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ORIGINAL ARTICLE

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Recent advances in assessment of soil erodibility: A comprehensive review

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ABSTRACT

Concept of soil erodibility originated from efforts to identify specific soil characteristics that influence variations in soil resistance to erosion. Soil erodibility refers to the susceptibility of soil to erosion. Various methods can be used to assess soil erodibility, including measuring physiochemical characteristics, scouring experiments, simulated rainfall experiments, plot studies, and wind tunnel tests. To determine soil erodibility, researchers have utilized nomograms and soil erosion models. These studies are characterized by their applications, objectives, importance, methods of use, and research locations. Additionally, an analysis summarizing the "what," "why," "where," and "how" of soil erodibility has been conducted. Soil erodibility remains a key factor in environmental management and conservation practices. This review aims to enhance understanding of the impacts of soil erosion through studies on soil erodibility. It also emphasizes the scope and significance of investigating soil erodibility, broadening our comprehension of the mechanisms involved and developing improved methods for measuring and calculating soil erodibility. This review suggests that the USLE NOMO model is the most widely accepted and utilized method and provides reliable results for assessing soil erodibility.

1 | INTRODUCTION

The process of detachment, transportation and deposition of soil from their original position to other sites by the action of water, wind, etc., is called soil erosion. In this process, the topsoil (most fertile portion of the land) rich in organic matter, plant nutrients and soil micro-organisms is physically removed from its place, decreasing the soil's fertility and productivity. Due to anthropogenic activities and climate change, soil erosion has been accelerating, posing a danger to sustainability and agricultural productivity (Deng *et al*., 2017). This has resulted in the significant deterioration of land and ecosystem services. Numerous biological processes, including surface runoff and erosion, are impacted by changes in land use (LU), which also alters the soil's ability to withstand environmental pressures. Through modifications to the physical and chemical qualities of the soil, the intensifying LU may result in erosion and soil compaction (Misir *et al*., 2007).

More than 50% of the world's pasture land and about 80% of agricultural land suffer from significant erosion, as per global estimates. Seventy-five billion tons of soil is estimated to be lost annually from fertile lands around the world (Borelli *et al.,* 2017). A high rate of soil erosion with an average of 40 t $ha^{-1}yr^{-1}$ was estimated in Asia, Africa and South America in India, out of the total geographical area (TGA) of 328.7 M ha, about 146 M ha (44.42%) of land is estimated under soil degradation, including 94 M ha (28.57%) from water erosion, 16 M ha (4.86%) from acidification, 14 M ha (4.26%) from flooding, 9 M ha (2.74%) from wind erosion, 6 M ha (1.82%) from salinity and 7 M ha (2.13%) from a combination of erosion factors (Bhattacharyya *et al*., 2015).

Soil erodibility is defined as the soil's inherent susceptibility to erosion by rainwater and runoff. It is heavily influenced by various other soil properties for instance the soils with faster infiltration rates, higher levels of organic matter and improved structure have a greater resistance to erosion. Soil erodibility varies with soil textures, aggregate stability, shear strength, soil structure, infiltration capacity, soil depth, bulk density, soil organic matter (SOM), transmission properties and chemical constituents. Soils below the plough layer are often compact and less erodible. Organic carbon (OC) content is important for determining soil erodibility, which can be severely affected by land cover (LC). However, it is a complex concept affected by many factors, including soil properties, terrain, climate, vegetation and LU (Tang *et al*., 2016). Slope gradient, another aspect of topography, significantly impacts the intensity of soil erosion (Smith and Wischmeier, 1958). Understanding the connection between slope gradient and soil erosion is essential for effective LU planning in a watershed, especially in mountainous locations. Using field runoff plots or simulated trials, numerous researchers have recently explored the relationship between slope gradient and soil erosion, and some expressions have been established (Zhao *et al*., 2014). Soil erodibility is estimated by various methods/models such as NOMO, M-NOMO, EPIC, Shirazi etc.

1.1 | Concept of Soil Erodibility

In the process of water and wind erosion, the significance of soil's innate resistance to erosive power, or soil erodibility, is commonly acknowledged. Middleton (1930) formalized the "erodibility" idea from water erosion research and proposed two indices of soil erodibility that combined runoff- and particle-detachability-related features that were connected to the behavior of soils in the field in Carolina. Then, the idea of erodibility was added to the study of wind erosion to reflect the vulnerability of soil to wind erosion. China initiated research on soil erodibility as early as 1950s, and has been always using the concept "erosion resistance of soil". The "erosion resistance of soil" is classified into two types *i.e.* soil anti-erosion and soil anti-scour. The term "soil anti-erosion" refers to a soil's ability to resist being mechanically destroyed by erosive forces like water and wind. The term "soil anti-scour" refers primarily to the soil's resistance to the dispersing and suspending effects of flowing water. In general, there is no clear differentiation between soil erodibility and erosion resistance. The former highlights soil susceptibility to erosion, while the latter stresses soil resistance to erosion. Both of them essentially reflect a common concept of how soil qualities relate to erosion.

