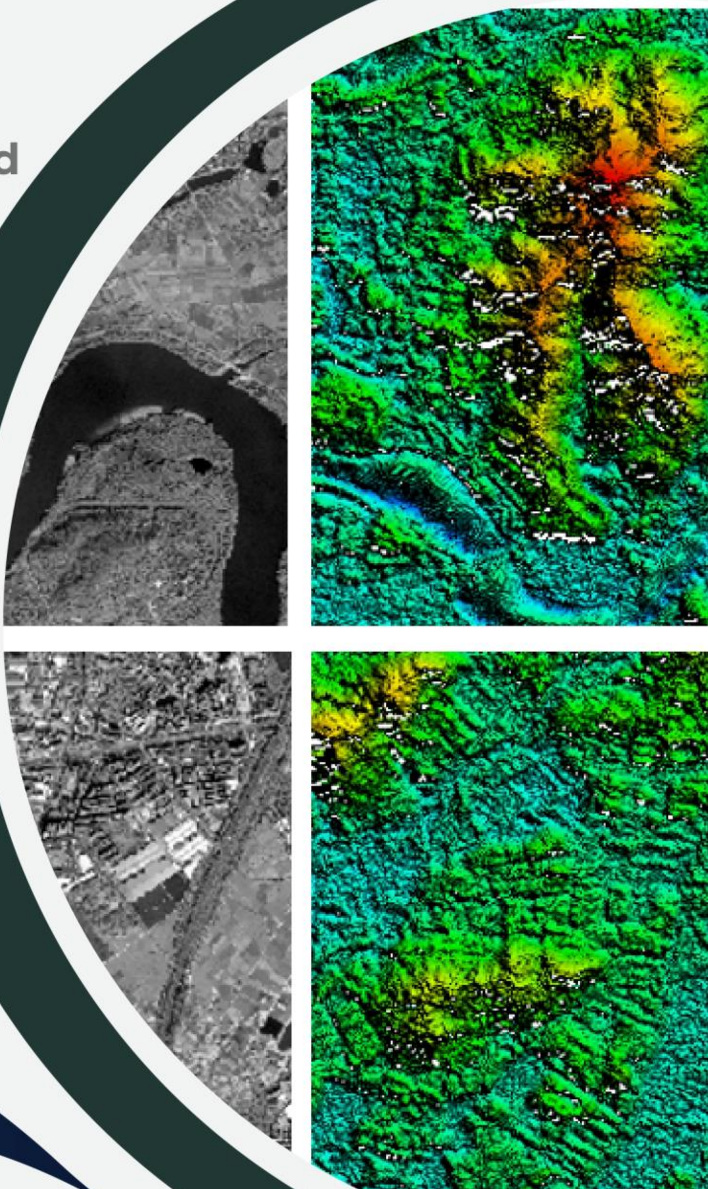
STANDARD OPERATING PROCEDURE

SOP

GEOSPATIAL MAPPING OF LAND DEGRADATION DUE TO WIND EROSION

Potential Soil Loss Rate by Revised Wind Erosion Equation (RWEQ)



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INTRODUCTION

Wind Erosion Equation (WEQ), developed during the late 1960s based on wind tunnel experiments and field measurements by Chepil (1959), is an empirical model for estimating loss due to wind erosion (Woodruff and Siddoway, 1965). With the advent of computer in the late 1990s, the task of soil loss assessment was completely reformed and WEQ was considered as a highly sophisticated empirical model (Blanco-Canqui and Lal, 2008a; Fisher and Skidmore, 1970). Since its development, WEQ remained the only model available for planning of wind erosion control systems and it was subjected to continuous improvement till the year 1998 when the Revised Wind Erosion Equation (RWEQ) was developed by Fryrear et al. (1998). The RWEQ model was more realistic than WEQ as it considered more information from agricultural fields and its main intent was to permit the short-term estimation of soil erosion (Fryrear et al., 1998).

