University of Tehran Press

Online Issn: 475-2345X

DESERT

Home page: https://jdesert.ut.ac.ir/

Monitoring the Areas of Dust Production and Assessing the Damages Caused by This Phenomenon to the Agriculture Sector (Case study: Alborz Province, Iran)

Katayoon Hojati[1], Zahra Abedi[1*], Behzad Rayegani[2], Mostafa Panahi[3]

[1] Environment and Natural Resources Faculty, Islamic Azad University, Tehran, Iran. Email: z.abedi@srbiau.ac.ir
[2] Research Group of Environmental Assessment and Risks, Research Center of Environment and Sustainable Development (RCESD), Department of Environment, Tehran, Iran.
[3] Environment and Natural Resources Faculty, Islamic Azad University, Tehran, Iran.

Article Info.

Article type:
Research Article

Article history:
Received: 24 Dec. 2022
Received in revised from: 28 Feb. 2023
Accepted: 11 March 2023
Published online: 27 June 2023

Keywords:
Index of Land Susceptibility to Wind Erosion (ILSWE),
Contingent valuation method (CVM),
Remote Sensing,
Willingness to Pay (WTP).

ABSTRACT

In recent years, the dust phenomenon has become one of the most important environmental challenges throughout the world, and one of its negative effects is on the agriculture sector. The aim of this research is first to determine dust emission sources in Alborz Province and then to estimate the willingness to pay (WTP) for reducing the effects of dust on the agriculture of dust emission sources and their surrounding areas. The Index of Land Susceptibility to Wind Erosion (ILSWE) was used to determine dust emission sources. ILSWE consisted of the combination of 5 effective factors in wind erosion, namely climate erosivity, soil erodibility, soil crust, vegetation cover, and surface roughness. In the next step, according to the produced map of dust emission sources, the affected rural districts were identified, and then using the contingent valuation method (CVM), individuals' WTP for preventing and reducing the negative impacts of the dust phenomenon on the agriculture was calculated by 400 questionnaires. According to the results, the classification map of ILSWE indicated that while classifying the areas in terms of their sensitivity to wind erosion 7.8% of the study area was placed in the very high sensitivity class. This class was considered the center of dust production, which was located chiefly in the southern parts of Alborz Province. Using the CVM method, the expected value rate and the WTP were calculated as 1654231 Rials (approximately $ 5.5). According to the population of the affected area, the total value of protecting the agricultural products against dust phenomenon is 27433766904 Rials ($91445.89) annually.

Cite this article: Hojati, K., Abedi, Z., Rayegani, B., Panahi, M. (2023). Monitoring the Areas of Dust Production and Assessing the Damages Caused by This Phenomenon to the Agriculture Sector (Case study: Alborz Province, Iran). DESERT, 28 (1), DOI: 10.22059/jdesert.2023.93543

