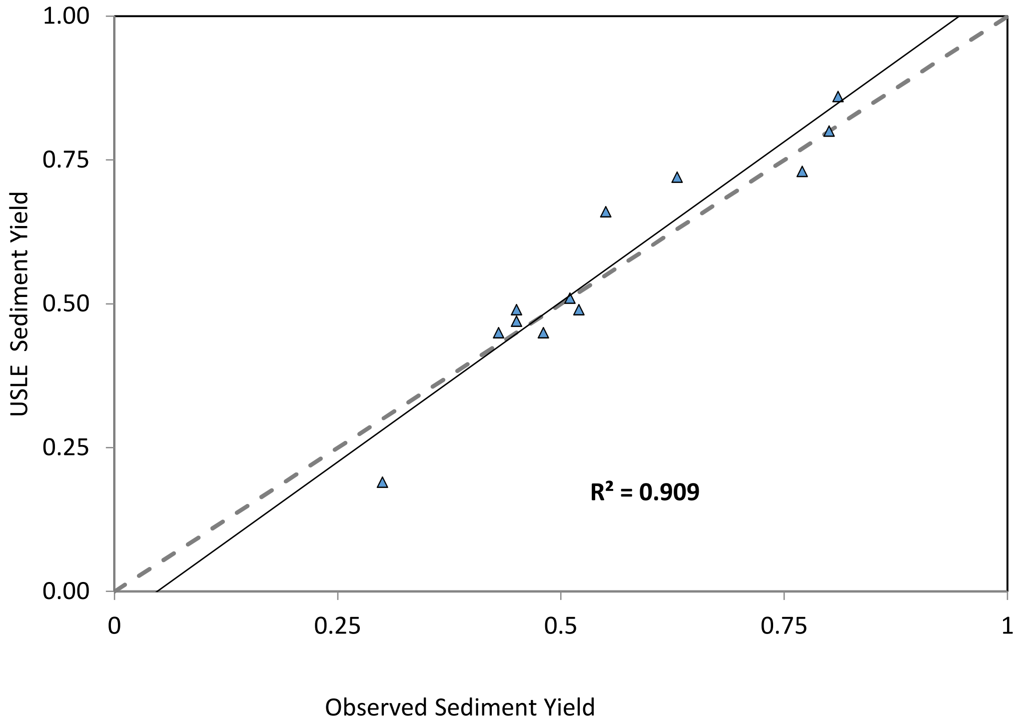

Figure 5: Linear model fitting between USLE and observed sediment yield

RESULTS AND DISCUSSION

Soil erosion for different dam sites in Kandi Area is obtained by Universal soil Loss Equation. The different parameters involved in USLE are estimated for different dam sites. The value of soil erosion calculated by USLE is compared with the observed values found at different dam sites. It shows that the values obtained from USLE are very close to the observed value. Hence this method can be used to determine soil erosion for a catchment area applicable to the kandi Area of Punjab.

It has been found that the both the values of soil erosion of Maili catchment area are very close to each other. This is due to the fact that the topography of the area and the soil characteristics are uniform throughout the catchment area.

The values of soil erosion for Jainti catchment area are having a larger variation. This is due to the irregularities of the topographic area and the variation of soil characteristics in the region.

Various empirical approaches recommended by various researchers were tried; however these gave results highly divergent from the actual siltation rates observed from the capacity survey studies of the reservoirs in the study area as mentioned in Table 4 & 5. This study did not yield any useful parameters that could be correlated with sediment output of a basin.

CONCLUSION

A linear relationship is established between the soil erosion calculated from USLE and the observed soil erosion which gives value of R^2=0.909. This indicates that there is a positive correlation between the calculated and observed value. Hence this methodology can be adopted for estimating the soil loss for kandi area project.

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