The WEQ model estimates the mean wind erosion along a line-transect across a wide, unsheltered, isolated, bare, smooth, non-crusted surface in mass per unit area per year (Fryrear et al., 1999; Woodruff and Siddoway, 1965). The input data for the WEQ are derived from maps, tables, and graphs to make an estimation of soil erosion with a graphical solution to simplify input relationships. In fact, RWEQ model is based on WEQ and contains both empirical and process-based components and hence has the ability of describing wind erosion processes physically by combining field datasets with a computer model for the estimation. Thus, this model is not completely a physically-based model (Blanco-Canqui and Lal, 2008a; Fryrear et al., 1999).

RWEQ includes a weather factor (WF), soil crust factor (SCF), erodibility factor (EF), roughness factor (K), and combined crop factor (COG), a field parameter for size and orientation of the field, and wind speed which depends on slope and height of the hills (Youssef et al., 2012). Hence, input parameters of RWEQ model are based on both field and laboratory studies (Fryrear et al., 1999). As with most of the wind erosion estimation models, wind plays a key role as the basic driving force in this model. The model estimates the amount of sediment flux [Q(Z) in kg m^{-1}] for specified periods based on a single-event, to a height of 2 m above ground level at a downwind distance (Z in m) for a specific field length based on the balance between wind erosivity and soil erodibility (Fryrear et al., 1998; Youssef et al., 2012).

An extensive literature search revealed that RWEQ model has attracted many researchers worldwide to conduct local as well as global studies for estimating soil loss due to wind erosion. At the same time, it is also felt that the methodology for applying RWEQ model is not clearly explained and a gap is sometimes experienced. This document is an attempt to abridge this gap by illustrating step-by-step procedure for applying RWEQ model for estimating potential soil loss rate due to wind erosion. Furthermore, the adopted methodology utilized application of geospatial modeling for computing each parameter spatially in geographic information system.

OBJECTIVE

To compute and map land degradation due to wind erosion based on climate, soil and land parameters using remote sensing and geospatial tools, and validate the developed map.

SCOPE

The developed SOP can be applied for regional-level or national-level mapping of land degradation due to wind erosion using Revised Wind Erosion Equation (RWEQ).

DATASET USED

S. No.	Type of data	Unit	Duration and Period	Temporal resolution	Spatial resolution	Source
1	Climatic parameters:					National Aeronautics and Space Administration (NASA) Langley Research Center's Prediction of Worldwide Energy Resources (POWER) project funded through the NASA Earth Science Division. POWER Project's Hourly 2.5.21 version on 2025/08/06. https://power.larc.nasa.gov/data-access-viewer/
	Maximum temperature at 2 m height	°C	5-year (2020-2024)	Daily	0.5°×0.625°	
	Minimum temperature at 2 m height	°C	5-year (2020-2024)	Daily	0.5°×0.625°	
	Rainfall	mm	5-year (2020-2024)	Daily	0.5°×0.625°	
	Relative humidity at 2 m height	%	5-year (2020-2024)	Daily	0.5°×0.625°	
	Wind speed at 2 m height	$m\ s^{-1}$	5-year (2020-2024)	Daily	0.5°×0.625°	
	All sky surface shortwave downward direct normal irradiance	$kWh\ m^{-2}\ day^{-1}$	5-year (2020-2024)	Daily	0.5°×0.625°	
	All sky surface shortwave diffuse irradiance	$kWh\ m^{-2}\ day^{-1}$	5-year (2020-2024)	Daily	0.5°×0.625°	
2	Soil parameters:					National Agricultural Science Fund (NASF)-funded project on 'Hyperspectral reflectance and multi-nutrient extractant-based rapid assessment of soil properties for sustainable soil health' with lead centre at ICAR-CAZRI, Jodhpur.
	Content of primary soil particles (Sand, Silt, Clay)	% by mass	2023-2024	Single time	Spatially distributed point samples	
	Soil organic matter content	% by mass	2023-2024	Single time		
	$CaCO_3$ content	% by mass	2023-2024	Single time		
3	Satellite imageries and products:					
	Landsat/LC08/C02/T1_L2 dataset	-	5-year (2020-2024)	Fortnightly	30 m × 30 m	United States Geological Survey (USGS) data*
	Snow depth	m	5-year (2020-2024)	Hourly	0.1°×0.1°	ECMWF/ERA5-Land (European Centre for Medium Range Weather Forecasts)*
	SRTM-Digital elevation model (Shuttle radar topography mission)	m	February 2000	Single time	30 m × 30 m	United States Geological Survey (USGS)*

