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Investigating soil erodibility in Nandurbar district, Maharashtra: Estimating the 'K' factor

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ABSTRACT

The Nandurbar district faces significant challenges due to soil erosion, resulting in soil degradation and reduced land productivity and sustainability.The primary objective of this study is to assess and estimate the soil erodibility factor 'K' for the soils and to develop soil erodibility maps of Nandurbar district. This study employs a comprehensive methodology that integrates field-based soil sampling, laboratory analyses, and empirical modeling techniques. Various key soil properties, including soil texture, soil organic matter content and permeability of soils, were analyzed to understand their impact on soil erodibility. Soil erodibility factor 'K' was estimated by using equation of Wischmeier and Smith .The average percentages of sand, silt and clay in the soils of Nandurbar district are 26.55%, 23.66% and 49.01%, respectively. These soil types span a range of textural classes including clay, loam, silty clay loam and sandy clay loam. Mostly the textural class observed in the agriculture soils of the district are clay soils. Soil structure codes found in the Nandurbar district are 2 and 4, having structure type fine granular and massive blocky. Soil structure mostly found in the district is massive blocky. Massive blocky soils are more erodible than granular soils. Permeability codes in the district mostly are 2, 3, 4 and 6. Soils mostly are slow and very slow permeable. Soil erodibility was found more in very slow permeable soil. The mean soil organic matter percentage in Nandurbar district ranges from 0.39% to 1.67% with an average value of 1.34%. Additionally, the soil erodibility factor across the district varies from 0.22 to 0.46 t ha h ha^{-1} MJ mm, with mean value of 0.27 t ha h ha^{-1} MJ mm. This mean soil erodibility value of 0.27 places Nandurbar district within the 0.20 to 0.30 range, indicating that the soil in the district is moderately erodible. The analysis of soil erodibility of Nandurbar district will help to predict soil erosion and for decision making related to land management especially for soil and water conservation practices to arrest soil erosion.

1. INTRODUCTION

Maharashtra has high hills and significant rainfall, which contributes to the state's high rates of land degradation (Challa *et al*., 2000). The most serious issue with land degradation is soil erosion, which has a significant impact on the quality and productivity of the land in many ways. The strain of an expanding population coupled with excessive and incorrect land use practices has led to the degradation of a significant portion of arable land. Soil erosion,as highlighted by Challa *et al*. (2000) contributes to the decrease in regional productivity. This issue is not confined to a particular region but is a global concern. Annually, vast quantities of top soil are lost from agricultural fields due to erosion, exacerbating the problem.

According to Singh and Khera (2008), soil erosion is a function of both the soil's erodibility and the rainfall's erosivity. It is a complex process influenced by various factors, including climate, topography, land use practices, and soil properties. Lal (2003) underscored the significance of organic matter in mitigating erosion and its crucial role in the global carbon budget. Cerda *et al*. (2009) conducted a study examining the influence of rock fragment cover on soil properties and splash erosion under different rainfall intensities, emphasizing the importance of structural stability.

Soil erodibility stands out as a pivotal factor determining the soil vulnerability to erosion amidst these considerations.

Understanding and quantifying the soil erodibility factor, 'K' , is crucial for effective soil erosion management and conservation practices. By assessing the erodibility of different soil types, land managers and policymakers can make informed decisions regarding land use planning, erosion control measures, and sustainable land management strategies.

Despite its significance, the estimation of the soil erodibility factor, 'K', remains challenging due to the complex nature of soil erosion processes and the inherent variability of soil properties across landscapes. Furthermore, the existing methods for measuring soil erodibility often require labor-intensive field experiments or rely on empirical relationships derived from limited datasets, which may limit their accuracy and applicability. However, Wischmeier and Smith (1978) have found it to be related with surface soil texture, structure, organic matter content and profile permeability and can be determined from these properties either through regression equation or monograph produced by them (Yadav *et al.,* 2005).The importance of the soil's organic and chemical components can be attributed to their impact on aggregate stability.

This study aims to investigate and analyze the soil erodibility factor 'K', with a focus on developing improved methodologies for its estimation. This study aims to enhance our understanding of soil erodibility factors through field observations, lab tests, and advanced modeling techniques, providing valuable insights for erosion control and land management strategies. Its objectives are to establish of the soil erodibility factor 'K' and create soil erodibility maps for the soils of Nandurbar district while examining variations.

