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SOIL PROPERTIES AND MAPPING OF THE ARALIK-IĞDIR WIND EROSION AREA-I (SURFACE)

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Abstract: In arid and semi-arid regions, one of the biggest problems for soil which is bare and/or has insufficient vegetation is wind erosion caused by strong winds. The second largest wind erosion area of Türkiye is in the province of Aralık-Iğdır. In this study, surface soil analysis of 40 km^2 of the wind erosion area (clay,% silt,% sand, carbonate%, OM%, pH and EC), dry sieving analysis (4, 2, 1, 0.84, 0.42, 0.106, 0.020, <0.020 mm), erodible fraction (EF1%, EF2%), stability index (SI) and relative aggregation index (RSI) were determined. In addition, elevation, slope, silt, >0.84 mm, 0.106 mm, >0.020 mm, EF1, EF2, SI and RSI values as percentage were mapped using Geographic Information Systems (GIS). As a result, the texture classes of the wind erosion area of surface soils were determined as S-LS-SL, the carbonate percentages as 0.4-0.8, the organic matter percentages as 0.3-2.4, the pH values as 8.0-9.1, the electrical conductivity measurements as 0.03-0.12. In dry sieving processes; the resistant material (>0.84%) as 0-40, the erosive material (<0.84%) as 43-99; the erodible material percentages calculated with equations EF1 as 50-58, EF2 as 60-100; the stability index SI as 0-1 and the relative aggregation indices were RSI 0-11. It has been determined that the surface soils of all plots in the study area were sensitive to wind erosion, and that some plots were more sensitive.

Keywords: Wind erosion area, dry sieving, erodible fraction, stability indices, GIS mapping.

1. INTRODUCTION

Strong winds and insufficient soil properties (low organic matter, low soil moisture, insufficient surface cover) are the factors that make wind erosion inevitable in arid and semi-arid region soils. Wind erosion is an environmental problem that has negative effects on health, agriculture, economy, and ecosystem (Dahmardeh et al., 2019). Especially its affects the agricultural sector as it decrease in land productivity and agricultural products, a rise in water scarcity, and a deterioration in quality and yield of pastures (Sadeghi Ravesh et al., 2012).

In order to reduce and prevent wind erosion, determining land characteristics and land sensitivity is considered to be a very important step. Different tools and techniques have been proposed to investigate the different aspects and consequences of wind erosion, such as remote sensing, data mining, and sediment fingerprinting to well identify regions prone to generating wind erosion (Collins et al., 2020). However, these techniques require extensive field sampling and expensive laboratory analysis (Gholami et al., 2020a) and are not effective for very large areas (Gholami et al., 2020b).

The mapping of different studies carried out in areas where wind erosion occurs and the use of different methods for this is quite common. It is an important method to reveal the extent and effects of erosion. The areas where wind erosion is effective in heavily textured soils and their sizes were determined and mapped using meteorological data (Dufková & Podhrázská, 2011). Kilic (2021), with the help of GIS, calculated and mapped the changes in water erosion in the Almus lake basin between 1990 and 2018.

At each level of wind erosion studies, dry aggregate sizes (0.84 mm; 0.106 mm), their distribution in percent and as a result of these the percentage of erosive material (EF) are necessary and important. It is an accepted finding that soil particles larger than 0.84 mm in diameter are resistant to wind erosion (Chepil, 1953). On the other hand, particles moved by the wind can reach up to 1 mm in diameter, however particles transported over long distances are usually smaller. The saltation is the bouncing of soil particles with a diameter greater than 106 µm at the surface, and erodes inert surface clods and crusts. As long as the saltation continues, new bouncing, drifting and suspended (<0.106 mm) particles are created through the transfer of kinetic energy (Hagen et al., 2010) and wind erosion continues when the strong wind is effective. The saltation is an important process of wind erosion in production of suspended particles (PM10) with aerodynamic diameters less than 10 µm and poses a risk to human health (Ono, 2006; Zobeck & Van Pelt, 2006) and spreads of dusts (Shao, 2001; Hagen et al., 1999).

The wind transport capacity for suspended sediments is much greater than the transport capacity for bouncing sediments. Therefore, portions of sediment carried in airborne particles on large erosive surfaces increase downwind and can easily exceed the amount of bouncing sediments (Gillette et al., 1997). The percentage of particles smaller than 0.020 mm obtained from the dry sieving results is significant. As wind erosion continues, the amount of suspended particles will increase.

The American Environmental Protection Agency (USEPA) required the amended Clean Air Act (CAA) in 1990 to establish the National Environmental Air Quality Standards (NAAQS). These standards impose limitations on airborne pollutants, including dust that is considered harmful to public and environmental health. The standards have been developed to protect public health and well-being and to include protection against low visibility that harms animals, crops, plants, and structures (USEPA, 2022). The amount of mineral dust emission as a result of wind erosion in arid and semi-arid regions has been reported as 1-3 million tons per year (IPCC, 2001). These mineral dusts add approximately 30-50% ($g \cdot g^{-1}$) total aerosol to the troposphere (Andreae, 1995). Many studies on this subject have been carried out on total airborne dust smaller than 0.020 mm. As NAAQS deals with PM10, recent studies have been conducted on PM10 emissions (Gillette et al., 1997; Saxton et al., 2000; Gomes et al., 2003; Ono et al., 2004; Kjelgaard et al., 2004, Van Pelt et al., 2019).