It is necessary to have knowledge of the extent and intensity of the erosion process to plan any erosion control measures. The calculation of erosion data is necessary to assess the intensity of the soil erosion process. The assessment of erosion hazard can be quantified by soil erodibility factor (SEF) 'K' of USLE from the runoff plot by using a simple nomograph or by different erosion indices of soil such as erosion ratio, dispersion ratio (DR) etc. as described by Middleton (1930) and correlating these with OC (%), pH, exchangeable sodium percentage, moisture equivalent (%) etc. by (Dabral *et al.*, 2001). Some of the efficient indices of soil erodibility are shown to be %age-weight of water stable aggregates (WSA)>3 mm, %age-weight of WSA>0.5 mm, erosion ratio, surface-aggregation ratio, modified surface-aggregation ratio, and clay ratio, DR, modified clay ratio and erosion ratio. Thus, the present attempt majorly aimed at reviewing soil erodibility and its indices in different LU/LC.

HIGHLIGHTS

- Soil erodibility research is constrained by data accessibility and estimation complexity.
- Most erosion models require extensive data and are less practical.
- The Wischmeier model (USLE) continues to dominate erodibility research with its easy-to-use nomograph method.
- Improved methods for calculating soil erodibility are needed, as many existing prediction models are empirical and challenging to compare across regions.

2 | METHODOLOGY FOR THE REVIEW

The papers related to soil erodbility studies published during the past seven decades (1955-2022) were selected using Google Scholar and publishers websites using the primary key word, soil erodibility. The papers, including soil erodibility, SEF 'K' and related papers, were selected from different sources published worldwide to cover the work done across the globe. A total of 1919 papers appeared using Google Scholar and Web of Science websites by using the search word "Soil erodibility", and after customising years by the last seven decades, a total of 1100 papers appeared. Among the top searches, 551 papers were filtered, which were directly related to the subject. After removing repetitions of papers, finally 543 papers were selected to review the various approaches to obtain the erodibility factor and methods of measuring soil erodibility and their trend is shown in Fig. 1. Additionally, the studies were grouped into seven decades to determine the decade with the highest number of studies (Fig. 2). The methodology used was based mainly on approaches outlined by researchers such as Tang *et al.* (2016) and Kanwar and Sharma (2023), with some modifications as required.

2.1 | Various Methods to Measure Soil Erodibility

Quantitative research on soil erodibility involves four distinct methodological approaches. Both water and wind erosion studies commonly measure soil physico-chemical properties. Water erosion research often relies on scouring

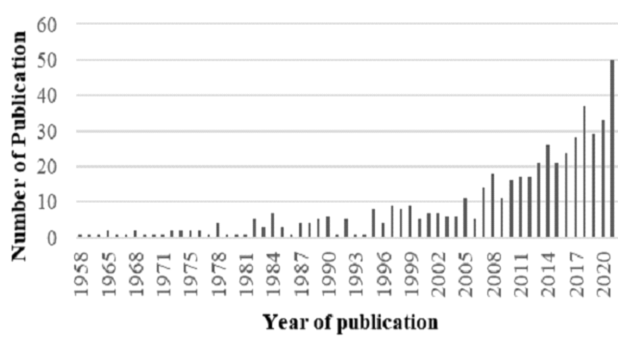

FIGURE 1 Total number of publications from 1958 to 2022

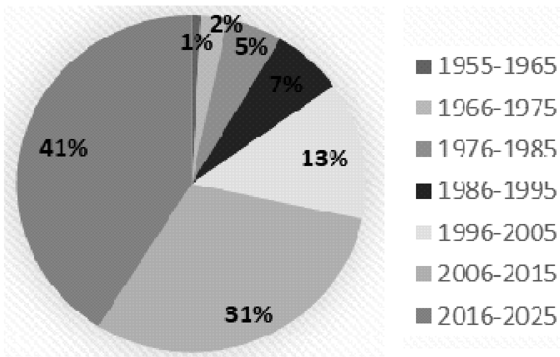

FIGURE 1 Total percentage of publications decadal wise from (1955-2025)

experiments, while wind erosion studies predominantly employ wind tunnel experiments.

2.1.1 | Measurement of soil physico-chemical properties

Since 1930s, many scientists such as Middleton (1930) and Peele (1938) have estimated soil erodibility by measuring soil physicochemical properties. Various researchers evaluated soil erodibility indices of different soils by measuring soil physicochemical properties such as soil texture, aggregate content, soil temperature, etc.

2.1.2 | Measurement of scouring, simulated rainfall and plot experiment

Some researchers started to determine soil erodibility directly by measuring soil loss scoured by water in the 1930s. The quantum of the scouring experiment was done and defined $E = \frac{dh}{a}$ as the best soil erodibility index.