Note: *data were generated through Google Earth Engine platform

METHODOLOGY

- This standard operating procedure (SOP) document presents methodology for geospatial mapping of land degradation due to wind erosion using Revised Wind Erosion Equation (RWEQ). The potential soil loss rate due to wind erosion is computed using the RWEQ model, expressed as follows.

$$SL = \frac{2x}{S^2} Q_{\max} e^{-\left(\frac{x}{s}\right)^2} \quad (1)$$

where, SL = potential soil loss rate (kg m^{-2}); x = distance from non-erodible border (m), and S = critical field length (m).

- The critical field length and maximum transport capacity are computed using the following expressions.

$$S = 150.7\left(WF \times EF \times SCF \times K' \times COG\right)^{-0.3711} \quad (2)$$

$$Q_{\max} = 109.8\left(WF \times EF \times SCF \times K' \times COG\right) \quad (3)$$

where, S = critical field length (m) and Q_{max} = maximum transport capacity (kg m^{-1}), WF = weather factor, EF = soil erodibiliy factor, SCF = soil crust factor, K' = soil roughness factor and COG = combined crop factor.

- Computation of S and Q_{max} involves five factors, i.e., WF, EF, SCF, K' and COG, and steps involved in computation of each factor are summarized below.
- The computed values of potential soil loss rate (SL) were categorized into six classes, i.e., micro-degree (0-20 t ha^{-1} yr^{-1}), slight (20-250 t ha^{-1} yr^{-1}), moderate (250-500 t ha^{-1} yr^{-1}), intense (500-800 t ha^{-1} yr^{-1}), extremely intense (800-1500 t ha^{-1} yr^{-1}) and severe (>1500 t ha^{-1} yr^{-1}).
- A step-by-step procedure of applying RWEQ model for estimating potential soil loss rate is illustrated by a flowchart.

Step 1: Data Procurement

- Collect daily data of climatic parameters (maximum temperature, minimum temperature, rainfall, relative humidity, wind speed), one-time data of soil parameters (percentage of sand, silt and clay proportions, organic matter content, calcium carbonate content) and fortnightly data of land (normalized difference vegetation index) parameters, digital elevation model for spatially-distributed points/grids/sites.

- All the above said data may be collected either as a spatial grid data or point data or as maps in the form of raster. If it is available in point or grid data, then these are two be converted to maps/raster through geostatistical approaches (e.g. fitting semivariogram model followed by ordinary kriging).
- Quality check of the collected data and necessary corrections are applied in case of missing data, and irregularity and inconsistency in the data.