Publisher: University of Tehran Press

1. Introduction

One of the impacts of desertification and land degradation, particularly in arid and ultra-dry lands of the world is dust storm (Jebali *et al.*, 2021). This phenomenon occurs due to strong winds and as a result of separating unstable and fine particles from the soil surface (Rayegani et al., 2020). East Asia, the Middle East, Australia, and North Africa are the main sources of dust storms throughout the world (Shao *et al*., 2013). In various studies, the annual amount of dust entering the atmosphere is estimated at 100 to 10000 tons/year (Shao, 2008). Although a significant amount of dust emitted settles in the oceans (Ashrafi *et al*., 2017), dust is the most abundant airborne particulate in the atmosphere (Albugami *et al*., 2019). Iran, Iraq, Saudi Arabia, Syria and Egypt are the main areas of dust emission in the Middle East (Shao *et al*., 2011; Rayegani, 2019). The extent of dust production resources in the Middle East is estimated one million Km^2 (Papi *et al*., 2022). The studies indicate that the frequency of dust phenomenon occurrence in the Middle East has increased (Alizadeh-Choobari *et al*., 2016). Drought is one of the most chronic and harmful natural disasters (Khosravi *et al*., 2016) and dust is one of its negative effects. Iran has experienced numerous dust events due to dry weather and (Nasabpour *et al*.,2017) due to meteorological droughts and consequently hydrological droughts and agriculture droughts (Ebrahimpour et al., 2015; Rayegani et al., 2017; Darand & Sohrabi, 2018; Manesh *et al*., 2019; Ebrahimi Khusfi *et al*., 2020;), leading to significant negative consequences on socio-economic conditions (Mirmousavi, 2016). Occurrence of the dust phenomenon in one area depends on some factors, such as wind speed, area of soil without cover (Mei *et al*., 2008; Rayegani *et al*; 2017), soil moisture, amount of vegetation cover (Huang t al., 2006; Effati *et al*., 2019; Rayegani *et al*., 2020), intensity and extent of de-desertification, intensity and duration of drought, land use changes, and human activities (Qu *et al*., 2006; Rayegani *et al*., 2015). This phenomenon imposes negative socio-economic, health, and environmental impacts on vulnerable areas and reflects their sources' physiochemical and biological characteristics (Middleton & Kang, 2017; Tajiki *et al*., 2021; Sorkheh *et al*., 2022; Mohammad Asgari *et al*., 2023) and dealing with it requires multilateral approaches, including policy, ecosystem management, economy, and capacity building. Therefore, the correct identification of dust production sources is regarded as one of the first steps in managing and controlling the dust phenomenon. The most advanced models like field-scale wind erosion prediction systems (WEPS) are too complex to achieve appropriate and acceptable results (Fenta *et al*., 2020). In addition, when the aim is to determine dust production centers on a regional and larger scale, the implementation of this method faces serious challenges. On a large regional scale, factors affecting wind erosion and susceptible dust emission sources are identified using tools, such as remote sensing and geographical information system (Rayegani et al., 2016; Rayegani *et al*., 2020). Since wind erosion and dust are a complex geomorphological processes affected by several factors, and they make all effective factors difficult to investigate on regional and larger scales, then these scale studies resort to a method capable of both reducing complexity and maintaining key factors affecting wind erosion.

To date, many studies have been done using different methods to determine large-scale dust centers, which can be mentioned Mehrabi *et al*. (2015), Rayegani *et al*. (2017 & 2020), Deiravi Pour et al (2019), Effati et al. (2019), Schepanski and Feuerstein (2019), Mansouri & Asgari (2021) and Deiravipour *et al* (2022) studies. One of the regional models employed on a large scale is the Index of Land Susceptibility to Wind Erosion (ILSWE) that is developed by the European Soil Data Centre (Borrelli *et al*., 2016). In recent years, this index has been used to specify sensitive areas and centers of dust and wind erosion by Fentat *et al*. (2020) and Borrelli *et al*. (2015; 2016). Based on the literature, no study in Iran has yet used this index to assess soil susceptibility to wind erosion and to determine the centers of dust and wind erosion. The primary aim of the current study is to determine dust centers in Alborz Province, Iran using ILSWE.

The other goal of this study is to estimate the willingness to pay (WTP) in order to reduce the damage caused by this phenomenon to agriculture in the affected areas by dust and wind erosion in Alborz Province. It is generally demonstrated that dust storms mostly affect agriculture negatively (Hojan *et al*., 2019). This phenomenon causes crop yield reduction, destruction of the plant tissue (Stefanski *et al*., 2009), decrease photosynthesis, and delay in plant growth and so forth (Xuan *et al*., 2004). Therefore, further understanding the aforementioned phenomenon and estimating damages caused by it to agriculture sector can be an effective step toward reducing its destructive effects. Evaluation of the response and willingness of a community to reduce the intangible effects of dust are particularly important. Regardless of this issue, planning and protective strategies would be meaningless. One of the ways to estimate this willingness is to define the degree of willingness of a community to protect itself from dust impacts (Ardakani, 2016). Economics of nature has developed methods to assess natural phenomena constructed based on the willingness to pay (WTP) (Howarth & Farber, 2002). Among the available methods, the contingent valuation method (CVM) is considered the most important and appropriate method regarding environmental goods (Venkatachalam, 2003). Some researches, such as studies conducted by, Young (2008), Arkani (2016), Zhang et al. (2019), and Kim *et al*. (2021) have investigated the various aspects of people's willingness to pay for reducing the impacts of the dust phenomenon. However, the willingness to pay for reducing the impacts of dust on agriculture has received less attention. As mentioned earlier, this study pursues two main aims of determining the dust production areas and willingness to pay for reducing the impacts of dust on agriculture in areas around dust production regions in Alborz Province, Iran.