2. MATERIALS AND METHODS

The purpose of this study was to determine the soil erodibility factor 'K' for soils of Nandurbar district. The study was undertaken for the soils of Nandurbar district and district is shown in Fig.1. The soils studied were selected on the basis of their agricultural importance and their wide range of characteristics representative of soils within the Nandurbar district. The district comprises 6 tehsils namely, Nandurbar, Nawapur, Shahada, Taloda, Akkalkuva and Akrani. The study area lies between latitudes 21°00'00"N to 22°00'30"N and longitudes 73°31'00"E to 74°45'30"E. Agriculture serves as the primary occupation for the inhabitants of the district, which lies within Tapi and Narmada basins. Covering an area of 5034 sq km, it constitutes approximately 1.9% of the total land area of the state. District falls receives 801 mm of average annual rainfall mostly through south west monsoon. The region experiences erratic rainfall patterns with uneven distribution, leading to increased uncertainties in agricultural activities.

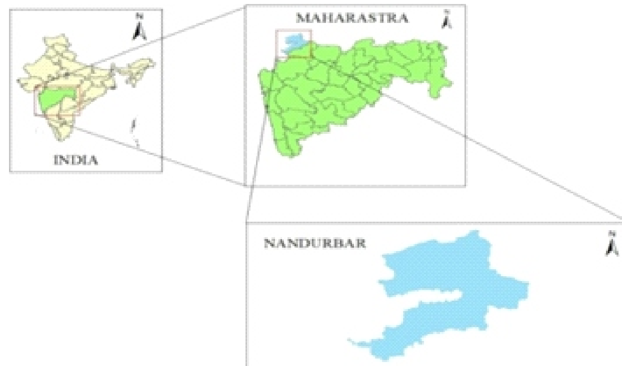

Fig. 1. Location map of study area

Main crops cultivated include jowar (*Sorghum bicolor*), bajara (*Pennisetum glaucum*), maize (*Zea mays*), wheat (*Triticum aestivum*), groundnut (*Arachis hypogaea*), cotton (*Gossypium* spp.) and sugarcane (*Saccharum officinarum*).

Soils in study area are mainly black. Five soil parameters are predicted the erodibility factor according to Wischmeier and Smith *et al.* (1978).

The data require for computation of soil erodibility factor 'K' is percent sand, percent silt, percent clay, percent organic carbon, soil structure and soil permeability. A total of 162 composite soil samples from the study area were taken by plotting the 5 × 5 km grid. The collected Soil samples were mostly from the agricultural land. Soil structure and soil permeability was determined by using soil texture.

Soil Analysis

The collected soil samples were analyzed for determination of soil texture, textural class, soil permeability codes and soil structure codes.

Soil Texture

Soil texture was assessed based on the proportion of sand, silt and clay particles present in the soil samples, a critical determinant of soil erodibility. Soils containing significant amounts of silt, very fine sand or expanding clay minerals typically exhibit higher erodibility, while those rich in clay tend to have lower erodibility (Ogeen *et al.,* 2007). The international pipette method was employed to analyze the particle size distribution of the soil samples.

Determination of Soil Textural Class

Soil texture was required for determination of structure codes and permeability codes. The USDA triangular textural classification chart was used to determine the textural class.

Determination of Organic Carbon

In practical analysis, methods primarily measure soil organic carbon levels Murphy (2014). The titration method was employed to quantify organic carbon in collected soil samples, following Nelson and Sommers' formula (1996), which utilizes a conversion factor of 1.724 to determine soil organic matter from organic carbon content is following Nelson and Sommers formula 1. Ratings of soils on the basis of organic carbon Zende and Danger (1978) are shown in Table 1.

$$\textit{Organic matter} = \textit{Organic carbon} \times 1.724$$

Soil structure

The soil textural pyramid produce by United State Geology and Soils (USGS) was used in determination of the soil structure codes for soils of Nandurbar district. Structure code for different types of soil proposed by NBSS&LUP (1988) are shown in following Table 2.