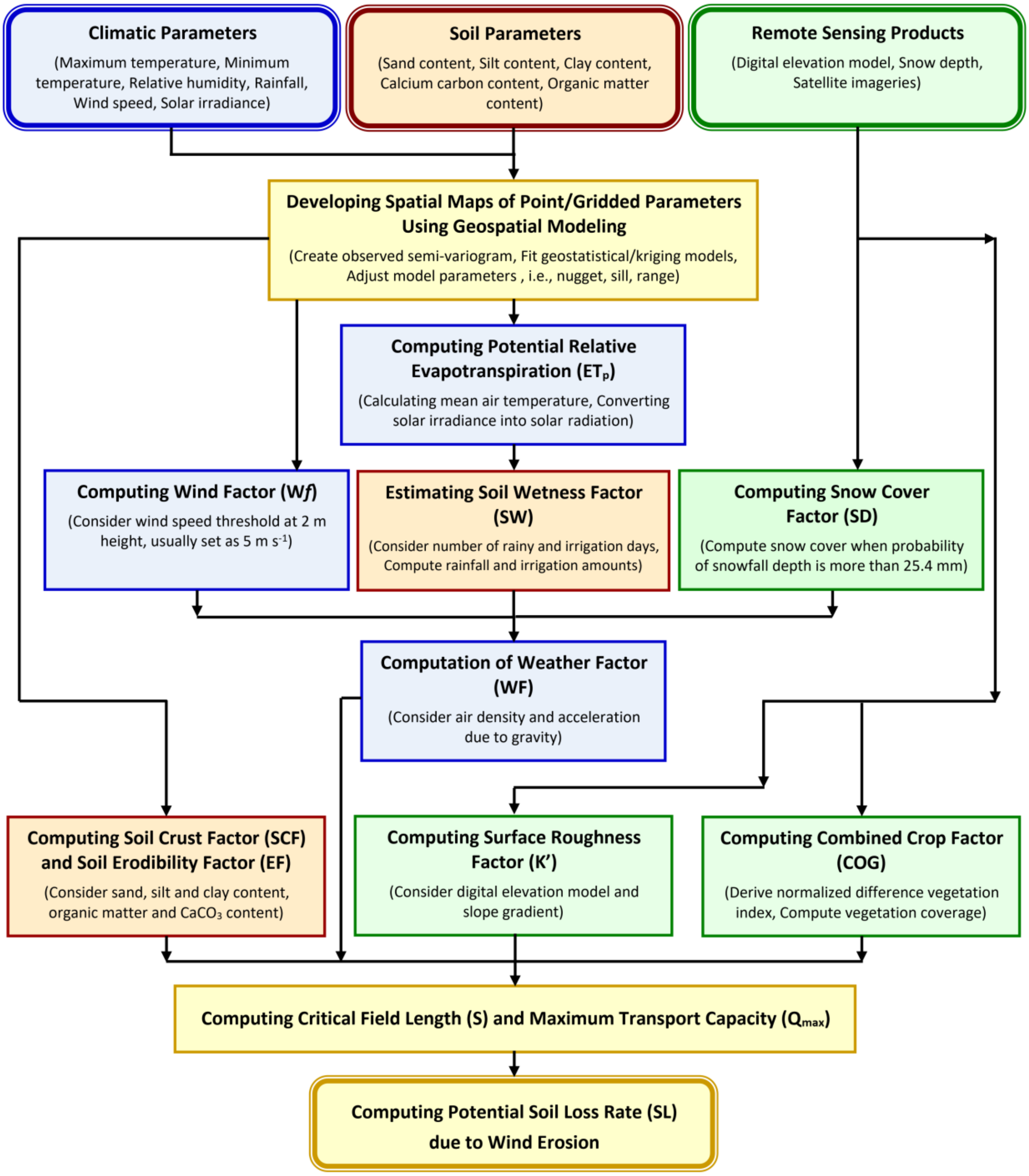

Fig. 1. Flowchart illustrating step-by-step procedure for applying Revised Wind Erosion Equation (RWEQ) model for geospatial mapping of potential soil loss rate

Step 2: Geospatial Modeling for Generating Rasters of Parameters

- All kind of point data such as soil related parameters (e.g., sand, silt and clay proportions, organic matter content, $CaCO_3$ content) and gridded data such as climatic parameters (e.g., maximum and minimum temperatures, relative humidity, wind speed, solar irradiance, etc.) were subjected to geostatistical modeling. In geostatistical modeling, if Z(x) represents any regionalized variable with a parameter measured at n locations in space $z(x_i)$, i = 1, 2, … n and if the parameter of the function Z has to be estimated at the point x_0, which has not been measured, the kriging estimate is defined as (Journel and Hujibregts, 1978; Kitanidis, 1997):

$$Z^*(x_0) = \sum_{i=1}^{n} \lambda_i \, z(x_i) \quad (4)$$

where, $Z^*(x_0)$ = estimation of variable at point x_0, n = number of known locations surrounding the unknown location x_0 and λ_i = weighting factors.