The equations proposed to determine the wind erosion susceptibility of the soils aimed to provide information about the resistance of the studied soils. Some of those were presented by different researchers, such as stability index (SI) by Chepil's (1957), erodible fraction (EF1) by Fryrear et al., (1994), erodible fraction (EF2) by Zobeck et al., (2003), relative stability index (RSI) by Avecilla et al., (2015).

The second largest wind erosion area in Türkiye is spread over an area of 135542 decares within the borders of the Aralık district of Iğdır province (Özdoğan, 1976). It extends from the skirts of Mount Ararat to the centre of the Aralık district, in a strip of approximately 8 km in width and 20 km in length (Çelebi, 1981). Studies have been carried out to determine the surface and profile soil properties, the amount of erosive material and the estimated soil losses in the erosion area (Karaoğlu et al., 2017; Sevim, 1999; Sevim & İstanbulluoğlu, 1985; Çelebi, 1981).

In this study, which was carried out on 54 surface soil samples collected at 1 km^2 intervals from the 40 km^2 section of the wind erosion area with a slope of less than 6% and more susceptible to abrasion; elevation, slope, % silt, >0.84 mm, 0.106 mm and <0.020 mm maps were created by GIS method from the data obtained from analysis and dry sieving.

2. MATERIAL AND METHOD

2.1. Material

2.1.1. Study site

The climate features of Aralık-Iğdır wind erosion area are as follows: Annual average temperature is 12.9°C, annual total precipitation is 244.2 mm, annual average relative humidity is 58%, annual potential evapotranspiration amount is 1094.9 mm, and annual average wind speed is 5 km h^{-1} (Karaoğlu, 2012). The wind data (MGM, 2023) which is taken from Automatic station installed in Aralık-Iğdır in 2014 are given in Table 1.

Table 1. Aralık-Iğdır wind data (m sec^{-1}).

Month/Year	1	2	3	4	5	6	7	8	9	10	11	12
2014	1.1	1.2	2.1	1.9	1.7	2.2	1.9	1.7	1.7	1.2	0.9	0.9
2015	1.4	1.2	1.5	2.1	1.6	1.9	2.2	1.5	1.3	1.0	1.1	1.0
2016	1.4	1.2	2.1	1.8	1.8	2.0	2.5	1.8	2.1	1.2	1.0	1.5
2017	1.1	1.0	1.5	2.1	2.0	2.4	2.0	1.7	1.4	1.3	1.0	1.0
2018	1.2	1.2	2.0	1.9	1.6	1.6	2.0	2.0	1.5	1.3	1.0	1.3
2019	1.4	1.5	1.8	1.6	1.6	1.8	2.5	2.2	1.6	1.0	0.7	0.9
2020	1.1	1.7	1.7	1.7	2.0	1.9	2.0	1.8	1.5	0.8	1.1	0.9
2021	0.9	1.6	2.1	2.0	1.9	2.2	2.0	1.7	1.8	1.2	0.9	1.1
2022	1.3	1.4	2.5	1.9	2.3	2.2	2.6	1.8	1.8	1.3	0.9	0.9

In the Aralık-Iğdır wind erosion area, which has the lowest annual precipitation in Turkey, monthly average wind values are higher in the March-October period and in this period wind erosion is effective.

The sampling area is 5 km wide and 9 km long. With the help of Netcad 7.6 program, 54 sampling point of 1 km^2 grid display on Google Earth between 44.54-44.58 west longitude and 44.47-44.51 east longitude and 39.77-39.80 north latitude and 39.82-39.85 south latitude, where wind erosion is most common (Karaoğlu et al., 2017), were identified (Figure 1). In the Aralık-Iğdır wind erosion area, which has the lowest annual precipitation in Türkiye, monthly average wind values are higher in the March-October period and this period is the period when wind erosion is effective.

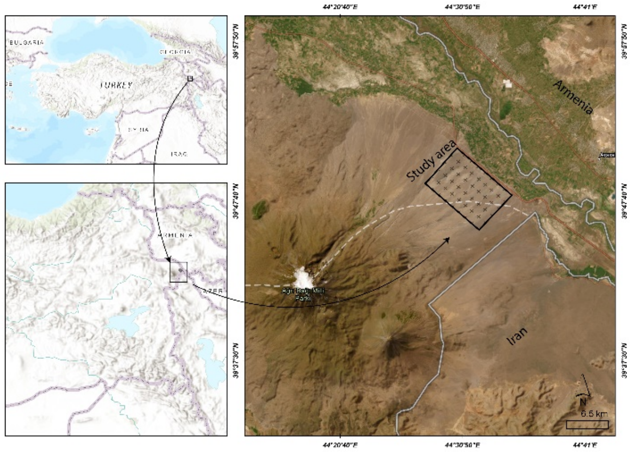

Figure 1. Study area and sampling points.

2.2. Method

2.2.1. Soil sampling, soil physical and chemical analyses

The coordinates of the selected points were loaded onto the Leica Viva CS15 GPS device and a total of 54 soil samples in each was 500 gr were collected, their exact location in the field and from 0-5 cm depth (Li et al., 2009), which is the most important depth in terms of wind erosion.