Determination of Soil Permeability

To analyse the permeability code 10 soil samples of the study area was tested by using constant head permeability test. From analyzed soil samples it is cleared that the permeability code of the soils would be determined from the soil texture pyramid (Yusof *et al.,* 2011).

Table: 1
Rating of soils on the basis of organic carbon Zende and Dangar (1978)

Ratings	Organic carbon (%)
Very low	< 0.2
Low	0.21 to 0.40
Medium	0.41 to 0.60
Moderate high	0.61 to 0.80
High	0.81 to 1.00
Very high	>1.00

Table: 2
Structure code for different types of soil proposed by NBSS& LUP (1988)

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

Table: 3
Permeability code from soil texture class (National soil handbook, USDA, 1983)

Soil texture	Permeability code
Heavy clay, clay	6
Silty clay loam, sandy clay	5
Sandy clay loam, clay loam	4
Loam, silt loam	3
Loamy sand, sandy loam	2
Sand	1

The soil texture class was used to determine the permeability code of the soil. Soil permeability codes determined from soil texture are shown in below Table 3.

Computation of Soil Erodibility Factor 'K'

The erodibility of soil is an expression of its inherent resistance to particle detachment and transport by rainfall.

Soil erodibility factor (K) values for the soil samples were computed using the formula developed by of Wischmeier and Smith (1978), represented as:

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

Where, K = Soil erodibility factor, t ha h ha^{-1} MJ mm; M = (percent silt + percent very fine sand) × (100% clay); a = Percent organic matter content; b = Structure code used in soil classification; c = Soil permeability code.

Classification of Soil Erodibility

The K values were classified into 6 classes keeping an interval of 0.10 given by Manriquein,1988 are shown in Table 4.

3. RESULTS AND DISCUSSION

The results remarks the highlight of the estimation of soil erodibility factor K. Study includes 6 tehsils of Nandurbar district namely Nandurbar, Nawapur, Shahada, Taloda, Akkalkuva and Akrani. The parameters including percent very fine sand, percent silt, percent clay, organic matter content, permeability codes and structure codes of soil were determined for six tehsils.

In this, work were done to study the physico-chemical properties (sand, silt, clay and organic carbon), permeability of soil and soil erodibility of surface samples of soils. Maps of Soil erodibility factor 'K' was prepared using IDW interpolation technique in Arc-GIS 10.1 software. The obtained results during investigation are listed under following titles:

i. Physico-chemical properties of soil.
ii. Permeability codes and structure codes of soil.
iii. Soil erodibility factor.

Table: 4
Classification of soil erodibility (Manrique, 1988)

Class	Soil erodibility	K values (t ha h ha^{-1}MJ mm)
1.	Very low	0.00-0.10
2.	Low	0.10-0.20
3.	Moderate	0.20-0.30
4.	Moderate high	0.30-0.40
5.	High	0.40-0.50
6.	Very high	>0.50

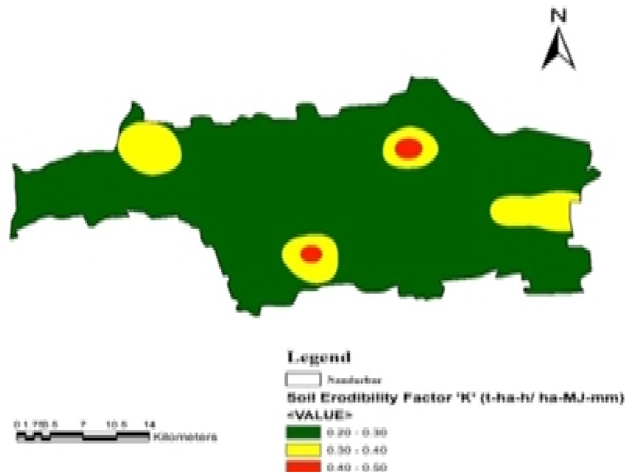

Fig. 2. Soil erodibility factor (K) map for soils of Nandurbar tehsil

Table: 5
Permeability code of collected soil samples

Sample No.	Soil texture	Permeability (mm h^{-1})	Permeability code
1.	Clay	0.83	6
2.	Clay	0.96	6
3.	Sandy clay loam	1.01	4
4.	Clay	0.88	6
5.	Sandy clay loam	1.08	4
6.	Clay	0.94	6
7.	Sandy clay loam	1.14	4
8.	Clay	0.76	6
9.	Clay	0.71	6
10.	Clay	0.91	6

