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Soil Erodibility Mapping Using GIS– A Case Study of Dang District in Gujarat

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Abstract

Dang district is severely affected by soil erosion due to heavy rainfall and higher slope, which in turn causes land degradation. Soil erodibility is one of the important factors for land degradation. Keeping this in mind, there is a need to determine the soil characteristics required for estimating the erodibility factor of representative soils of the Dang district. The soil erodibility of the Dang district ranged from 0.18 to 0.44 being, high for the soils with high silt content. The highest value of soil erodibility factor was found in the soils of Satbabla village which had 52.4% sand, 30.2% silt and 17.4% clay, while the lowest soil erodibility factor was found in the soils of Borkhet village having 48.1% sand, 14.3% silt and 37.6% clay. The 44.5% area with higher erodibility values (>0.34) showed higher susceptibility of soils to erosion, while 24.3% area with lower erodibility values (<0.29) showed comparatively lower susceptibility of soils to erosion. Field measurements of soil erodibility are difficult, costly, and often impractical for many hydrologic analyses. This multidisciplinary approach is useful in decision-making and can save time when planners are required to assess the land use management policy with respect to soil erosion.

Keywords: *Soil erosion, USLE, erodibility, texture*

Introduction

Soil erosion is one of the major global environmental risks that are significantly causing severe land degradation. Additionally, it destabilizes the world's population by reducing agricultural output due to the loss of nutrients and other additives from topsoil (Jebur *et al*. 2014). Natural processes such as topographical settings, changes in land use and land cover, rainfall intensity, soil qualities, and wind characteristics all contribute to soil erosion, and can be increased further by human activities such as intensive farming, deforestation, and tillage on steep slopes (Yan *et al*. 2018). The estimated mean rates of soil erosion across the world range from 12 to 15 t $ha^{-1}yr^{-1}$ (Ashiagbor *et al*. 2013; Sitayelo *et al*. 2022). An estimated 4.87 billion tonnes of soil are lost each year in India due to erosion, which affects around 53% of the country's total geographical area (Mandal *et al*. 2020). Globally, soil erosion rates are 10–40 times higher than soil formation rates, threatening food security and environmental quality (Spalevic *et al*. 2013). Therefore, measuring soil erosion is an important indicator of ecological soil change and global environmental changes.

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There are various empirical, conceptual and physical based models namely Universal Soil Loss Equation (USLE) and its derivatives as Revised Universal Soil Loss Equation (RUSLE), and Soil and Water Assessment Tool (SWAT) or the Water Erosion Prediction Project (WEPP) have been developed to estimate soil loss. These models differ in complexity, data needs, methods and calibration. In general, model selection depends on data availability, characteristics of a working place and intended use. In USLE or RUSLE, the component factors relating to (R), topography (LS), soil erodibility (K), crop cover and management (C) and conservation practice (P) are multiplied to calculate the long-term average annual soil loss per unit area.

The soil erodibility or K-factor is an essential parameter in erosion prediction and conservation planning. Soil erodibility is the susceptibility or vulnerability of soil to erode, the transportability of sediment. It is an important parameter of soil which helps researchers and planners in the study of soil erosion characteristics. The erodibility is mainly influenced by four major soil characteristics: soil texture, structure, permeability and organic matter content (USDA 2013). However, in India, at most the locations, values of all these parameters are not recorded/accessible, or if recorded, the available database may be poor in terms of quantity and the number of parameters recorded. In such situations, estimating the various soil parameters from locally available limited information is challenging. So, the efforts of researchers are focused on extracting maximum knowledge from the available database by correlating various parameters of soil on a sound scientific footing with the help of soft computing tools like a statistic, data forming *etc*. Many factors are responsible for the soil erosion problem in Dang district, so it becomes essential to study the soil characteristics of various soil types responsible for this hydrologic phenomenon. However, in this context, Thelkar *et al.* (2019). attempted to asses the soil erosion in basaltic landscape of central India using integrates approach of RUSLE, remote sensing and GIS. In many soil testing laboratories, textural classes and organic carbon of soils of all villages are recorded, but other parameters like conductivity, permeability and erodibility are not available. These parameters are very important from the point of view of soil mechanics and hydrology of the region. Therefore, if these unavailable parameters of major representative soils are estimated from the knowledge of available parameters and their relationships, it will be a great help to researchers, academicians and planners.