Here, h is hydrophilicity, d is dispersion rate, and a is the content of indiscrete aggregate (≥ 0.25 mm) in an hour under water scouring with a speed of 100 cm min^{-1} (Dusan, 1982). Many researchers have expounded different soil erodibility indices using this method. Since the 1960s, rainfall simulators and plot experiments have been used to calculate soil erodibility.

2.2 | Estimation of Soil Erodibility

Soil erosion models have been applied in soil erodibility research based on experimental-quantitative studies since the 1950s. It was estimated using the graphic or integral method. Different models, like USLE, nomograph by Wischmeier (1978), revised universal soil loss equation (RUSLE) given by Renard *et al.* (1997), and erosion productivity impact calculator (EPIC) model given by Williams *et al.* (1983), are used to predict erosion for different conditions. Different formulas are listed in Table 1 for calculating soil erodibility.

3 | SOME IMPORTANT WORLDWIDE STUDIES ON SOIL ERODIBILITY

Bennett (1926) observed soil texture, structure, organic matter and chemical composition as the most important soil properties influencing soil erodibility. Using these soil properties, Middleton (1930) devised several indices that reflect the erodibility characteristics of several soils. All the indices developed by Bennett (1926), Middleton (1930), and later researchers can be grouped into two main categories. One category focuses exclusively on the soil properties that influence dispersion, while the other addresses the properties affecting the soil's water transmission characteristics. Olson and Wischmeier (1963) evaluated soil-erodibility for soils on the runoff and erosion stations of the United States. They observed soil erodibility (K) at the fallow plot and cropped plot, which ranged between 0.02 to 0.69 and 0.02 to 0.48, respectively. A strong and positive correlation (0.8455) between the erosion and DRs was observed, supporting previous studies (Sharma *et al*., 1987; Dabral *et al*., 2001; Agnihotri *et al*., 2007).

Evrendilek *et al*. (2004) found that SEF was greater in the cropland than in the forest site. Korkanc *et al*. (2008) found that the DR of soils did not show a significant difference. But the DR of soils in farmlands was greater than in forests and rangelands. The DR depends on the aggregation of soil particles. Soils in rangelands and forests are generally considered to have higher structural stability than soils in farmlands for soils in farmlands are cultivated continuously.

Shabani *et al.* (2010) investigated the effect of LUs and slopes on SEF under different LUs *viz.,* forest, pasture, irrigated farming and dry farming in Amol area of northern Iran. Maximum erodibility (0.078) was observed under irrigated farming land and minimum (0.023) was under pasture land at 8-18 % slope.

Ozalp *et al.* (2014) studied the soil parameters like soil texture, permeability, field capacity, bulk density, organic matter, DR in forest and pasture land of Mount Sacinka in Artvin, Turkey. The highest permeability, field capacity, organic matter were found to be 43.05 mm h^{-1}, 43.45 and 6.36% under forest soil while lowest 18.82 mm h^{-1}, 38.08% and 5.34% were under pasture land. Higher bulk density and soil pH were found to be 1.06 g cm^{-3}, 6.55 under pasture land and lower 0·91 g cm^{-3}, 5.89 under forest land, respectively. The mean DR value for forest and pasture land were 27.55 and 33.58%, respectively. Considering the threshold value 15 for DR between erodible and non-erodible soil, forest and pasture land were found to be erodible in nature.

Aytenew (2015) studied the effect of slope gradients on soil properties at Dawja watershed, Ethiopia. The textural class of the soils varied between sandy clay loam and sandy clay. The mechanical composition of the soil, *i.e.* sand and