Some of the disturbed soil samples were sieved through a 2 mm sieve and physical and chemical analyses were done. Soil texture was analysed with Bouyoucus hydrometer method (Gee & Bauder, 1986); soil reaction (pH) was measured in a 1:2.5 soil-water suspension potentiometrically with a "Glass Electrode" pH meter (McLean, 1982); carbonates were determined with Scheibler Calcimeter as volumetric (Nelson, 1982); organic matter was analysed according to the Walkley & Black method (Walkley & Black, 1934); electrical conductivity was determined with electrical conductivity instrument (Demiralay, 1993).

2.2.2. Dry sieving processes

Aeolian events in arid and semi-arid regions occur during the driest periods. For this reason, dry screening is essential in wind erosion studies (Chepil, 1962). This process was carried out with a Rotar Sieve in previous studies, and it is still in use. However, with the development of vibrating sieving tools, speed and save of time in these studies and ease of working on soils with sand texture have been achieved. Dry sieving process was applied to 100 g of degraded soil samples taken from 54 points with a Retsch AS 200 basic vibrating dry sieving device (Karaoğlu et al., 2017). The apertures of the sieves were 4, 2, 1, 0.840, 0.420, 0.106- and 0.020-mm. Vibration intensity of 50 Hz and 5-minute sieving time was applied in all sieving processes.

2.2.3. Equation related to erosion

The material at the top (0-5 cm) of the soil is defined as erodible fraction by the wind (EF). Erodible fraction (EF) is the percentage of particles smaller than 0.84 mm and are considered to be sensitive soil particles that can be carried by the wind (Chepil, 1942). EF is used by the wind erosion equations WEQ (Woodruff & Siddoway, 1965) and RWEQ (Fryrear et al., 2000) as a potential erosion index. The EF value varies as a function of soil texture (Lyles & Woodruff, 1960), organic matter content (Chepil, 1955), and the amount of free $CaCO_3$ (Chepil, 1954). The effect of percentage clay and organic matter on aggregate formation, which will reduce all kinds of erosion in the soil and keep it at tolerance values, is defined as the relative stability index (RSI) (Avecilla et al., 2015).

Stability index (SI)

The equation for the stability index (SI) developed by Chepil (1957) were given below:

$$SI = \left(\frac{A}{B}\right) \quad (1)$$

where SI is stability index, A percentage of non-eroding dry material (>0.84 mm), and B the percentage of dry erodible material (<0.84 mm). If the ratio of the percentage of erosion-resistant material to the percentage of non-resistant material is less than 1.5, the sampled soil is defined as non-resistant to weathering, and if it is more than 1.5, it is defined as resistant.

Erodible fraction percentage (EF)

To determine the amount of erodible fraction EF1 as a percentage,

$$EF1 = 29.9 + 0.31Sand + 0.17Silt + \frac{0.33Sand}{Clay} - 2.59OM - 0.95CaCO_3 \quad (2)$$

(Fryrear et al., 1994) and for EF2,

$$EF2 = (W_{<0.84}/TW)\ x\ 100 \quad (3)$$

(Zobeck et al., 2003) equations were used and the erosion susceptibilities of the samples were investigated. Where EF is the amount of erodible fraction (g), OM is organic matter (%), $CaCO_3$ is carbonate (%), $W_{<0.84}$ is the amount of material (g) less than 0.84 mm, and TW is the total weight of the soil sample.

Relative stability index (RSI)

The use of clay (≤2 μm) and organic matter percentages in the development of the relative stability index is based on the idea that these materials are the main factors affecting aggregation in the soil

(Mirzamostafa et al., 1998; Perfect et al., 1995). The equation developed to determine the relative stability index as a function of the amount of clay and organic matter given by Avecilla et al., (2015) is following:

$$RSI = Clay\% \, x \, OM\% \quad (4)$$

where clay% is the percentage of soil material <2 µm, and OM% is the organic matter content of the soil.

2.2.4 Creation of maps

Using the data obtained from field surveys, physical and chemical analyses, and dry sieving processes; maps of contour, slope%, silt%, >0.84 mm, 0.106 mm of the sampled part of the surface soils of the wind erosion area were created. Geographic information system (GIS) technologies were used to obtain the maps, and ArcGIS 10.4.1 software was used to produce the base maps.

In this study using 1:25,000 scaled I52b3-I53a4 maps of the General Command of Mapping, contour lines with 10 m intervals were digitized. From these digitized contours, a Digital Elevation Model (DEM) was produced using the "topo to raster" in the "Spatial analyst" tool in ArcGIS software and using the "slope" tool in the "raster surface" from this generated DEM data the slope map was created. In addition, as a result of field studies, the results obtained from 54 different sampling areas were modelled based on the "spline interpolation" method by providing data entries in the ArcGIS environment. Spline interpolation method emerges as a method that is used to estimate the approximate value of unknown points within a defined area of data with variable values at different intervals and provides the creation of continuous surfaces (Aktaş & Yılmaz, 2013; Akyürek et al., 2013).

3. RESULTS AND DISCUSSION

3.1. Results of physical and chemical analyses

The physical and chemical analysis results of the surface (0-5 cm) soils are given as the lowest and highest values for rows A, B, C, D, E and F in Table 2 due to the excessive data on texture classes.