Materials and Methods

Study area

The Dang district (20.39° to 21.05° N; 73.29° to 73.51°E) is located in the southern part of Gujarat and situated between near Saputara hills (Fig. 1). It is divided into three Talukas: Ahwa, Waghai and Subir. The district has high hills in the eastern and southern parts, and the rest of the district has flat-topped low-lying hills. The total geographical area of Dang district is 1,764 sq. km. with an average annual rainfall of 3,048mm.

The major rivers of the district are Purna, Ambika, Khapri and Gira. These rivers form valleys with major slopes towards the western side and are covered by dense vegetation. A number of small streams meet these rivers on their way towards the Arabian Sea. The entire district experiences a dry climate in winter from November to March, after which the humidity starts to increase, and the monsoon sets in June and lasts till October.

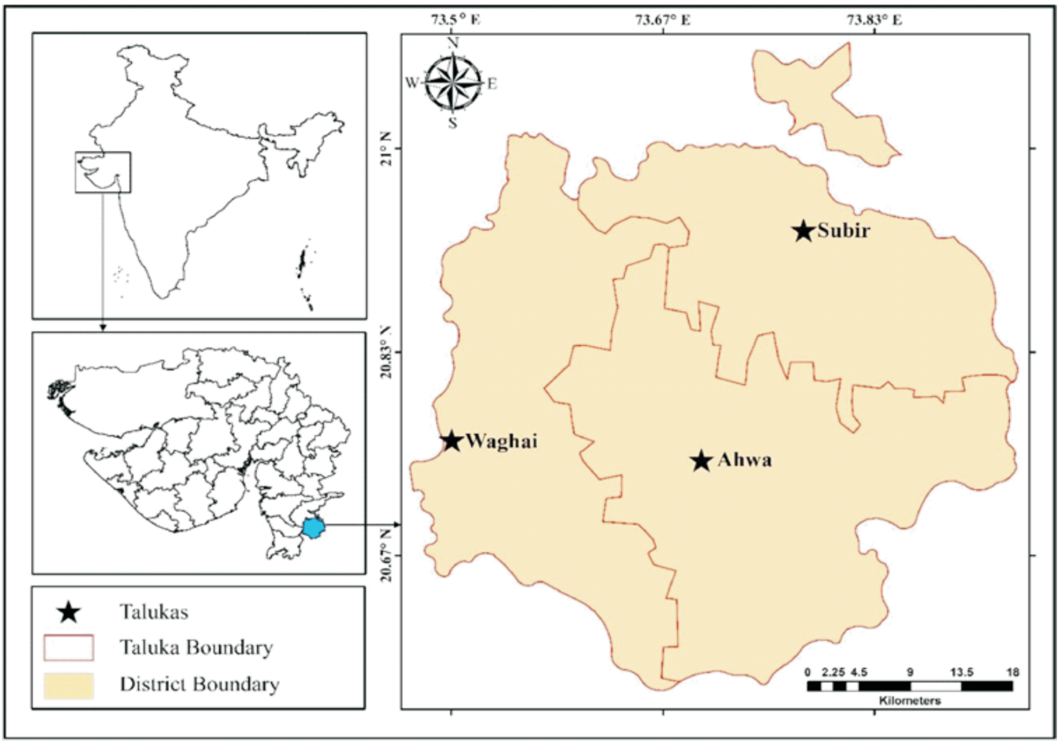

Fig. 1. Location Map of Dang district

Collection of soil samples

Survey of India toposheet and Google Earth image were used to prepare a sampling plan to ensure that samples could be taken systematically and distributed well. Soil samples were collected from seventeen villages representing the whole Dang district for estimating the soil erodibility (Fig. 2). Soil samples were collected and analyzed for soil texture (sand, silt, clay) and organic carbon in the laboratory of Krishi Vigyan Kendra (KVK), Waghai. The soil texture was analysed by the International Pipette method.