TABLE 1 Various models used to estimate soil erodibility

S.No.	Time	Models	References
1.	1963	K = summation is rainfall-induced soil loss, EI30 is the rainfall erosive factor among E and I_{30} represent the total storm energy and the maximum 30 min intensity for a storm respectively, and e designates the times of rainfall.	Olson and Wischmeier
2.	1976	$K = -0.03970 + 0.00311x_1 + 0.00043\,x_2 + 0.00185\,x_3 + 0.00258\,x_4 - 0.00823\,x_5$. Here, x_1 is the ratio of unstable aggregate (>01250 mm); x_2 is the revised content of silt (01002~011mm) multiplied by the revised content of sand (0.1~2 mm); x_3 is basic saturation; x_4 is silt fraction in untreated soil; x_5 is revised content of sand in the soil.	E1-Swaify & Dangler
3.	1977	$K = -0.204 + 0.003\,x_2 + 0.385\,x_6 - 0.0137\,x_7 + 0.247\,x_8 - 0.005\,x_9$ $K = 0.004 + 0.00023\,x_{10} + 0.00023\,x_{10} - 0.108\,x_{11}$. Here, x_2 is revised content of silt (01002~011mm) multiplied by revised content of sand (0.1~2mm); x_6 is aggregate coefficient; x_7 is montmorillonite fraction of soil; x_2 is average bulk density in the depth of 50~125 mm; x_9 is soil dispersion; x_{10} is revised content of silt (01002~011mm) multiplied by revised content of sand (0.1~2mm); x_{11} is the oxide fraction of soil in % (Al_2O_3, Fe_2O_3) which can be abstracted by CDB (Citrate-sulphate-carbonate)	Young and Mutchler
4.	1978	$K = [2.1 \times 10^{-4}\, M^{1.14}(12\text{-}a) + 3.25\,(b\text{-}2) + 2.5\,(c\text{-}3)] / 100$. M is given by $[(S_t - S_{vf}) / 100] - C_t$; a is the %age of soil organic matter content; b is the structural code; C is the permeability class of the soil; S_t is the silt fraction of soil in %age, S_{vf} is a very fine sand fraction in soil in %age; C_5 is clay fraction in soil in %age.	Wischmeier and Smit (USLE NOMO Model)
5.	1983	$K = \{0.2 + 0.3\exp[0.0256\,SAN\,(1.0 - SIL/100)]\}\,[SIL/((CLA+SIL)]^{0.3}\,[1.0 - \frac{0.25C}{C+\exp(3.72-2.95c)}]$ $[1.0 - \frac{0.7SN1}{SN1+\exp(-5.51+22.9SN1)}]$. Here, *SAN, SIL, CLA* and C refers to sand, silt, clay and organic carbon in % respectively, $SN_1 = 1 - SAN/100$	Williams *et al.* (EPIC Model)
6.	1984	$K = 7.594\,\{0.0034 + 0.0405\exp[-\frac{1}{2}\left(\frac{\log(Dg)+1.659}{0.7101}\right)^2]\}$ $K = 7.594\,\{0.0017 + 0.049\exp[-\frac{1}{2}\left(\frac{\log(Dg)+1.675}{0.6987}\right)^2]\}$, Dg is geometrically average particle size.	Shirazi and Boersma
7.	1990	$K = \{0.2 + \exp[-0.0256\,SAN\,(1.0-SIL)]\}\left(\frac{SIL}{CLAY+SIL}\right)^{0.3}[1.0 - \frac{0.25C}{C+\exp(3.72-2.95C)}]$ $[1.0 - \frac{0.75N\,1}{C+\exp(3.72-2.95C)}]$ *SAN, SIL, CLA* and C refers to same silt, clay and organic carbon in % respectively; $SN_1 = 1 - SAN/100$	Sharpley and Smith
8.	1994	EP = 26.69 + 0.31(sand) + 0.17(silt) + 0.33(sand/clay)-4.66 (OC)-0.95($CaCo_3$) ($R^2 = 0.67$). *EP, sand, silt, clay* and *OC* is erodible particle, sand, silt, clay and organic carbon fraction of soil respectively.	Fryrear *et al.,*
9.	1995	$K = 0.563\,(\frac{A}{P * LS * CP})$ A is soil loss in catchment measured by artificial simulation of Rain, R rainfall, LS is length and slope; *CP* is vegetation factor, soil and water conservation factor.	Chen *et al.,*
10.	2002	$S = \frac{1.57 - 2.57k_j + 3.29B}{r}$ ($R^2 = 0.712$, $\alpha = 0.05$) Soil index model I $S = S_1 + S_2$ ($R^2 = 0.624$, $\alpha = 0.05$) Soil index model II $S_1 = 258.8 - (18/x_i - 84.1\,x_i - 2.6\,x_i^2) + (32.5\,x_2 + 6.2\,x_2^2) - (2.1\,x_3 - 0.9\,x_3^2)$ $S_2 = (2.7/x_4 + 1.1\,x_4) + 0.56\,x_5 - (341.2\,x_6 + 211\,x_6^2) + 17.6\,x_7 - 23.7\,x_8$ S is soil index, B is soil collapse rate, k_j is soil anti-shearing intensity, r is soil steady filtration rate; $x_1 + x_5$ refers to silt/clay, capacity, specific gravity, water content, granule content of water-stability, cation exchange amount, Organic matter and effective root amount.	Zhang *et al.,*

silt fraction, was in order: moderate sloping> strong sloping >sloping> gentle sloping, whereas, for clay, it was vice versa. The bulk density of the soils in moderately steep slope (1.42 g cm^{-3}) was the highest, followed by strongly sloping (1.41 g cm^{-3}), sloping (1.36 g cm^{-3}) and gently sloping (1.32 g cm^{-3}). The highest soil pH and organic matter (6.8 and 1.67%) were observed under a gentle slope, and the lowest was under a moderate slope (5.7 and 1.28%).