2. Material and methods

2.1. Study area

The current study is performed in Alborz Province, Iran, (Fig.1), which is located at latitudes 35°32′ to 36°20′ N and longitudes 50°09′ to 51°27′ E with an area of approximately 514186 hectares at the foothills of the Alborz Mountain and has a diverse climate (Rayegani *et al*., 2020). Plains in the south of this province have an arid and semi-arid climate with a rainfall rate less than 200 mm per year, where plant growth is difficult. In addition, overgrazing in pastures has destructed the vegetation and consequently increased soil erosion (Iran Meteorological Organization, 2014; Rayegani et al., 2017; Rayegani, 2019; Rayegani *et al*., 2020). Almost one third of Alborz Province has encountered sand and dust storm due to the intensity and extent of wind erosion and desertification (Department of Environment, 2014). Recently, the number of dust storms in Alborz Province has increased, so that more than 89 local dust storm events were reported in this province over the past three years, while the number of such events was 15 from 1990 to 1995 (Rayegani *et al*., 2020) (Sarmadian & Taghizadeh-Mehrjerdi, 2010).

2.2. Methodology

2.2.1. Determination of the susceptible areas of dust production

According to the goals of this research, the first part of this study aims to determine the susceptible areas of dust production using the index of land susceptibility to wind erosion (ILSWE). This index is based on this concept that wind erosion occurs when three conditions, namely enough wind power, presence of susceptible soil, and lack of protection for the surface in contact with wind, are met (Borrelli *et al*., 2016). ILSWE consisted of 5 factors, including climate erosivity (CE), soil erodibility (SE), soil crust (SC), vegetation cover (VC), and surface roughness (SR). Fig.2 presents a flowchart of the steps of conducting this research.

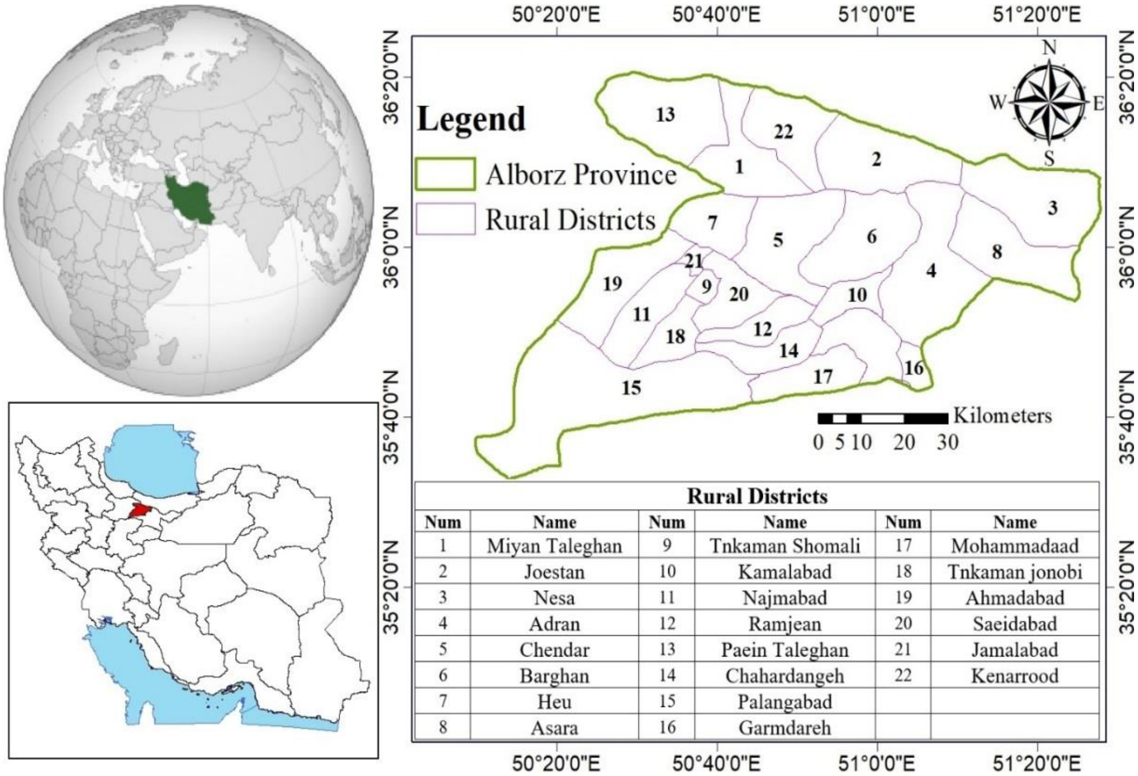

Fig. 1. Geographic location of Alborz Province of Iran and its rural districts.