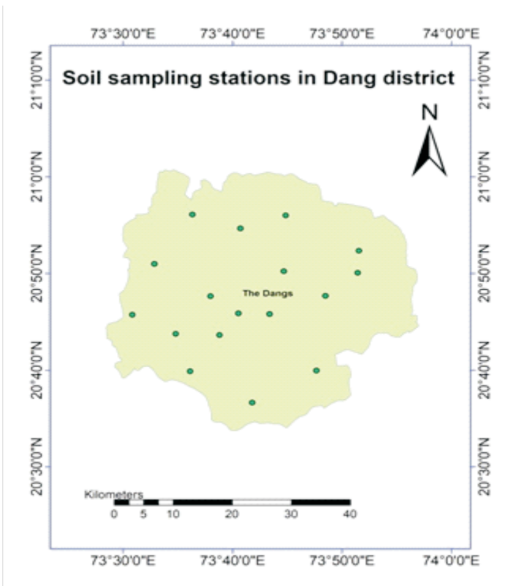

Fig. 2. Map of soil sampling stations in Dang district

Computation of soil erodibility

Soil erodibility measures the total effect of a particular combination of soil properties on soil loss. Wischmeier and Mannering (1971) developed a multiple regression equation based on variables such as the proportion of sand, silt and clay ratio, organic matter content, antecedent soil moisture, bulk density, amount of slope, pH of surface and subsoil, structure, the thickness of soil layer, land use/land cover *etc*. The equation is statistically accurate and technically valid but has proven too complex as an operational tool for a technician. Wischmeier *et al*. (1971) further simplified the procedure for the determination of soil erodibility factor by developing an equation based on five soil parameters, which is used in the present study. Among these parameters, sand, silt and clay percentage and organic matter content have been calculated from soil analysis data. Permeability code and soil structure code were determined using table 1 and table 2, respectively.

$$100\,K = 2.1\,M^{1.14}\,(10^{-4})\,(12 - a) + 3.25\,(b - 2) + 2.5\,(c - 3) \quad \text{..............} \quad (1)$$

Where,

K = soil erodibility factor
M = (% silt + 0.7 * % sand) * (100 - % clay)
a = organic matter content, %
b = structure of the soil
c = permeability of the soil
% O.M. was estimated as (1.724 * % organic carbon).

Soil permeability code

The rate of water entry into the soil is called its infiltration rate, which is initially high for all soils if they are dry. But once they are wet, this rate depends on the distribution, continuity and stability of the open spaces, voids, joints and other secondary openings in earth materials, which are the receptacles that store and transmit water. The size, type, shape and arrangement of voids are the major factors controlling the storage capacity and transmissibility of the water. Water intake is at a maximum when soil is fairly dry, for after water is added, the pore space becomes full. Wischmeier *et al*. (1971) presented the integrated effect of the various factors influencing infiltration rate, by a single permeability factor to determine the erodibility of soils. Permeability code was derived based on the hydraulic conductivity of soil (Smith and Browning 1946), as shown in table 1.

Table 1. Soil permeability code and permeability classes based on hydraulic conductivity

Code	Permeability	Rate mm hr^{-1}	Permeability classes	Hydraulic conductivity (cm hr^{-1})
1	Rapid	>130	Extremely slow	< 0.0025
2	Moderate to rapid	60-130	Very slow	0.0025-0.025
3	Moderate	20-60	Slow	0.025-0.25
4	Slow to moderate	5-20	Moderate	0.25-2.5
5	Slow	1-5	Rapid	2.5-25.00
6	Very slow	<1	Very rapid	>25.00

Soil structure code

The soil structure is defined as how 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 organise and retain them in specific structural units, or peds of definable shape and size. The structure may be designated as blocky, prismatic, platy, granular and structureless. A very fine granular structure is stable, does not break down under cultivation, and has a high infiltration capacity. Blocky and platy structures are more erodible. Structural code was obtained from different particle sizes proposed by NBSS and LUP (1988), as shown in table 2. Particle-size distribution of sand, silt, clay was taken into account for deciding texture class.