- Weights are assigned to each measured location, $z(x_i)$ in the semivariogram, which is calculated as follows.

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} (Z_{x+h} - Z_x)^2 \quad (5)$$

where, $\gamma(h)$ = semivariance at a lag distance 'h', N(h) = number of spatially located pairs within a lag distance 'h', Z_x = variable at location x, Z_{x+h} = variable at location x+h.

- Calculated semivariance values at different lag distances were plotted to depict semivariogram, which was further fitted to standard theoretical models. Fitting the semivariogram in standard model results into three spatial variation parameters (nugget, sill and range). These three spatial variation parameters corresponding to the best fitted models were used in ordinary kriging process to assign the weights. Weighted least square fitting is generally followed to identify the best fit model with lowest error of fitting.

- As the land related parameters involved the satellite imageries or raster maps such as digital elevation model, geospatial modeling was not done for the land parameters. The spatial resolution of all the rasters was brought to a same resolution by resampling operation in geographic information system (GIS). All subsequent steps were performed using the rasters of the climatic, soil and land related parameters.

Step 3: Computation of Daily Potential Relative Evapotranspiration

- Using daily climate data, compute potential relative evapotranspiration (ETp) using the following expression.

$$ET_p = 0.0162 \times \left(\frac{SR}{58.5}\right) \times (DT+17.8) \quad (6)$$

where, ET_p = potential relative evapotranspiration (mm), SR = solar radiation (cal cm^{-2}), and DT = mean air temperature (°C).

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- The solar radiation, defined as sum of shortwave downward direct normal irradiance and shortwave diffuse irradiance, is expressed as shown below.

$$SR = \frac{(IR_{DNI} + IR_{Diff}) \times 3.6 \times 100}{4.1868} \quad (7)$$

where, SR = solar radiation (cal cm^{-2}), IR_{DNI} = all sky surface shortwave downward direct normal irradiance (kWh m^{-2} day^{-1}), and IR_{Diff} = all sky surface shortwave diffuse irradiance (kWh m^{-2} day^{-1}).

- The daily mean air temperature was computed by taking the average of the daily maximum and minimum temperatures, as defined below.

$$DT = (T_{max} - T_{min})/2 \quad (8)$$

where, DT = mean air temperature (°C), T_{max} = maximum temperature (°C), and T_{min} = minimum temperature (°C).

- The daily values of ET_p are finally converted to fortnightly values by taking sum of 15-year, which resulted in bi-monthly values and total 120 values for 5-year period (2020-2024).

Step 4: Estimating Soil Wetness Factor

- The soil wetness factor was estimated using the formula mentioned below.

$$SW=\frac{ET_p-(R+I)\frac{R_d}{N_d}}{ET_p} \quad (9)$$

where, SW = soil wetness factor (unit less), ET_p = potential relative evapotranspiration (mm), N_d = number of days in the period, i.e., 15 for fortnightly interval, R + I = sum of irrigation and rainfall (mm), and R_d = number of rainfall and irrigation days.

Step 5: Computation of Soil Wind Factor

- Soil wind factor at fortnightly interval is computed using the following equation.

$$Wf = \frac{\sum_{i=1}^{N} U_{2,i} \times \left(U_{2,i}-U_t\right)^2}{N} \times N_d \quad (10)$$

where, Wf = wind factor ($m^3\ s^{-3}$), $U_{2,i}$ = wind speed at 2 m height at i^{th} hour of time ($m\ s^{-1}$), U_t = wind speed threshold at 2 m height ($m\ s^{-1}$), which is usually set as 5 $m\ s^{-1}$, N_d = time interval for wind speed measurements, i.e., 15-day for fortnightly computations, and N = total number or frequency of wind speed observations, i.e., 360 observations with 24 hourly observations for a 15-day fortnight, 336 observations for 14-day fortnight and 384 observations for 16-day fortnight sometimes.