Wang *et al.* (2016) determined soil erodibility by using multiple spectral models of soil properties SOM, WSA > 0.25 mm, and the geometric mean radius (Dg). The results showed that the SOM contents (R = -0.64, $p < 0.05$for a; R = -0.69, $p < 0.05$ for ae) and WSA >0.25 mm (R = -0.81, $p < 0.01$ for a; R = -0.60, $p < 0.05$ for ae) were significantly negatively correlated with soil erodibility indicators, which suggested that a large amount of SOM and WSA played an important role in preventing erosion. Djuwansah and Mulyono (2017) observed the SEF using USLE and EPIC models on Lombok Island. The values of soil erodibility (K-factors) varied from 0.07 to 0.74 for the USLE model and 0.18 to 0.46 for the EPIC model. There was no statistical difference between the results of both methods.

Cassol *et al.* (2018) determined the SEF of the USLE using direct and analytical methods, using the Wischmeier nomograph. The USLE K-factor was found susceptible to erosion with a value of 0.0338 Mg ha h $ha^{-1}MJ^{-1}mm^{-1}$ for the Ultisol in the field. The K-factor recorded was 0.0325 Mg ha h $ha^{-1}MJ^{-1}$ mm^{-1} from the analytical method, a value very close to that determined experimentally. Thus, the Wischmeier nomograph proved to be valid for the determination of the K-factor of the Ultisol. Using different models, Zhao *et al.* (2018) estimated soil erodibility (K) in the Ansai watershed in China. The K-value ranged between 0.046 to 0.092, 0.032 to 0.060, 0.047 to 0.088, 0.018 to 0.044 and 0.009 to 0.066 in nomograph equation (NOMO) erosion-productivity impact model (EPIC), modified nomograph equation (M-NOMO), Shirazi model and Torri model, respectively.

Siswanto and Sule (2019) observed the effect of slopes (8-15, 16-25, 26-40%) and LUs (forest, mixed plantation, dry cultivation area) on soil properties in Citarum watershed, West Java. Hydraulic conductivity was maximum (1.55 mm min^{-1}) in both forest and mixed plantation at 8-15% slope while minimum (1.13 min^{-1}) was under dry cultivation land at 26-40% slope. The forest land observed maximum erodibility factor, *i.e.* 0.984 at 8-15% slope, whereas minimum K-value was observed at 16-25% slope in mix plantation.

EI Jazouli *et al.* (2019) investigated the effect of LU/LC change on soil erosion by using RS and GIS techniques in the high basin of the Oum Er Rbia river, located in Morocco. Multidate satellite images of Sentinel 2A, Landsat Oli-8 and ETM were acquired, respectively in 2017, 2013 and 2003, and the cellular automata (CA) Markov model was used to forecast the LU/LC map and their change detections. The RUSLE was integrated in a GIS environment to estimate soil loss and to map erosion risk of the specific years. The average annual estimated soil loss was 58 t $ha^{-1}yr^{-1}$ in 2003, while the predicted average annual soil loss was 142 60 t $ha^{-1}yr^{-1}$ for 2030.

Liu *et al*. (2020) studied the effects of soil depth and LU on soil erodibility in Yingwugou watershed in China. They determined the spatial distribution of the K-value by kriging interpolation. The SOC content in the study area was 0.09-150.00 g kg^{-1}, and the soil was dominated by silt. The K-values increased with increasing soil depth. Soil erodibility of surface soil (0-10 cm) for the six different vegetation types ranked in the following order: oak forest > peanut field > grassland > pine forest > tea field > corn field.

Baskan (2021) studied the spatial and temporal changes of the RUSLE 'K' SEF in semi-arid areas of Turkey to investigate soil erosion potential with the sequential gaussian simulation (SGS) method. The soil erodibility values were determined in 2000 and 2010, and erosion susceptibility distribution maps were produced. The vulnerability of the soils in the catchment increased markedly, with the area classified under 'very severe erodibility' increasing more than threefold, from 762 ha to 2477 ha. The results revealed that soil erodibility values changed spatially and temporally, with the relationship dependent on climatic factors, even though LU practices remained unchanged.

Pirah and Roslee (2022) studied SEF database for West Coast of Sabah, Malaysia; covering the total area of 9,000 km^2. The range of the SEF values was found between 0.011 to 0.056 for soils of the Peninsular Malaysia. Arunrat *et al.* (2022) assessed soil organic carbon (SOC), soil nutrients and soil erodibility under terraced paddy fields and upland rice in northern Thailand. They observed no significant difference in SEF between terraced paddies range (0.2261-0.2893 t h $MJ^{-1}mm^{-1}$) and upland rice (range 0.2238-0.2681 t h $MJ^{-1}mm^{-1}$).

Li *et al.* (2022) determined rill erodibility and critical shear stress of saturated purple soil slopes. They observed soil erodibility status of saturated and unsaturated soils of Beibei, Chongqing, China by different methods. Unsaturated soil's erodibility ranged from 0.0515 to 0.0611 (s m^{-1}), whereas saturated soil's erodibility was found between 0.0814-0.101 (s m^{-1}).