Table 2. Soil structure code and textural class proposed by NBSS&LUP (1988)

Code	Structure	Size, mm	Textural Class	Thickness (mm)
1	Very fine granular	<1	Very fine	<1
2	Fine granular	1-2	Fine	missing
3	Coarse granular	2-10	Medium	2 – 5
4	Blocky, platy or massive	>10	Coarse	5 – 10
			Very course	>10

Organic matter

Organic matter (OM) has a variable influence on the soil, affecting its chemical and physical properties. The effect of organic matter on physical properties relates largely to its availability in binding soil particles together. The organic constituents of the soil are important because of their influence on aggregate stability. By virtue of its binding action, OM helps stabilise loose soils against erosion. Some soils with very high OM, particularly peats, are highly erodible by water and wind, whereas others with very low OM can become very hard and, therefore, stronger under dry conditions. The effect of organic matter on physical properties relates largely to its ability to bind soil particles together. The organic matter of soil was determined by following the equation (Hesse 1971) for all villages.

$$\text{Organic matter} = \text{organic carbon} \times 1.724 \quad \text{.................... (2)}$$

Results and Discussion

Analysis of soil samples

The majority of soils in Dang district were of sandy clay loam texture followed by sandy loam (Table 3). The value of organic matter was found to be in the range of 0.71 to 3.71 per cent, with (mean 1.70 per cent). Based on hydraulic conductivity and a textural class of the soils, the structure type of soils was found to be fine granular to coarse granular for all the soils. Therefore structural codes 2 and 3 were assigned for all soils of 17 villages in the Dang district. The permeability of soil was obtained from hydraulic conductivity. The hydraulic conductivity of soils varies from 0.25 to 25 cm hr^{-1}. So, all soil samples come under the permeability class of moderate to rapid and moderate; and permeability codes 2 and 3 were assigned to these samples.

Table 3. Textural properties of soil samples

Site/No.	Village	Sand (%)	Silt (%)	Clay (%)	Textural Class
1	Waghmal	53.3	30.0	16.72	Sandy loam
2	Khapri	52.2	26.4	21.4	Sandy clay loam
3	Chikatiya	46.8	23.8	29.4	Sandy clay loam
4	Dodipada	49.8	27.5	22.7	Sandy clay loam
5	Kalibel	44.9	35.6	19.5	Loam
6	Ghoghli	41.9	35.6	22.5	Loam
7	Kadmal	52.4	24.1	23.5	Sandy clay loam
8	Dhodhalpada	49.4	22.8	27.8	Sandy clay loam
9	Mahal	42.5	38.9	18.6	Loam
10	Wakarya	52.8	24.5	22.7	Sandy clay loam
11	Borkhet	48.1	14.3	37.6	Sandy clay
12	Chinchvihir	61.0	23.6	15.4	Sandy loam
13	Pipalpada	53.7	31.0	15.3	Sandy loam
14	Kotba	59.0	20.1	20.9	Sandy clay loam
15	Ranpada	51.3	31.2	17.5	Loam
16	Satbabla	52.4	30.2	17.4	Sandy loam
17	Nanapada	42.2	27.1	30.7	Clay loam

Estimation of soil erodibility and creation of soil erodibility map

. The soil erodibility values ranged from 0.18 to 0.44, with a mean value of 0.33 (Table 4). The average percentage of sand, silt and clay in the soils of Dang district were found to be 50, 28 and 22 per cent , respectively.