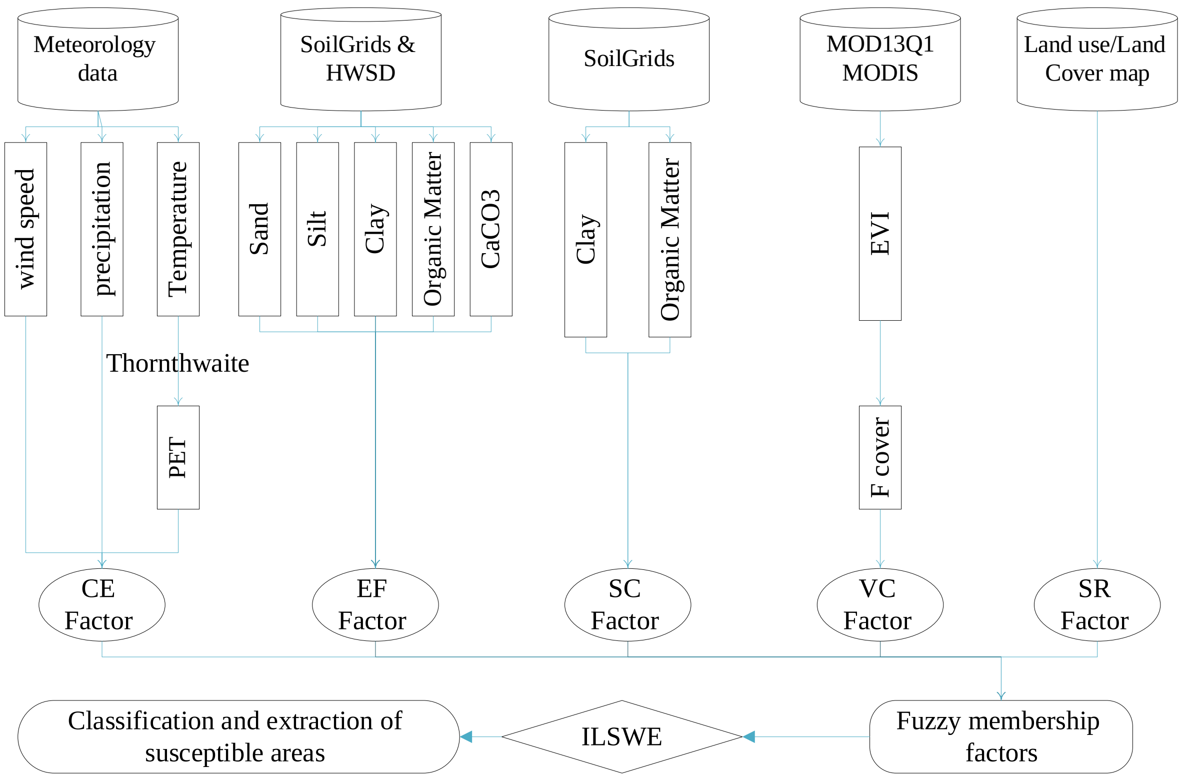

Fig. 2. Flowchart of determining the susceptible areas of dust production using ILSWE

Climate erosivity (CE)

This factor indicates the potential and proneness of the study region to provide conditions leading to wind erosion (13). In this research, Equation 1 developed by FAO (1979) was used to calculate climate erosivity.

$$CE = \frac{1}{100} \times \sum_{i=1}^{i=12} u_i^3 \times \left(\frac{PET_i - P_i}{PET_i}\right) \times d_i \qquad (1)$$

where u_i is the mean monthly wind speed (m/s) at 2 m height in month i, , PETi is the potential evapotranspiration (mm) in month i, Pi is the precipitation (mm) in month i, and di is the total number of days in month i. To calculate this factor, first monthly data related to the average wind speed, temperature, and precipitation mass were collected from 16 stations in Alborz Province and its surrounding areas (Fig.3) over a 10-year period (2010-2019). Then, the monthly potential evapotranspiration and temperature data of each station were calculated using the Torrent White method. The monthly average of three components of precipitation, temperature, and wind speed was calculated using 10-year data. Afterward, zoning was performed using the inverse distance weighting (IDW) method in the ArcGIS software for all three components in 12 months of the year. Finally, the CE factor was calculated using Equation 1.