3.1 | Soil Erodibility Studies in India

Singh *et al*. (2006) analyzed soil properties and erodibility indices at three depths, *i.e.* 0-5 cm, 5-15 cm, and 15-30 cm, across five LUs: *Leucaena*, *Prosopis*, rainfed agriculture, grasses and open gullies in Rajasthan, India. Based on erosion and DRs, soil erodibility ranked as follows: open gullied > rainfed agriculture > *Prosopis* > *Leucaena* > grasslands. Das *et al*. (2007) assessed the SEF 'K' and its correlation with various soil properties in the Marmring-Patle micro-watershed of Darjeeling, India. The findings indicated that soils on escarpments and dip slopes (33-50% slope) had the highest 'K' values, while the lowest 'K' values were found in soils on hilltop ridges and summits (10-15% slope).

Singh and Khera (2010) evaluated soil erodibility indices about runoff and soil loss in Punjab. They observed erodibility indices under natural and simulated rainfall conditions under four LUs, *viz.,* barren, cultivated, grassland and forest LU. The order of indices among different LUs was found, like cultivated > grassland > forest. However, WSA followed the opposite trend. The CR and MCR were highly positively correlated with soil loss except for the WSA index, where the values were highly negative. WSA and MCR were observed to be better indices of soil erodibility. Singh and Khera (2010) estimated soil erodibility by nomographic and fuzzy logic methods under four LUs: cultivated, grassland, barren, and forest, in Punjab, India.

The SEF 'K' by nomographic model was in order as: cultivated land (0.34) > grassland (0.24) > barren land (0.20) > forest land (0.17) whereas, in case of fuzzy logic method it was decreasing as forest land (0.27) > cultivated land (0.12) > barren land = grassland (0.10). Fuzzy model showed very less values as compared to nomographic model.

Parveen and Kumar (2012) used USLE to study the annual soil loss risk in upper south Koel basin, Jharkhand and GIS. The soil erodibility (K-factor) varied from 0.23-0.37 in different soil types of watersheds whereas, the soil loss was found to be 12.2 t $ha^{-1}yr^{-1}$ by USLE.

Bera (2017) observed the soil loss by using USLE in basin of Muhuri river, Tripura. The average rainfall erosivity ranged from 863.44 to 926.43 mt $ha^{-1}cm^{-1}$ annually, SEF 'K' from 0.15 to 0.36, LS factor varied from 0.15 to 0.36 and CP value varied from 0.008 to 0.6. The average annual soil loss was found up to 650 t $ha^{-1}y^{-1}$. Moderately high risk of annual soil loss was recorded under study area.

Dutta *et al*. (2017) studied the different LU (orchard, shifting cultivation, low land and forest) effect on soil erodibility parameters in Botsa in Kohima district, Nagaland. The erosion index of the surface soils in different villages under orchard, shifting cultivation, lowland and forest varied from 14.85 to 22.67, 13.30 to 18.91, 11.29 to 22.47 and 5.28 to 9.28 with a mean value of 18.46, 16.78, 16.14 and 6.86, respectively. The highest value of erosion index in surface soils was recorded under orchards, and the lowest was recorded under forest LU. The DR of the soils ranged from 8.16 to 30.53, whereas the erosion index varied between 5.28 and 23.91. The highly significant and positive correlation between the erosion index and DR indicated the susceptibility of these soils to water erosion.

Kusre *et al.* (2018) studied the spatial variation of susceptibility of erosion in Sikkim estimated by various soil erodibility indices. The result revealed that the soils of the study area are dominated mainly by sand particles (40.5-81.06%). The DR values were >15%, indicating a very high vulnerability to erosion. The clay ratio (3.44-9), modified clay ratio (mean value of 6.9), and critical level of SOM content (<5%) indicated high susceptibility to erosion. The indices trend was developed by the IDW interpolation method to understand the spatial variation of the susceptibility to erosion.

4 | PROBLEMS AND DISCUSSION

Despite extensive research on soil erodibility, several barriers still hinder further investigation. Much of the existing research has concentrated on agricultural soils that have been disturbed and homogenized, as well as on gentle slopes where the geomorphological and hydrological properties and processes are less significant, leading to the homogenization of natural soil profile features. There is a need for improved methods to calculate soil erodibility. Many soil erosion prediction models are empirical, making it challenging to compare results across different regions. Some models, like WEEPS, are process-based but are complex and currently undergoing testing and refinement. Additionally, for a long time, wind erosion and water erosion have been studied separately, resulting in limited

TABLE 2 Summary of some important worldwide publications addressing the erodibility status of soil