Physico-chemical Properties of Soils of Nandurbar tehsil

In this study, the soil erodibility of Nandurbar tehsil was assessed by analyzing soil samples from 36 villages. The percent sand, silt and clay content of soil in Nandurbar tehsil were determined using international pipette method. Results revealed varying percentages of sand (9.95 to 69%), Silt (9.9 to 51.3%) and clay (18.09 to 60.1%) with average values of 24.07, 24.78 and 50.37%, respectively. The predominant soil types identified in the tehsil include clay, silty clay loam, sandy loam and sandy clay loam, with clay soils being predominant. Organic carbon content ranged from 0.23 to 0.97%, indicating a moderate to high level, with a mean value of 0.77%. Calculated organic matter values ranged from 0.39 to 1.67% , averaging 1.3408%.

Permeability of Collected Soil Samples

The constant head permeability test was used to analyse 10 soil samples of the study area for determining the coefficient of permeability and therefore the permeability code. According the permeability code is shown in Table 5.

Permeability codes and structure codes of soils of Nandurbar tehsil

The permeability code depending on soil texture for all the villages in Nandurbar tehsil are depicted in the above table that soils of Nandurbar tehsil are moderate to rapid, moderate, slow to moderate, slow and very slow permeable with permeability codes 3, 4, 5 and 6, respectively. Structure code observed in the soils are 2, 3 and 4 having structure type fine granular, moderate or coarse granular and massive blocky, respectively.

Soil erodibility factor K for soils of Nandurbar tehsil

The value of soil erodibility factor of Nandurbar tehsil varies between 0.2235 to 0.4670 t ha h ha^{-1}MJ mm with mean value 0.2728 t ha h ha^{-1}MJ mm. Soil erodibility factor (K) map for soils of Nandurbar tehsil are shown in Fig. 2. Soil has been termed as moderate high erodible soil.

Physico-chemical properties of soils of Shahade tehsil

In this study, the soil erodibility of Shahade tehsil was assessed by analyzing soil samples from 33 villages. The percent sand, silt and clay content of soil in Shahade tehsil were determined using international pipette method. Results revealed varying percentages of sand (10.05 to 56%), silt (10.8 to 32.82%) and clay (21.22 to 59.33%) with average values of 27.04, 22.81 and 49.36%, respectively. The predominant soil types identified in the tehsil include clay, silty clay loam, and sandy clay loam, with clay soils being predominant. Organic carbon content ranged from 0.63 to 0.88%, indicating a moderate to high level, with a mean value of 0.77%. Calculated organic matter values ranged from 1.0861 to 1.5171% , averaging 1.3310%.

Permeability codes and structure codes of soils of Shahade tehsil

It is observed from soils of Shahade tehsil are slow to moderate, slow and very slow permeable with permeability codes 4, 5 and 6, respectively. Structure code observed in the soils was 4 having structure type massive blocky.

Soil erodibility factor K for soils of Shahade tehsil

The value of soil erodibility factor of Shahade tehsil varies between 0.2230 to 0.4384 t ha h ha^{-1} MJ mm with mean value 0.2738 t ha h ha^{-1} MJ mm. Soil has been termed as moderate high erodible soil. Soil erodibility factor(K) map for Shahade tehsil are shown in Fig. 3.

Physico-chemical properties of soils of Talode tehsil

In this study, the soil erodibility of Talode tehsil was assessed by analyzing soil samples from 23 villages. The percent sand, silt and clay content of soil in Talode tehsil were determined using international pipette method. Results