The surface soils are sandy, loamy sandy, sandy loam (S-LS-SL), with very low clay percentages (0-6%). In some plots (4-46%) percentage of silt is high but in the entire study area (54-96%) percentage of sand is high. Karaoğlu et al. (2017) determined the percentages of clay, silt, and sand on topsoil (0-10 cm) samples in the same region as 4-13, 5-26, 64-86, respectively and texture classes as SL-LS. Sevim (1999) reported the texture classes of the surface soils of 18 profiles as S-LS-SL. Sevim & İstanbulluoğlu (1985) explained the percentages of clay, silt and sand of the surface soil samples (0-2.5 cm) from 17 profiles on two lines sampling the erosion area 5-7, 5-13, 81-87, respectively and texture classes as S-LS. Çelebi (1981) declared the percentages of clay, silt, and sand of surface soil (0-2.5 cm) samples taken from 12 points in the Dil State Breeding Farm (Kazım Karabekir Agricultural Business Management) land 4-11, 9-18, 76-85, respectively and texture classes as LS. In all the studies carried out in the area, the surface soils were found to be poor in clay content, variable in silt and high in sand. Sandy loam (SL) and sandy (S) soils with insufficient organic matter content form weakly bonded aggregates and are more susceptible to erosion.

Mostly fine-textured soils form solid and resistant aggregates against wind erosion. Any dry and fragmented soil is susceptible to wind erosion. As a result, the order of particles resistant to displacement is clay>silt>fine sand (Blanco & Lal, 2008).

The carbonate% ($CaCO_3$) content of the soil samples is between 4-8 and it is moderately calcareous (Aydın and Sezen 1995). The percentages of carbonate were found by Karaoğlu et al., (2017) as moderate and high values between 4-27, by Sevim & İstanbulluoğlu (1985) as low values between 1-4, by Çelebi (1981) as low and moderate values between 0-10. Organic matter (OM) percentages were between 0.2-2.4 and were between extremely low and medium values (Güçdemir, 2008). The percentages of organic matter were determined by Karaoğlu et al., (2017) as 0.3-1.2%, by Sevim & İstanbulluoğlu (1985) 0.8-1.2% and by Çelebi (1981) as 0.8-2.0. In the studies carried out in the field to date, the percentages of

Table 2. Results of physical and chemical analyses

S.P.	%					Texture	pH	EC
	Clay	Silt	Sand	Carbonate	O.M.			
A1-A9	0-6	8-46	54-92	4-6	0.3-1.4	S-LS-SL	8.4-9.1	0.06-0.12
B1-B9	0-2	2-29	69-96	4-6	0.5-0.9	S-LS	8.4-9.0	0.04-0.10
C1-C9	0-1	4-33	66-95	5-7	0.5-0.8	S-LS	8.0-8.9	0.06-0.09
D1-D9	0-6	5-24	74-94	4-7	0.4-1.4	S-LS	8.3-8.7	0.03-0.08
E1-E9	0-4	2-16	81-97	4-6	0.7-1.1	S-LS	8.0-9.0	0.05-0.09
F1-F9	0-6	8-24	70-90	5-8	1.3-2.4	S-LS-SL	8.1-8.9	0.06-0.09

S.P.: Sampling points; O.M.: Organic matter; pH: Soil reaction; E.C.: Electrical conductivity (mS/cm);

carbonate and organic matter have been found variable and low, respectively. It is known that carbonate and organic matter protect soils against erosion by increasing aggregation (Taysun et al., 1984), and organic matter is the most effective soil feature on soil erosion (Wischmeier & Mannering, 1969). Most of the soils in the world contain less than 1.5% organic matter, and the majority of sand and sandy loam soils contain less than 2% (Morgan, 2005). Soils with less than about 2% organic content can be considered erosive (Evans, 1980). In general, the susceptibility of soils to erosion decreases with the increase in the percentage of aggregate stability (Tate, 2000). It has been reported that the dominant aggregates in agricultural lands are smaller than those in natural areas, and that agricultural lands have a more sensitive structure against erosion due to the decrease in aggregate diameter and stability (Taysun, 1986). The pH values of the surface soils varied between 8.0-9.5, and they were moderately to strongly alkaline (Weil & Brady, 2017). In previous studies, values of pH have been measured by Karaoğlu et al. (2017) 7.4-8.2, by Sevim & İstanbulluoğlu (1985) 7.4-8.0, by Çelebi (1981) 7.0-7.3. Consequently, the pH values measured up to now in the erosion area ranged between neutral and strongly alkaline. Soil reaction is effective on the availability of nutrients (Sönmez, 2013) and the amount of toxic substances formed in the soil. As a result, it is a soil chemical property that controls plant growth and microorganism activities (Ergene, 2012). The pH values required by the plants for optimal development are different. For example, while plants such as barley, tobacco, and clover are sensitive to acid conditions, plants such as oats, potatoes, and tea tolerate acid conditions (Güneş et al., 2007). All of the electrical conductivity (EC) values (0.03-0.12 mS cm^{-1}) of the soil samples were low and the soils were salt-free soils. Karaoğlu et al., (2017), Sevim & İstanbulluoğlu (1985) and Çelebi (1981) have found EC values as 0.0-0.3, 0.9-2.4, 0.1-0.6, respectively. In the erosion area, EC values measured hitherto were low and sampled soils were salt-free (Richards, 1954), and only suitable for the productive growth of some limited plant species (Aydemir, 1992).

3.2. Results of dry sieving findings

Dry sieving findings of surface (0-5 cm) soils of the study area for 4, 2, 1, 0.84, 0.42, 0.106, 0.020 and <0.020 mm sieve apertures as percentage and the lowest and highest values for rows A, B, C, D, E and F were given in Table 3.