Step 6: Computation of Snow Cover Factor

- The snow depth/cover factor is expressed as follows.

$$SD = 1 - P(\text{snow cover} > 25.4\ \text{mm}) \quad (11)$$

where, SD = snow depth factor (unit less), and P (snow depth> 25.4 mm) = probability that the snow cover depth is more than 25.4 mm in the calculation interval (unit less). For a fortnightly computation, calculation interval is 15 days.

- The SD is equals the number of days when the snow thickness exceeds 25.4 mm in a given period, which can be calculated using the number of days when the average daily temperature is less than 0°C and the rainfall is more than 2.5 mm based on the method of Guo et al. (2013).

Step 7: Computation of Weather Factor

- The weather factor is calculated by using following expression.

$$WF = SW \times SD \times Wf \times \frac{\rho}{g} \quad (12)$$

where, WF = weather factor (kg m^{-1}), SW = soil wetness factor (unit less), SD = snow depth factor, W*f* = wind factor (m^3 s^{-3}), ρ = air density (kg m^{-3}) and g = acceleration due to gravity (9.8 m s^{-2}).

- The WF is computed fortnightly by using fortnightly values of the different variables/parameters. The wind erosion can be omitted when the wind speed is less than 5 m s^{-1}.
- The equation generally estimates wind erosion between the soil surface and a height of 2 m at a field scale (Fryrear et al., 1998).

Step 8: Calculating Soil Erodibility Factor and Soil Crust Factor

- The erodibility factor (EF) and soil crust factor (SCF) are determined from soil texture data, including the soil sand, silt, clay, and organic matter contents (Fryrear et al., 1994). The EF corresponds to the fraction of sand particles or soil aggregates that are smaller than 0.84 mm in diameter, which is calculated using the following equation.

$$EF = \frac{29.09 + 0.31Sa + 0.17Si + 0.33\frac{Sa}{Cl} - 2.59OM - 0.95CaCO_3}{100} \quad (13)$$

where, Sa = soil sand content (% by mass), Si = soil silt content (% by mass), Cl = soil clay content (% by mass), Sa/Cl = ratio of the sand content to the clay content (unit less), OM = soil organic matter content (% by mass), and $CaCO_3$ = calcium carbonate content (% by mass).

- The SCF reflects the fact that a soil surface crust can range from extremely hard to very fragile, and it may therefore decrease or increase the wind erosion potential. It is calculated using the following equation.

$$SCF = \frac{1}{1 + 0.0066(Cl)^2 + 0.021(OM)^2} \quad (14)$$

Step 9: Computing Surface Roughness Factor

- Surface roughness factor depends on the random roughness elements of the soil surface and can be measured and expressed by the following expression.

$$K' = \cos\alpha \tag{15}$$

where, K’ = surface roughness factor (unit less), α = slope gradient (degree), which is calculated by the Digital Elevation Model (DEM).

Step 10: Computing Vegetation Cover Factor

- The combined crop factor is computed using the following equation.

$$COG = e^{-0.0483(SC)} \tag{16}$$

$$SC = 100 \times (NDVI - NDVI_{soil}) / (NDVI_{max} - NDVI_{soil}) \tag{17}$$

where, COG = combined crop factor (unit less), SC = vegetation coverage (%), $NDVI_{soil}$ = normalized difference vegetation index value for bare soil pixel (unit less), $NDVI_{max}$ = maximum value of normalized difference vegetation index for the study area (unit less).