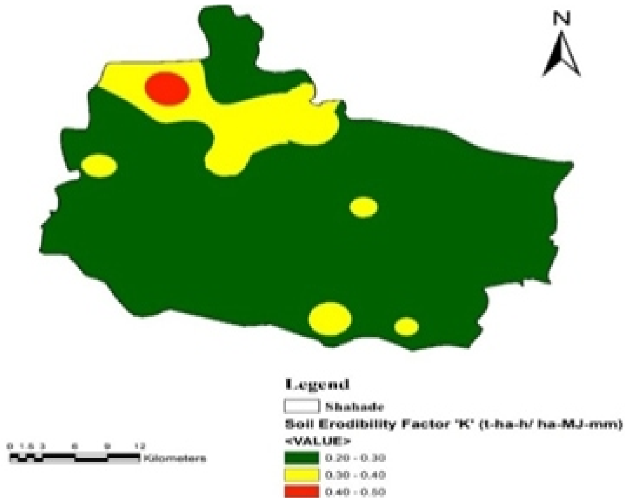

Fig. 3. Soil erodibility factor (K) map for soils of Shahade tehsil

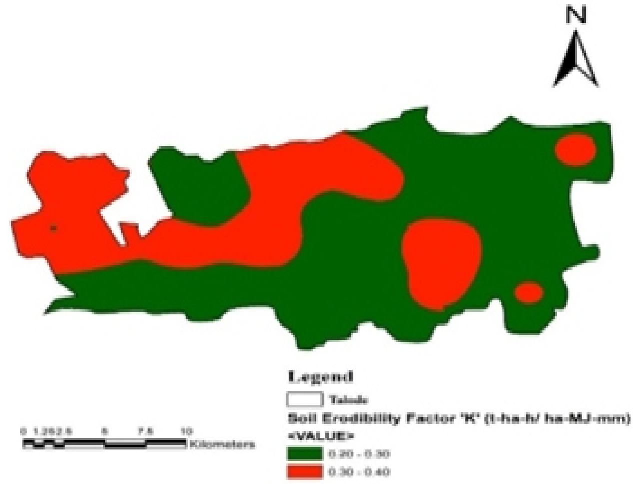

Fig. 4. Soil erodibility factor (K) map for soils of Talode tehsil

revealed varying percentages of sand (11.91 to 46.06%), silt (16.05 to 29.89%) and clay (37.01 to 59.31%) with average values of 25.18, 23.36 and 50.67%, respectively. The predominant soil types identified in the tehsil include clay, clay loam, and sandy clay, with clay soils being predominant. Organic carbon content ranged from 0.68 to 0.89%, indicating a moderate to high level, with a mean value of 0.78%. Calculated organic matter values ranged from 1.1723 to 1.5343% , averaging 1.3499%.

Permeability codes and structure codes of soils of Talode tehsil

It is observed that the soils of Talode tehsil are slow to moderate, slow and very slow permeable with permeability codes 4, 5 and 6, respectively. Structure code observed in the soils was 4 having structure typemassive blocky.

Soil erodibility factor K for soils of Talode tehsil

The value of soil erodibility factor of Talode tehsil varies between 0.2294 to 0.3208 t ha h ha^{-1} MJ mm with mean value 0.2698 t ha h ha^{-1} MJ mm. Soil has been termed as moderate erodible soil. Soil erodibility factor (K) map for soils of Talode tehsil are shown in Fig.4.

Physico-chemical properties of soils of Nawapur tehsil

In this study, the soil erodibility of Nawapur tehsil was assessed by analyzing soil samples from 39 villages. The percent sand, silt and clay content of soil in Nawapur tehsil were determined using international pipette method. Results revealed varying percentages of sand (11.91 to 46.06%), silt (13.93 to 29.89%) and clay (37.06 to 59.32%) with average values of 22.98, 23.64 and 52.58%, respectively. The predominant soil types identified in the tehsil include clay, and clay loam with clay soils being predominant. Organic carbon content ranged from 0.65 to 0.89%, indicating a

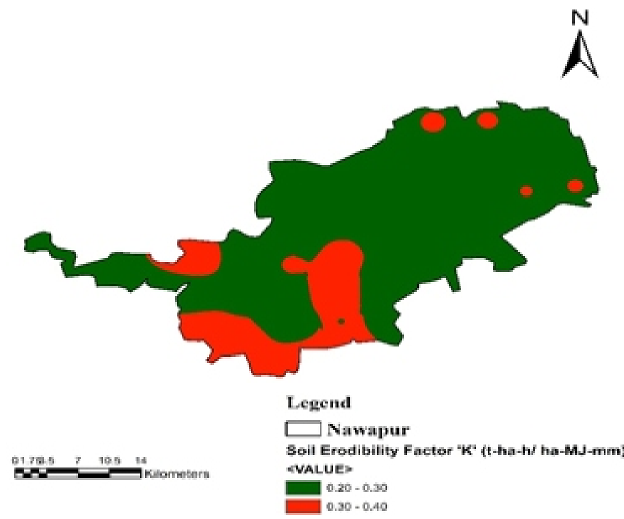

Fig. 5. Soil erodibility factor (K) map for soils of Nawapur tehsil

moderate to high level, with a mean value of 0.78%. Calculated organic matter values ranged from 1.1206 to 1.5343% , averaging 1.3402%.