The highest value of soil erodibility factor was found in the soils of Satbabla village which contains 52.4% sand, 30.2% silt and 17.4% clay, while the soil erodibility factor was lowest for soil sample of Borkhet village having 48.1% sand, 14.3% silt and 37.6% clay. The higher soil erodibility was observed in the soils with high silt content, while the low erodibility was due to low silt content.

Table 4. Soil erodibility value of different soil samples

Site/ No.	Village	M	a	b	c	K
1	Waghmal	5604.41	1.17	2	2	0.40
2	Khapri	4952.75	1.24	3	2	0.38
3	Chikatiya	3988.90	1.64	3	2	0.28
4	Dodipada	4816.71	1.74	2	2	0.32
5	Kalibel	5395.92	1.57	3	2	0.40
6	Ghoghli	5029.69	0.71	2	2	0.37
7	Kadmal	4650.59	1.86	2	2	0.30
8	Dhodhalpada	4138.52	3.71	2	2	0.21
9	Mahal	5588.11	2.93	2	2	0.33
10	Wakarya	4747.16	1.02	2	2	0.33
11	Borkhet	2992.22	1.5	2	2	0.18
12	Chinchvihir	5602.95	1.64	2	2	0.38
13	Pipalpada	5814.69	2.83	2	2	0.35
14	Kotba	4862.36	2.17	2	2	0.30
15	Ranpada	5539.07	1.03	2	2	0.40
16	Satbabla	5528.27	0.98	3	2	0.44
17	Nanapada	3927.67	1.14	2	3	0.26

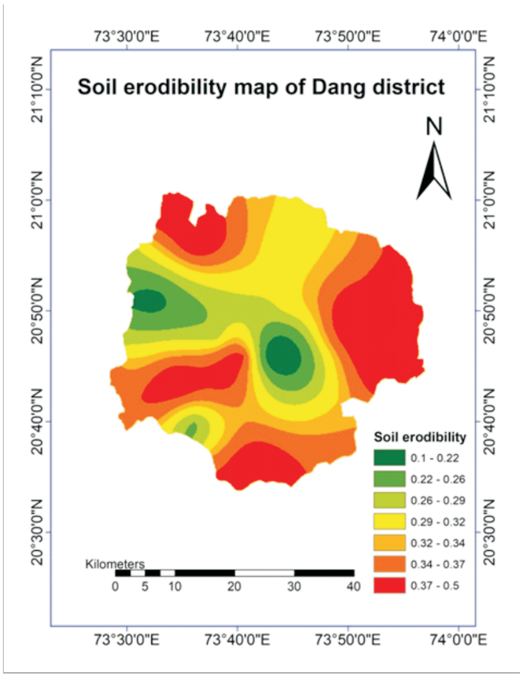

Fig. 3. Soil erodibility map of Dang district

The 44.5% area with higher K values (>0.34) showed higher susceptibility of soils to erosion (Table 5), while 24.3% area with lower K values (<0.29) showed comparatively lower susceptibility of soils to erosion. Further, these estimated values of soil erodibility were used to prepare a soil erodibility map of the Dang district using ArcGIS software (Fig. 3). Thematic mapping is useful to find out the intermediate values of villages to formulate proper land use management practices in future. The area which shows the higher erodibility values may cause more soil erosion as compared to other parts of the Dang district.

Table 5. Soil erodibility value of different soil samples

Erodibility class	Soil erodibility	Area (%)
Low	0.18 - 0.29	24.3
Medium	0.29-0.34	31.2
High	0.34-0.44	44.5

Conclusion

The soil erodibility of the Dang district ranged from 0.18 to 0.44, being high for the high silt content. The 44.5% area with higher erodibility values (>0.34) showed higher susceptibility of soils to erosion, while 24.3% area with lower erodibility values (<0.29) showed comparatively lower susceptibility of soils to erosion. Observations showed that when organic matter was high, the soil will be less susceptible to erosion. So by increasing the organic matter content of the soil, erodibility can be reduced. The estimates of soil erodibility will be helpful for the policy makers to identify potential erosion areas, to formulate the land use management policy with respect to soil erosion and to carry out conservation measures.

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