Surface soil samples, which were subjected to dry sieving process, have very low percentage values of 4, 2, 1, 0.84 and 0.42 mm on the sieve. While the coarse material (0-14%) on the sieve with 4- and 2-mm diameters has no direct significance in terms of wind erosion, it increases the total material value greater than 0.84 mm, in other words, it increases the percentage of material resistant to wind erosion. On the 1 mm diameter (1-2 mm) sieve material (0-14%) is important for wind erosion as it moves by rolling and sliding on the ground. Aggregates with this diameter can be eroded by transferring their kinetic energy of the bouncing particles and can be made into an erosion-resistant material. It is a well-known and accepted finding that soil aggregates greater than 0.84 mm in diameter are resistant to wind erosion (Chepil, 1953). Aggregate percentage values greater than 0.84 mm obtained in the study were quite low (0-41%) except for a few plots, and thus a large part of the study area was susceptible to wind erosion. Similar results in previous studies were found by Karaoğlu et al., (2017) as 1-31%, by Sevim (1999) as 11.4-29.6%, by Sevim & İstanbulluoğlu (1985) as 11-30%, by Çelebi (1981) as 13-54%. The percentage of material on the 0.42 mm diameter sieve (0.42-0.84 mm) was found to be between 0-21. Although these values are low, particles between 0.1-1 mm will contribute to the amount of material that makes splashing movement due to the splashing movement (Fryrear, 1995) and will increase the wind erosion damage. The 0.42 mm sieve values obtained in all studies in the erosion area were similar to each other, such as Karaoğlu et al., (2017) 4-25%, Sevim & İstanbulluoğlu (1985) 6-15%, Çelebi (1981) 4-22%.

Table 3. Results of dry sieving

S.P.	%									
	4 mm	**2 mm**	**1 mm**	**0.84 mm**	**∑>0.84**	**0.42 mm**	**0.106 mm**	**0.02 mm**	**<0.02 mm**	**∑<0.84**
A1-A9	0-12	0-5	0-9	0-2	0-23	0-17	46-64	8-41	0-8	77-100
B1-B9	1-9	1-7	2-11	1-4	5-28	7-18	46-73	3-33	0-8	72-95
C1-C9	1-14	2-9	2-14	0-9	7-41	4-14	39-77	6-14	0-6	59-93
D1-D9	0-6	1-8	3-11	0-5	8-25	6-19	49-73	4-13	0-3	75-92
E1-E9	0-13	2-8	5-11	0-4	13-26	3-21	51-69	2-14	0-2	74-87
F1-F9	1-12	2-11	4-10	0-2	15-30	9-20	39-61	10-20	0-1	70-85

S.P.: Sampling points.

The percentage of material on the 0.106 mm sieve is quite high, varying between 39-77. Karaoğlu et al., (2017) determined it as 38-73% in the same region. Particles larger than 0.106 mm in aggregate diameter make a saltation during wind erosion. In other words, these materials will trigger wind erosion by saltation as long as the strong wind continues. After the saltation begins, the immobile surfaces of the clods and crusts are eroded. As long as the saltation continues, new bouncing, drifting and suspended (<0.106 mm) particles are created through kinetic energy transfer (Hagen et al., 2010).

The percentage of material on the 0.02 mm sieve was found to be between 3-41 and <0.02 mm material percentage between 0-8. These values were determined to be high in some plots (Figure 7) and it was understood that these amounts will continue to increase due to abrasion as long as erosion continues. Karaoğlu et al., (2017) found that on the 0.02 mm sieve values between 14-49% and <0.02 mm sieve values between 1-7%. Particles that travel very long distances with the wind are smaller than 0.1 mm (Fryrear, 1995) and fine dust particles (<0.02 mm) have a low settling velocity even at low wind speeds (Gillette, 1981). In other words, they stay suspended in the air longer. The finest particles of mineral dust are less than 0.02 mm in diameter and can remain suspended in the atmosphere for more than a week and can be transported thousands of kilometres from their source. This mineral dust emission has many effects, such as the decrease in nutrients in the soil, the emergence of health hazards for the local population as a result of inhalation of silicon-rich particles, the occurrence of traffic problems as a result of reduced visibility and the effect on climate change by causing mixing of wavelengths in heat transfer (Alfaro, 2008).

Airborne dusts are evaluated in different sizes. Aerosols with an average aerodynamic diameter of less than 0.1 mm are called PM10 and aerosols with an average aerodynamic diameter less than 0.025 mm are called PM2.5. PM10 and PM2.5 dusts those can penetrate the lungs through inhalation and cause health problems. Although many pollutants are from industrial and other human sources, geological minerals are a significant contributor to airborne particles. Particles composed of geological minerals can have many sources and threaten the health of humans and animals, depending on any material retained on the surface of the particles and the size and geochemistry of the particles (Zobeck & Van Pelt, 2005).