Permeability codes and structure codes of soils of Nawapur tehsil

The soils of Nawapur tehsil are slow to moderate, slow and very slow permeable with permeability codes 4, 5 and 6, respectively. Structure code observed was 4 having structure typemassive blocky.

Soil erodibility factor K for soils of Nawapur tehsil

The value of soil erodibility factor of Nawapur tehsil varies between 0.2249 to 0.3223 t ha h ha^{-1} MJ mm with mean value 0.2608 t ha h ha^{-1} MJ mm. Soil has been termed as moderate erodible soil. Soil erodibility factor(K) map for soils of Nawapur tehsil are shown in Fig. 5.

Physico-chemical properties of soils of Akkalkuwa tehsil

In this study, the soil erodibility of Akkalkuwa tehsil was assessed by analyzing soil samples from 17 villages. The percent sand, silt and clay content of soil in Nawapur tehsil were determined using international pipette method. Results revealed varying percentages of sand (13.95 to 61.51%), silt (12.49 to 29.95%) and clay (16.16 to 60.48%) with average values of 32.75, 22.85 and 43.63%, respectively. The predominant soil types identified in the tehsil include clay, sandy clay loam, sandy loam and clay loam, with clay soils being predominant. Organic carbon content ranged from 0.66 to 0.88%, indicating a moderate to high level, with a mean value of 0.77%. Calculated organic matter values ranged from 0.1378 to 1.5171%, averaging 1.3315%.

Permeability codes and structure codes of soils of Akkalkuwa tehsil

The soils of Akkalkuwa tehsil are moderate to rapid, slow to moderate, slow and very slow permeable with permeability codes 2, 4, 5 and 6, respectively. Structure code observed in the soils are 2 and 4 having structure type fine granular and massive blocky, respectively.

Soil erodibility factor K for soils of Akkalkuwa tehsil

The value of soil erodibility factor of Akkalkuwa tehsil varies between 0.2245 to 0.4378 t ha h ha^{-1} MJ mm with mean value 0.2955 t ha h ha^{-1} MJ mm. Soil erodibility factor(K) map for soils of Akkalkuwa tehsil are shown in Fig. 6. Soil has been termed as moderate high erodible soil.

Physico-chemical properties of soils of Akrani tehsil

In this study, the soil erodibility of Akrani tehsil was assessed by analyzing soil samples from 13 villages. The percent sand, silt and clay content of soil in Akrani tehsil were determined using international pipette method. Results revealed varying percentages of sand (15.95 to 55.28%), silt (16.85 to 37.28%) and clay (18.08 to 59.26%) with average values of 37.20, 24.32 and 37.67%, respectively. The predominant soil types identified in the tehsil include clay, sandy loam, loam and clay loam ,with clay soils being predominant. Organic carbon content ranged from 0.73 to 0.89 %, indicating a moderate to high level, with a mean value of 0.80%. Calculated organic matter values ranged from 1.2585 to 1.5343%, averaging 1.3858%.

Permeability codes and structure codes of soils of Akrani tehsil

The soils of Akrani tehsil are moderate to rapid, moderate, slow to moderate and very slow permeable with permeability codes 2,3, 4, and 6, respectively. Structure code observed in the soils are 2 and 4 having structure type fine granular and massive blocky, respectively.

Soil erodibility factor K for soils of Akrani tehsil

The value of soil erodibility factor of Akrani tehsil varies between 0.2286 to 0.3949 t ha h ha^{-1} MJ mm with mean value 0.3123 t ha h ha^{-1} MJ mm. Soil erodibility factor(K) map for soils of Akrani tehsil are shown in Fig.7. Soil has been termed as moderate high erodible soil.