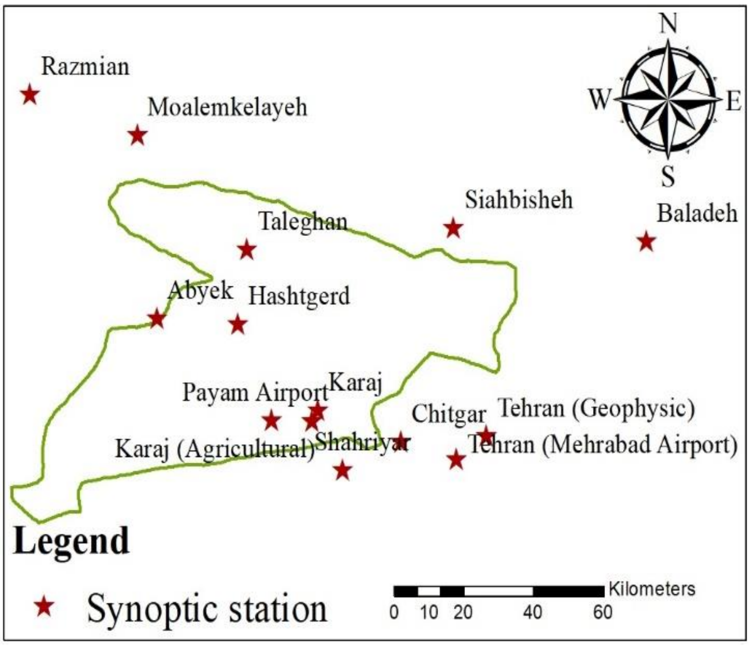

Fig. 3. Location of the synoptic stations used

Soil erodibility (SE)

Soil erodibility (SE) factor indicates the ability of soil to resist the wind force. Indeed, this factor represents the relationship between soil erosion by wind and soil properties (Fentat *et al*., 2020). Equation 2 illustrates how to calculate soil erodibility using the multiple regression equation presented by Fryrear *et al*. (1994) based on the soil texture and chemical properties.

$$EF = \frac{29.09 + (0.31 \times SI) + (0.33 \times \frac{SA}{CL}) - (2.59 \times OM) - (0.95 \times CaCO_3)}{100} \quad (2)$$

where SA, SI, CL, OM, and $CaCO_3$ are percentages of sand, silt, clay, organic matter and calcium carbonate, respectively. Soil erodibility factor is obtained in percent. To calculate the percentages of sand, silt, clay and organic matter of the surface soil of Alborz Province, the data obtained from the ISRIC SoilGrids with a spatial resolution of 250 meters (Hengl *et al*., 2017) were used. Furthermore, to calculate the calcium carbonate percentage of soil, the data obtained from the Harmonized World Soil Database with a spatial resolution of 1 kilometer (FAO/IIASA/IRSIC/ ISSCAS/JRC., 2012) were used.

Soil crust factor (SC)

Soil crust is defined as a relatively thin and monolithic layer formed on the soil surface, which is more compressed and mechanically more sustainable than subsoil (Zobeck, 1991). This layer is less susceptible to wind erosion than to the layers below (Fryrear *et al*., 2000), and in arid and semi-arid regions, where wind erosion is more dominant than water erosion, it plays crucial role in the conservation of soil (Zhang *et al*., 2004; Rayegani *et al*., 2015). Soil crust (SC) factor is used to estimate its effect on the soil erodibility (Borrelli *et al*., 2014). In this study, soil crust (SC) parameter was calculated using the following equation introduced by Fryrear *et al*. (1998).

$$SC = \frac{1}{1 + (0.006 \times CL^2) + (0.21 \times MO^2)} \quad (3)$$

where CL and OM are the percentages of clay and organic matter, respectively. As mentioned, data of these two components were obtained from the ISRIC SoilGrids database with a spatial resolution of 250 meters (Hengl *et al*., 2017).