3.3. Erodibility of soils

The values obtained by using the equations developed to determine the amount of material (<0.84 mm) that can be eroded by the initial effect of strong winds were given in Table 4 as the lowest and highest values for rows A, B, C, D, E and F due to excessive data. According to the stability index (%SI) values used to determine the resistance status of the soil material subject to wind erosion, it was determined that all sampled soils were not resistant to erosion. Similarly, Sevim & İstanbulluoğlu (1985), and Çelebi (1981) found that the %SI values of all surface soils that they applied dry sieving process were less than 1.5 and not resistant to erosion. Equation for erodible fraction EF1 (Fryrear et al., 1994) that considers soil texture as a function of reducing resistance, the organic matter and carbonate content as a function of increasing resistance values as 50-58%; equation for erodible fraction EF2 (Zobeck et al., 2003) which considers the total erodible fraction (∑<0.84 mm) as a function of reducing resistance values as 60-98%. Although the %EF1 values were not very high, the particles that transfer their kinetic energy to the soil by saltating in wind erosion increase the amount of particles sensitive to erosion by eroding other materials on the ground (Fryrear, 1995). As long as the wind erosion events that occurring with the effect of strong winds continue, these values will increase

Table 4. Erodibility of soils

S.P.	%SI	Meaning	%EF1	Meaning	%EF2	Meaning	%RSI	Meaning
A1-A9	0.0-0.3	E	50-58	SE	76-98	E	0-5	E
B1-B9	0.1-0.4	E	53-58	SE	71-95	E	0-2	E
C1-C9	0.1-0.7	E	54-58	SE	60-94	E	0-1	E
D1-D9	0.1-0.3	E	54-58	SE	75-91	E	0-7	LR
E1-E9	0.1-0.4	E	54-58	SE	66-86	LR	0-4	E
F1-F9	0.1-0.4	E	52-55	SE	72-85	LR	0-11	LR
r	0.98		-0.22		1		0.23	

S.P.: Sampling points; SI: Stability index; EF1, EF2: Erodible fraction; RSI: Relative stability index. E: Erodible; SE: Semi Erodible; LR: Low Resistible.

even more. Karaoğlu et al., (2017) found EF1 and EF2 values as 31-60 and 69-99, respectively. Relative stability index (RSI) was calculated at very low percentages (0-11) in the study area as a function of low clay content and insufficient organic matter. These values mean that the aggregation of the sampled soils of the erosion site is weak and therefore the resistance to wind erosion events is weak (Avecilla et al., 2015).

3.3.1. Dry sieving relations with erosion equations

The statistical relationships between the dry sieving values and the erosion equations were differed. Positive high correlation (r=0.98) between %SI based on dry sieving data and ∑>0.84, and a positive high correlation (r=1) between %EF2 based on dry sieving data and ∑<0.84 were found. Positive low correlation (r=0.23) between %RSI based on soil physical and chemical data and ∑>0.84, and negative low correlation (r=-0.22) between %EF1 based on soil physical and chemical data and ∑<0.84 were determined. In conclusion, the results obtained with the %RSI and %EF1 equations are not compatible for the Aralık-Iğdır wind erosion area soils. Dufková et al., (2021) found a low correlation between %EF1 and <0.84 mm and suggested a different equation for the Czech Republic.

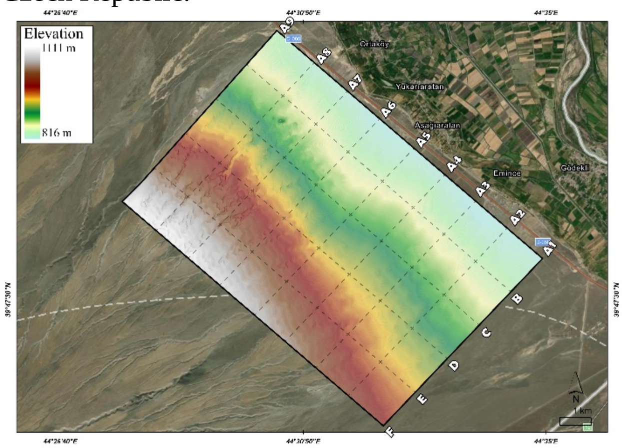

Figure 2. Study site elevation map

3.4. Maps

The contour map of the study area was given in Figure 2. The elevation rises from the Iğdır-Nahcivan State highway to Mount Ararat, in other words, from north to south. There is an elevation difference of approximately 200 m at a horizontal distance of 5 km.

The slope (%) map of the study area is given in Figure 3. The slope map is similar to the elevation map, and the slope values vary between 0-6% from north to south. The riskiest areas in terms of wind erosion are located between A1-B9 and C1-D2 points with 0-2% slope values.