Variation in soil erodibility of soils of Nandurbar district

Soil sample collected mostly from agricultural land. The clay content is high in all sample. Percent sand (9.95 to 69%), percent silt (9.9 to 51.3%) and percent clay (16.16 to 60.48%) with average sand (26.55%), silt (23.66%) and sand (49.01%), respectively. Organic matter percent varies between 0.3965 to 1.6722% with mean value 1.3426%. Soils of district are very slow permeable with permeability

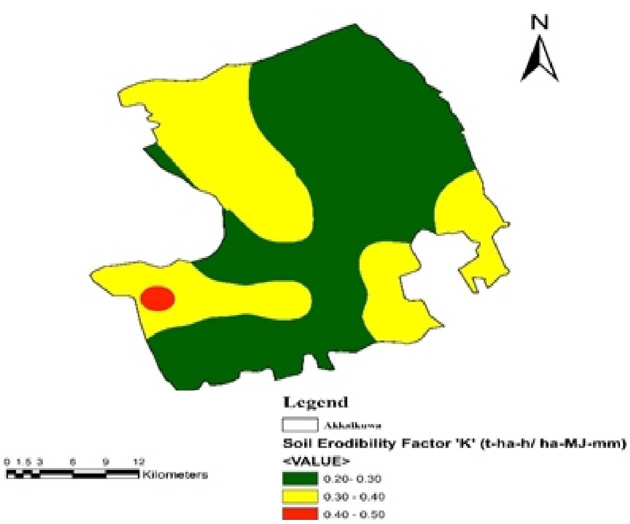

Fig. 6. Soil erodibility factor (K) map for soils of Akkalkuwa tehsil

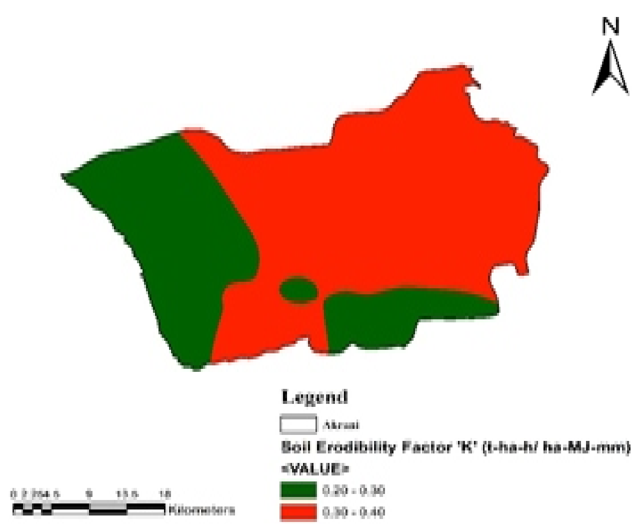

Fig. 7. Soil erodibility factor (K) map for soils of Akrani tehsil

code 6. Soil structure mostly found in the district is 4, having structure type massive blocky. Tehsil wise soil erodibility factor(K) values and map for soils of Nandurbar district are shown in Table 6 and Fig.8, respectively.

Soil erodibility factor of Nandurbar district varies between 0.223 to 0.467 t ha h ha^{-1}MJ^{-1}. mm^{-1}mm with mean value 0.2753 t ha h ha^{-1} MJ^{-1} mm^{-1}. K factor value of Talode and Nawapur tehsil belongs to class 0.20 to 0.30. Soils in the tehsils are moderate erodible. K factor value of Nandurbar, Shahade, Akkalkuwa and Akrani tehsil belongs to class 0.30 to 0.40 having type moderately high erodible. From mean value 0.2753 t ha h ha^{-1} MJ mm it can be said that soils in the district are moderately erodible. Generally Akkalkuwa and Akrani tehsil shows higher soil erodibility value with respect to other, this is due to different soil texture classes and variation in percent organic matter observed in these tehsils. Agricultural soils of tehsils except Akkalkuwa and Akrani shows same pattern in soil texture, soil permeability and soil structure.