Vegetation cover factor (VC)

The effect of vegetation cover on wind erosion can be expressed through the percentage of the area covered by vegetation (Borrelli *et al*., 2015, 2016). In this study, the fraction of vegetation covers (F_{cover}), which has been obtained from the vegetation cover index of the enhanced vegetation index (EVI), the product of the MODIS sensor MOD13Q1 with a pixel size of 250 × 250 m was used to describe the vegetation cover factor. The product used provides vegetation cover indexes every 16 days. First, the map of the annual average EVI was calculated using data related to Alborz Province from 2010 to 2019. Then, the calculation of F_{cover} was performed by Equation 4:

$$F_{cover} = \frac{EVI - EVI_S}{EVI_V - EVI_S} \quad (4)$$

where EVI is the map of the annual average obtained from the previous step, and EVI_s and EVI_v are the index value in arid soil and dense vegetation cover, respectively.

Surface Roughness (SR)

Roughness of the land surface enhances its friction, thereby reducing wind energy close to the land surface (Wever, 2012; Rayegani, 2019; Rayegani *et al*., 2020). Therefore, reduction in wind energy decreases wind erosion. In cases where land surface roughness information is unavailable, the classes of land use and cover are highly useful to estimate the length of surface roughness (Hansen *et al*., 1993). Special tables have been used to determine the surface roughness factor based on land use and cover in several studies, such as those conducted a regional scale by Reuter and Funk (2006), Borrelli *et al*. (2016) and Fentat *et al*. (2020). The standard provided by TA–LUFT (TA-Luft., 2001) was used in the current study. It should be noted that the land use/cover map of Alborz Province was extracted from the land use map of Iran prepared by the Forests, Range and Watershed Organization (Heydari Alamdarloo *et al*., 2020).

Calculation of ILSWE

After calculating ILSWE five factors, first the fuzzy membership function of factors was calculated. Accordingly, the factors were placed in the range between zero (minimum sensitivity) and 1(maximum sensitivity) (Rayegani, 2019). According to the research conducted by Fentat *et al*. (2020)) to create a fuzzy membership map for factors of climate erosivity (CE), soil erodibility (SE), and soil crust (SC), linear method, exponential method and logarithmic method were used to calculate vegetation cover (VC), surface roughness (SR), and fuzzy membership function, respectively. Then, ILSWE was calculated using Equation 5.

$$ILSWE = CE \times EF \times SC \times VC \times SR \tag{5}$$

After calculating ILSWE, this index was classified and dust centers were determined.

2.2.2. Economic valuation of damage caused by dust phenomenon to agriculture

In this study, the contingent valuation method (CVM) was used to estimate individuals' willingness to pay (WTP) for preventing and reducing the negative effects of the dust phenomenon on agriculture. Contingent valuation method (CVM) is an approach widely used by economists and policymakers to assess individuals' willingness to pay aiming at valuing non-market goods and services (Tussupova *et al*., 2015). To measure the visitors' willingness to pay, Double-bounded Diclotonious Choice was used (Bishop & Heberlein, 1979). In this method, respondents select only one choice among several predefined choices. They only answer yes or no while encountering a bid price in an assumed market situation. The next bid depends on the initial response of the respondent to the first bid (Arrowet *et al*., 1993). After identifying dust production-prone areas, rural districts that had areas prone to dust production-prone areas were regarded as the statistical population.

Then, the sample size was estimated using the Cochrane equation (1963), which is one of the most widely used methods for determining the sample size statistically (Komleh *et al*., 2011).

Content-face validity was used to examine the validity of the questionnaire. In other words, the questionnaire was first distributed among a number of experts who were the managers of the Department of Environmental Protection of the province and university professors investigating air pollution and dust. They were asked to express their opinions about assessing the relevant purpose, as well as issues, such as number of questions, level of clarity and transparency of the questions, intelligibility, use of simple words, and scientific level of the questionnaire. Cronbach's alpha coefficient with an internal correlation was used to determine the reliability of the questionnaire. In this method, the parts or components of the questionnaire are used to measure the reliability coefficient of the test.