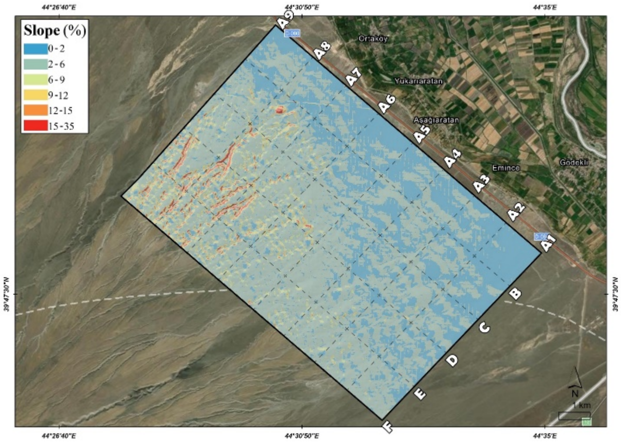

Figure 3. Study site slope (%) map

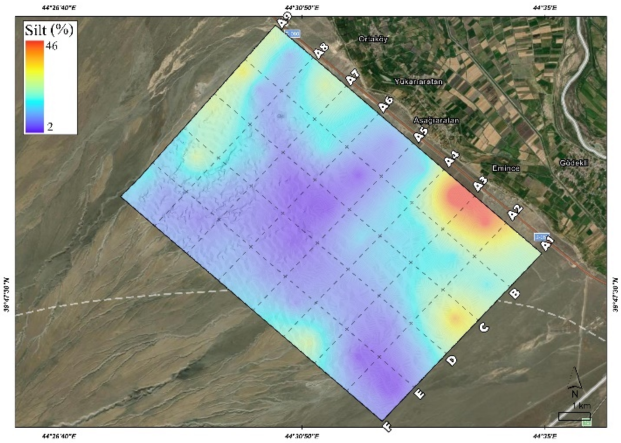

Figure 4. Study site silt (%) map

The surface (0-5 cm) silt (%) map of the soils sampled and physically analysed in the study area was presented in Figure 4. Silt values were selected for the texture map. The reason is that the silt material is more susceptible to erosion and the size of particles that trigger erosion by saltation especially in wind erosion processes and silt sizes are the same values. The plots with the highest silt percentages are between the points A1-C3 on the silt map. These plots are more susceptible to wind erosion.

In dry sieving processes, the 0.84 mm sieve material percentages indicate the amount of particles resistant to wind erosion. In the map given in Figure 5, the riskiest plots in terms of wind erosion were the points A2-A3, C1-D2, A5-A9, B8-C9 and D9. Karaoglu et al., (2017) calculated the estimated erosion losses determined by the wind erosion equation (WEQ) as 48.17 t ha-1 year-1 for the A2-A3 parcels.

The second important material size in dry sieving processes is 0.106 mm sieve values, which cause saltating and trigger erosion as long as the strong wind continues. In Figure 6, although the entire sampling area has high percentage values, B1-C1, D1-D3, C7-D9 plots stand out as the riskiest regions.

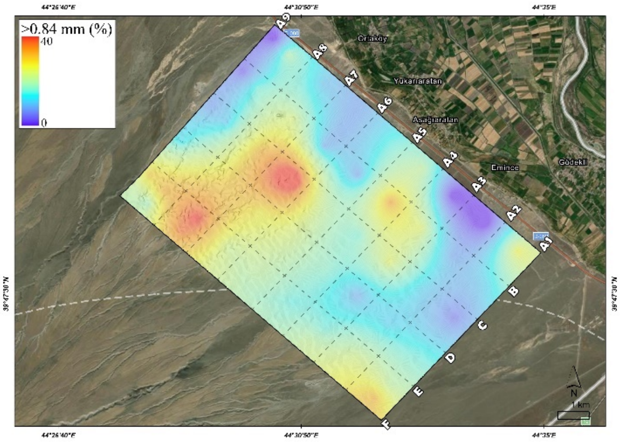

Figure 5. Study site >0.84 mm (%) map

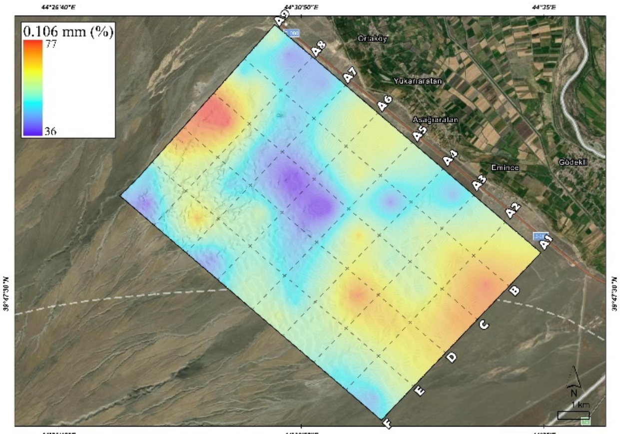

Figure 6. Study site 0.106 mm (%) map

Another important material size in dry sieving processes is the 0.020 mm under-sieve aerosol amount, which can be suspended in the air and can travel long distances as long as the strong wind continues and can cause negative health problems on living organisms, especially respiratory tracts. In Figure 7, plots A2, A3, A7, B2C3, D2 have high percentage values and appear as potential aerosol generating areas.

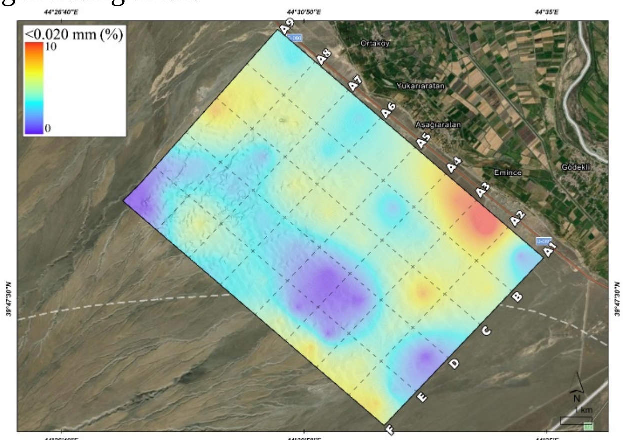

Figure 7. Study site <0.020 mm (%) map

The maps obtained with the values calculated using the equations expressing the stability indices are presented in Figures 8-11. The stability index (SI) map is shown in Figure 8. SI values are low in all plots, and they are not resistant to wind erosion.