S.No.	Year	Observed values of erodibility and its indices	Study area	Author
1.	1963	Soil erodibility (K) ina fallow cropped plot was found to be between 0.02 and 0.69 and 0.02 and 0.48, respectively.	America	Olson and Wischmeier
2.	2014	The mean dispersion ratio (DR) value for forest and pasture land was 27.55 and 33.58%, respectively.	Turkey	Ozalp *et al.*
3.	2015	The mechanical composition of soil, *i.e.* sand and silt fraction, was in order: moderate sloping > strong sloping > sloping > gentle sloping, whereas, for clay, it was *vice-versa.*	Ethiopia	Aytenew
4.	2004	K was greater in the cropland > forest site > grassland *i.e.* 0.26 > 0.11 > 0.14, respectively	Turkey	Evrendilek *et al.*
5.	2006	K ranked as follows: open gullied > rainfed agriculture > *Prosopis* > *Leucaena* > grasslands	India	Singh *et al.*
6.	2008	Erosion ratio (ER) of soils in farmlands, rangelands and forests was found to be 37, 31 and 31, respectively and the dispersion ratio (DR) of soils in farmlands > forests and range lands.	Turkey	Korkanc *et al.*
7.	2008	The erosion ratio for different land uses was in the order of barren (0.97) > cultivated (0.84) > grassland (0.74) > forest (0.63).	Punjab	Singh and Khera
8.	2010	Maximum soil erodibility (K), *i.e.* 0.078, was observed under irrigated farming land and minimum K was observed as 0.023 under pasture land at 8-18% slope.	Northern Iran	Shabani *et al.*
9.	2010	Soil erodibility factor K by nomographic model was in order as: cultivated land (0.34) > grassland (0.24) > barren land (0.20) > forest land (0.17) whereas, in case of fuzzy logic method, it was decreasing as forest land (0.27) > cultivated land (0.12) > barren land = grassland (0.10).	Punjab	Singh and Khera
10.	2012	The K-factor varied from 0.23-0.37 in different soil types of watershed	Jharkhand	Parveen and Kumar

TABLE 2 Continued....

S.No.	Year	Observed values of erodibility and its indices	Study area	Author
11.	2016	Determined soil erodibility by using multiple spectral models of soil properties soil organic matter (SOM), water-stable aggregates (WSA) > 0.25 mm, the geometric mean radius (Dg). The results showed that the SOM contents ($R = -0.64$, $p < 0.05$ for a; $R = -0.69$, $p < 0.05$ for ae) and WSA >0.25 mm ($R = -0.81$, $p < 0.01$ for a; $R = -0.60$, $p < 0.05$ for ae) were significantly negatively correlated with soil erodibility indicators.	China	Wang *et al.*
12.	2017	Observed soil erodibility factor (K) from 0.15 to 0.36.	Tripura	Bera
13.	2017	Studied soil erodibility parameters in Kohima, Nagaland. The different land use (orchard, shifting cultivation, low land and forest) effect on DR of the soils ranged from 8.16 to 30.53 whereas, EI varied between 5.28 and 23.91.	Nagaland	Dutta *et al.*
14.	2017	The observed soil erodibility (K-factors) values varied from 0.07 to 0.74 for USLE model and 0.18 to 0.46 for EPIC model.	Lombok Island	Djuwansah and Mulyono
15.	2018	The USLE K factor found susceptible to erosion with value 0.0338 Mg ha h $ha^{-1}MJ^{-1}mm^{-1}$ by using the Wischmeier nomograph for the Ultisol, in the field. The K factor recorded was 0.0325 Mg ha h $ha^{-1}MJ^{-1}mm^{-1}$ from the analytical method, a value very close to that determined experimentally.	Brazil	Cassol *et al.*
16.	2018	The soil erodibility indices, *i.e.* DR values, were found to be >15%, indicating very high vulnerability to erosion. The clay ratio (CR) (3.44-9), MCR (mean value of 6.9) and critical level of SOM content (<5%) indicated high susceptibility to erosion.	Sikkim	Kusre *et al.*
17.	2018	The K value ranged between 0.046 to 0.092, 0.032 to 0.060, 0.047 to 0.088, 0.018 to 0.044 and 0.009 to 0.066 in nomograph equation (NOMO) erosion-productivity impact model (EPIC), modified nomo graph equation (M-NOMO), Shirazi model and Torri model, respectively.	China	Zhao *et al.*
18.	2019	The forest land observed a maximum erodibility factor of 0.984 at an 8-15% slope, whereas a minimum K value was observed at a 16-25% slope in a mix plantation.	West Java	Siswanto and Sule
19.	2019	The average annual estimated soil loss was 58 t $ha^{-1}yr^{-1}$ in 2003, while the predicted average annual soil loss was 142 60 t $ha^{-1}yr^{-1}$ for 2030.	Morocco	Jazouli *et al.*
20.	2019	The forest land observed a maximum erodibility factor of 0.984 at an 8-15% slope, whereas a minimum K value was observed at a 16-25% slope in a mix plantation.	West Java	Siswanto and Sule
21.	2020	The K-values by kriging interpolation have an average value of 0.032 t $hm^2h/(MJ\ mm\ hm^2)$ and a medium degree variation. Soil erodibility of surface soil (0-10 cm) for the six different vegetation types ranks as following order: oak forest > peanut field > grassland > pine forest > tea field > corn field.	China	Liu *et al.*
22.	2021	Soil erodibility K factor and a comprehensive soil erodibility index from different aspects for cropland, orchard, grassland, shrubland and woodland on the Loess Plateau. The results showed that Coh, Ks, NDI, MWD, PR and K increased during one growing season for most of land use types. While, K was almost stable or decreased slightly under all five tested land use types.	China	Wang and Zhang
23.	2021	The mean values for K 2000 and K 2010 were similar at 0.28 and 0.27, respectively; however, the maximum values differed at 0.49 and 0.64, respectively.	Turkey	Baskan
24.	2022	The mean value of soil erodibility K values was 0.046 t·hm2·h/(hm2·MJ·mm) ranging from 0.039 to 0.052 t $hm^2h/(hm^2 MJ\ mm)$.	China	Huang *et al.*
25.	2022	The range of the Soil Erodibility Factors (SEF) values was found between 0.011 to 0.056 for soils of the Peninsular Malaysia	Malayasia	Pirah and Roslee
26.	2022	Assessed Soil Organic Carbon, Soil Nutrients and Soil Erodibility under Terraced Paddy Fields and Upland Rice in Northern Thailand. Observed soil erodibility (K) of terraced paddies and upland rice field; values found between 0.2261-0.2893 t h $MJ^{-1}mm^{-1}$ and 0.2238-0.2681 t h $MJ^{-1}mm^{-1}$ respectively	Northern Thailand	Arunrat *et al.*
27.	2022	Unsaturated soil's erodibility was found between 0.0515 to 0.0611 ($s\ m^{-1}$) whereas saturated soil's erodibility was found between 0.0814-0.101 ($s\ m^{-1}$)	China	Li *et al.*