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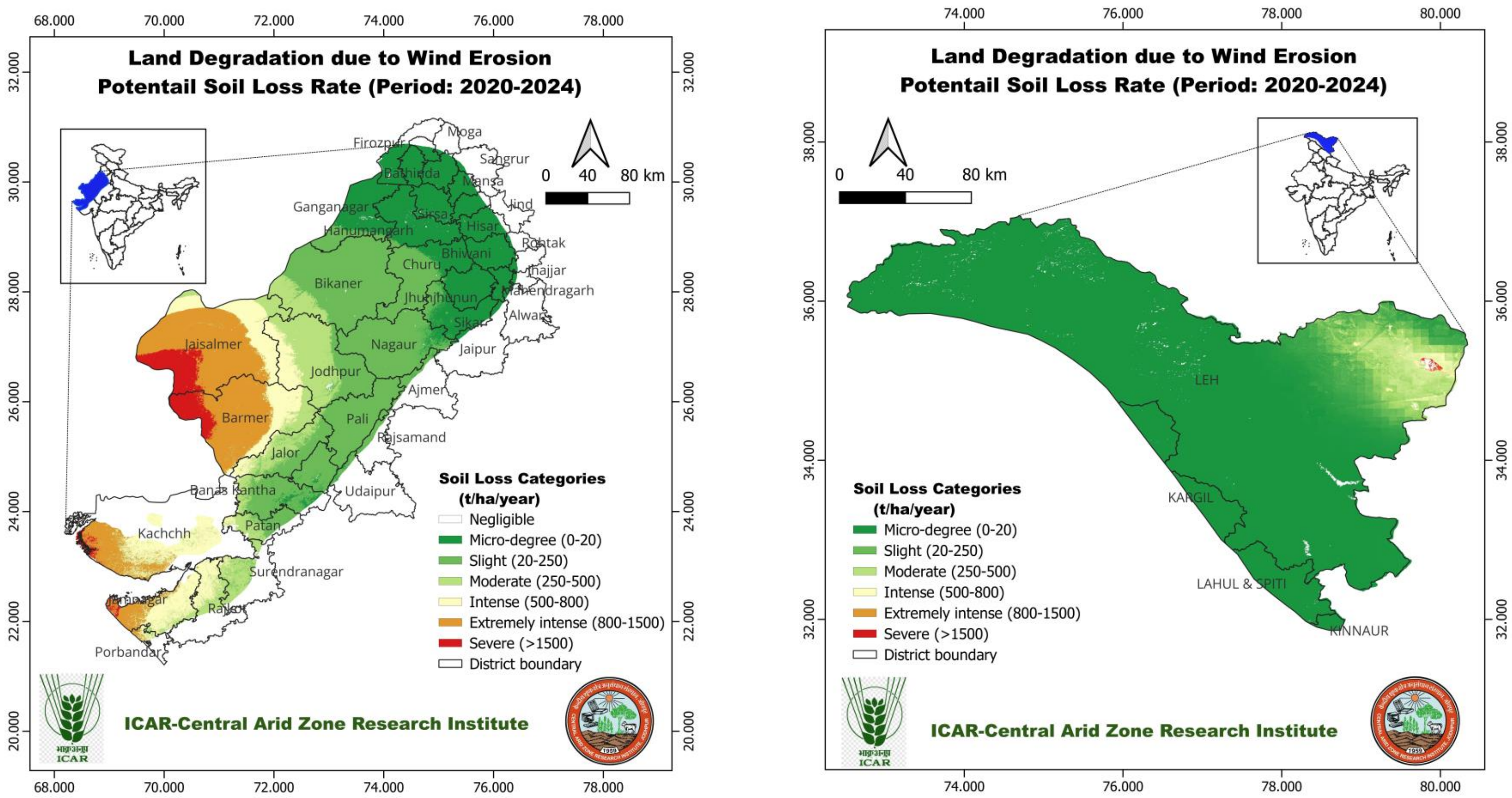

Fig. 2. Maps of Land degradation due to wind erosion estimated by Revised Wind Erosion Equation (RWEQ) for hot arid region (left) and cold arid region (right) of India