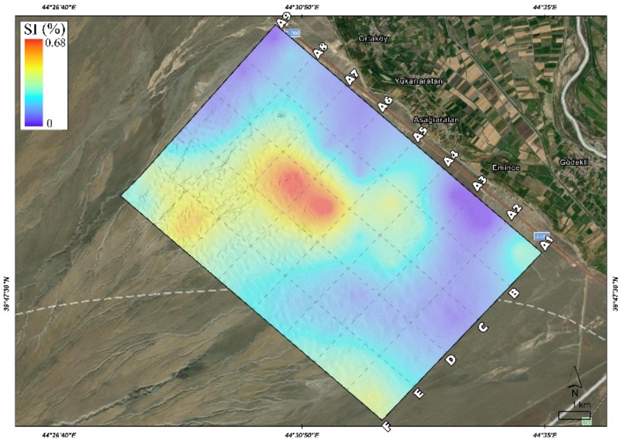

Figure 8. Study site SI (%) map

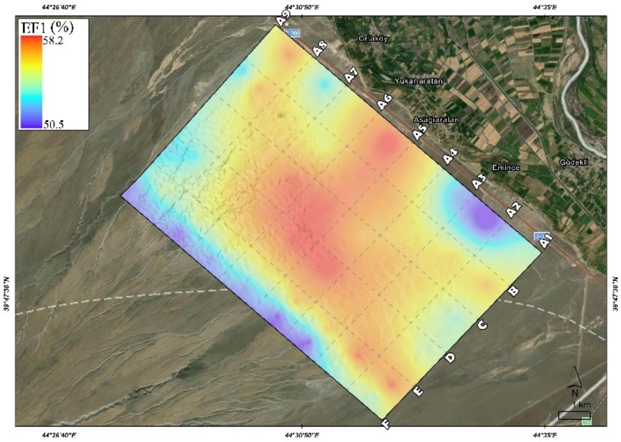

Figure 9. Study site EF1 (%) map

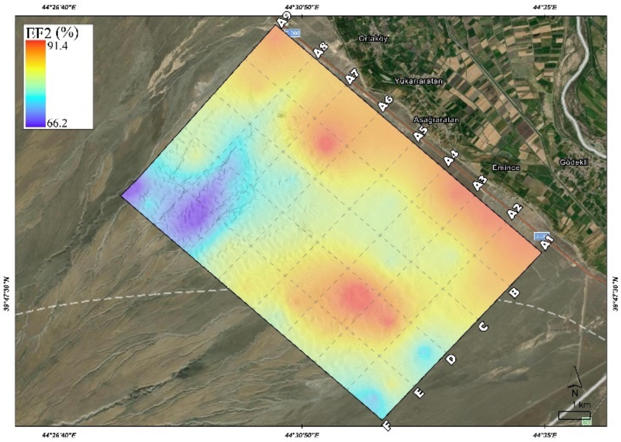

Figure 10. Study site EF2 (%) map

The map of erodible fraction (EF1), which is a function of soil properties, was given in Figure 9. In the A1-A3 plots, which are known as the least resistant plots, the percentages of erodible fraction were low. This showed that the EF1 equation was not compatible for the Aralık-Iğdır wind erosion area.

The map of erosive material (EF2), which is a function of dry sieving results, is shown in Figure 10. All values are high and are not resistant to erosion and transport events due to the effect of strong winds.

The relative stability index (RSI) map, which is a function of clay and organic matter, was given in Figure 11. The calculated values were found to be low for all plots with low clay and organic matter content, that is, no resistance.

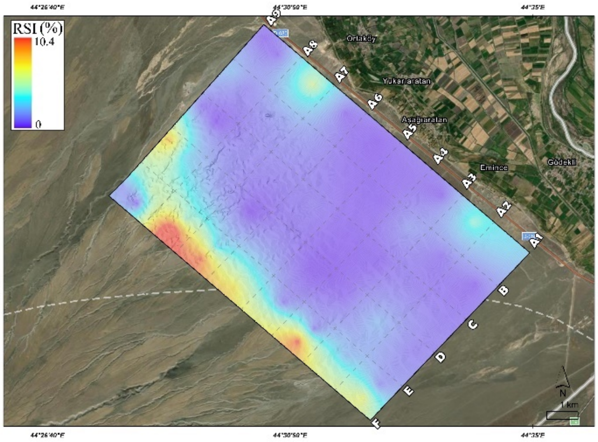

Figure 11. Study site RSI (%) map

4. CONCLUSION

The study of determining and mapping the characteristics of surface soils in terms of wind erosion carried out in a 40 km^2 section of Aralık-Iğdır which is the second largest wind erosion area of Türkiye showed similar results with previous studies (Karaoğlu et al., 2017; Sevim, 1999; Sevim & İstanbulluoğlu, 1985; Çelebi, 1981).

Although the percentages of erosive materials are low in some of the plots where the study is conducted, the risk of wind erosion is high in the field and continues to increase due to reasons, such as not taking protective precautions, not maintaining the precautions taken before, destruction of vegetation, overgrazing and animal movements.

In this study, unlike the others, the data obtained were mapped and the wind erosion potential was presented visually. These maps will facilitate direct wind erosion measurement studies in the field, which has been initiated and where new studies are planned in the future.

The fastest, easiest, and most economical protection precaution that can be applied in the wind erosion area is the protection and reproduction of the region-specific Ephedra *distachya* L. and the addition of organic matter. Other precautions may include creating protected parcels surrounded by windbreaks on all four sides that will not allow the formation of wind erosion, increasing the resistance of the soil by encouraging soil aggregation, and ensuring that the residents of the region own the land.

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