4. CONCLUSIONS

The estimation of the soil erodibility factor (K) typically involves field measurements and laboratory experiments, where soil samples are collected and analyzed for various properties influencing erosion potential. These properties are then combined through empirical methods to derive the K factor specific to a soil type. A study was conducted to determine the soil erodibility factor K for soils in Nandurbar district. Soil samples were collected across all tehsils to analyze both physical (soil texture, soil structure and soil permeability) and chemical properties (soil organic matter).

i. The average percentages of sand, silt, and clay in Nandurbar district soils were 26.55, 23.66, and 49.01%, respectively, with varying textural classifications including clay, loam, silty clay loam, and sandy clay loam. Clay soils predominately in the area.
ii. Soil structure codes of 2 and 4 were observed in Nandurbar district soils, with the structure types being fine granular and large blocky. The prevalence of large blocky structures renders soils more vulnerable to erosion compared to granular structures.
iii. Permeability codes of 4, 5, and 6 were predominant in the district, indicating soils ranging from slowly to very slowly permeable, thus increasing their susceptibility to erosion.
iv. Organic matter content in the district ranged from 0.39 to 1.67%, with mean value of 1.34%.
v. Soil erodibility factor values ranged from 0.22 to 0.46 t ha h^{-1} ha^{-1} MJ^{-1} mm^{-1}, with a mean value of 0.27 t ha h^{-1} ha^{-1} MJ^{-1}mm^{-1}. According to Manrique (1988), soils in Nandurbar district can be classified as moderate, moderate high and high erodible soils based on these values.

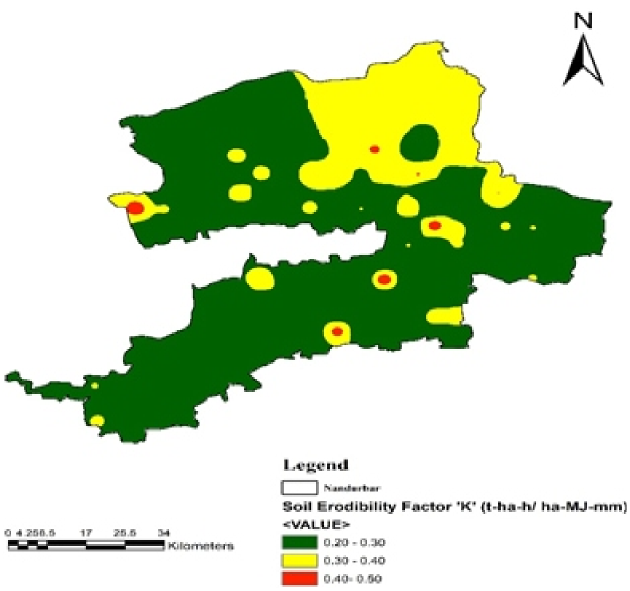

Fig. 8. Soil erodibility factor (K) map for soils of Nandurbar district

Based on the comprehensive study conducted on soil erodibility factor (K) estimation in Nandurbar district, the author has arrived at the following conclusions:

i. Soil Erodibility Variability: The research demonstrated that the soil erodibility factor (K) exhibits significant spatial variability across the Nandurbar district with mean value 0.27 t ha h^{-1} ha^{-1} MJ^{-1} mm^{-1}.
ii. Soil Erodibility Mapping:North-Eastern part of District (Akrani) has Moderate high soil erodibility, so this part needs attention for reduction of erosion on priority.
iii. Soil Conservation Recommendations: Based on the study's results, specific soil conservation strategies

Table: 6
Tehsil wise soil erodibility factor values of Nandurbar district

Tehsil	Sand (%)	Silt (%)	Clay (%)	OM	c	b	K (t ha h ha^{-1}MJ mm)
Nandurbar	24.07	24.78	50.37	1.3408	6	4	0.2728
Shahade	27.04	22.81	49.36	1.3310	6	4	0.2738
Talode	25.18	23.36	50.67	1.3499	6	4	0.2698
Nawapur	22.98	23.64	52.58	1.3402	6	4	0.2608
Akkalkuwa	32.75	22.85	43.63	1.3315	5	4	0.2955
Akrani	37.20	24.32	37.67	1.3858	5	3	0.3123

were proposed to mitigate erosion in vulnerable areas. Implementation of practices such as contour farming, terracing, cover cropping, and reduced tillage can effectively reduce soil erosion and maintain soil health.

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