research on soil erodibility (K) concerning both types of erosion. In semi-arid regions, however, wind and water erosion often occur in alternation. This separation contradicts the investigation of soil erodibility in the context of combined water and wind erosion.

5 | ADVANTAGES & DISADVANTAGES IN APPLICATION OF VARIOUS MODELS

For the Olsen model, the rainfall or precipitation data of the study area is required, and after that, estimation of rainfall erosivity is needed; the availability/procurement of rainfall intensity data is difficult, and the estimation of erosivity is a cumbersome process in itself. In Wischmeier model (USLE NOMO), El-Swaify model, Williams (EPIC) model, Sharpley model, and Fryrear model the dataset required are soil texture, soil structure, permeability class, SOM, estimation of these data in real field conditions is quite easy and the results are more reliable obtained from these datasets. Among these five models, the Wischmeier model is mostly used worldwide since the USLE is a universally accepted method for estimating average annual soil loss, in which K is also calculated by the Wischmeier model. Moreover, NOMO graphs are also easily available in the literature, which provides readily available values of K and saves a lot of time for estimating soil erodibility if sufficient data sets are not available. However, in the four models, complex lab analysis, including no. of soil properties and calculation process, is required essentially for the final estimation of soil erodibility.

For estimating the SEF by using the Shirazi model, the arithmetic mean of the particle size and weight percent of the particle size are required for the estimation of soil erodibility. In the case of the Young model, except for soil texture, other inputs required are the montmorillonite fraction of soils, bulk density of soil, soil dispersion, and oxide fraction of soil. Calculating soil erodibility through the Young model is a long process and involves several steps for deriving the DR; first, one needs to take the ratio of silt plus clay per cent dispersed in water and silt plus clay per cent in mechanical analysis. Whereas in the case of the Chen model, the input required are rainfall data, topographic factor, vegetation factor, soil and water conservation factor and in Zhang model, soil collapse rate, soil anti-shearing intensity, soil steady filtration rate; specific gravity, water content, granule content of water-stability, cation exchange amount and effective root amount are needed which in reality takes more time, manpower, is a cumbersome and expensive method.

6 | CONCLUSION

After reviewing the work of various authors and conducting a critical assessment of the studied models in this research, it is clear that the USLE NOMO model is the most widely accepted and commonly used method for estimating soil erodibility. This model primarily requires easily obtainable datasets from laboratory analyses, such as soil texture, SOM, soil structure, and permeability. If sufficient data are unavailable, erodibility values can still be estimated using nomographs. The USLE NOMO model produces reliable results for soil erodibility because the K-factor is a lumped parameter representing an integrated annual average of the soil's response to erosion and hydrological processes. This method is also incorporated into various hydrological models, including the soil and water assessment tool (SWAT) and the agricultural policy extender (APEX), to calculate soil erodibility values.

Improved methods for calculating soil erodibility are needed, as many existing prediction models are empirical and challenging to compare across regions.In semi-arid regions, wind and water erosion often occur alternately, highlighting the need for a more integrated approach to studying erodibility.

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DATA AVAILABILITY STATEMENT

Not applicable

CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

AUTHOR'S CONTRIBUTION

HK, GA, PK - conceptualization, writing - original draft preparation; HK, PK, GA and RK - writing - review and editing, visualization. All authors have read and agreed to the published version of the manuscript.

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