The basis of estimating willingness to pay (WTP) is based on this assumption that people are willing to pay or reject a bid for using environmental goods or services in order to improve their interests.

$$\nu(1,Y-A;s)-\varepsilon_1 \geq \nu(0,Y;s)+(\varepsilon_1+\varepsilon_0) \quad (6)$$

where v is the individual's indirect benefit expected to be equal to the value of its benefit. Y is the income, A is the pay offer and s contains different socio-economic characteristics affecting the individual's selection, such as age and education level. Independent and identically distributed random variables with a mean zero are represented by ε_0 and ε_1 (Maghsood *et al.*, 2019). Profit difference can be expressed as follows:

$$\Delta\nu=\nu(1,Y-A;s)-\nu(0,Y;s)+(\varepsilon_1+\varepsilon_0) \quad (7)$$

If Δυ is greater than zero, individuals augment their profits by accepting to pay the bid. Probit and logit models are usually used as qualitative selection methods. Meanwhile, logit uses simple computations (Maghsood *et al.*, 2019). The probability Pi that a person accepts an offered bid, A, can be described as a logit model as follows:

$$P_i=F\eta(\Delta\nu)=\frac{1}{1-\exp(-\Delta\nu)}=\frac{1}{1-\exp\{-(-\alpha-\beta A+\gamma Y+\theta s)\}} \quad (8)$$

Here, the F function or Cumulative Distribution Function (CDF) has been considered for a standard logistic variable and a socio-economic feature. γ, ß and θ are factors estimated using the collected data (Lee & Han, 2002; Ji *et al.*, 2018). In general, three ways of mean WTP, total mean WTP, and truncated mean WTP are calculated as the expected value of WTP from 0 to $+\infty$, $-\infty\ to + \infty$ and 0 to the maximum pay offer, respectively by numerical integration. In the current study, the truncated method was used due to simplicity interpretation and statistical efficiency (Duffield & Patterson, 1991).

The logit model was calculated using the maximum likelihood estimation technique, and the expected value of WTP can be calculated by the numerical integration, from zero to the maximum pay offer, A, using the following equation:

$$E(WTP)=\int_0^{Max.A}(a^*+\beta A)dA \quad (9)$$

where E(WTP) is the expected value of WTP, and a^* is the controlled interruption added to the original interception expression (a) by the socio-economic factor. The area under the function can be inferred to estimate the truncated mean WTP (Lee & Han, 2002; Jin *et al.*, 2019). It should be noted that to properly determine and analyze the willingness to pay to reduce the negative effects of dust on the agricultural sector, along with WTP bids including 1500000, 2000000 and 2500000 Rials (each US dollar is equal to 300000 Rials), the respondents were asked about their maximum willingness to pay (WTP).

3. Results

3.1. Determination of susceptible areas of dust production

Fig (4) and (5) indicate the map of the fuzzy membership of climate erosivity (CE) and soil erodibility (SE) factors, respectively. According to the map of the fuzzy membership of the climate erosivity (CE) factor, southern and eastern regions have the highest potential for causing wind erosion. The least amount is also related to the northern regions of Alborz Province i.e. heights of the Alborz range. The results of examining the map of the fuzzy membership of soil erodibility (SE) factor indicate that in general, as we go from the north of Alborz Province toward the southern parts of this province, soil erodibility increases compared to the wind erodibility. However, in the middle parts located in the west of Karaj city, a decreasing trend in erodibility is observed. Agricultural lands are located in these areas.

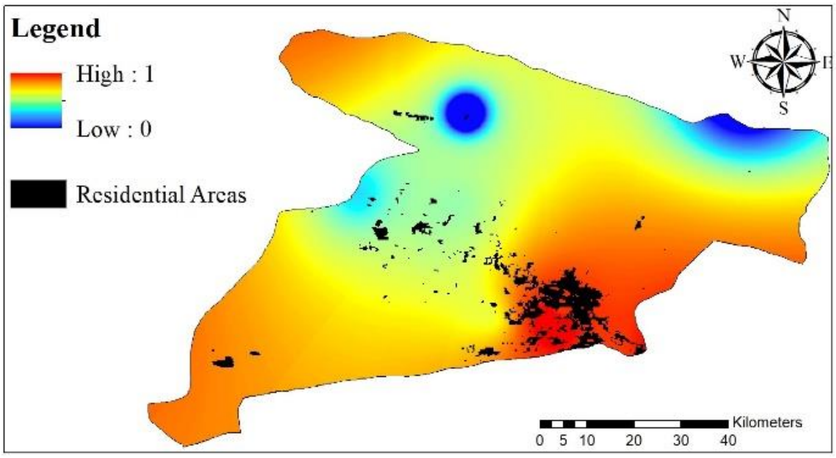

Fig. 4. Fuzzy membership map of the CE factor

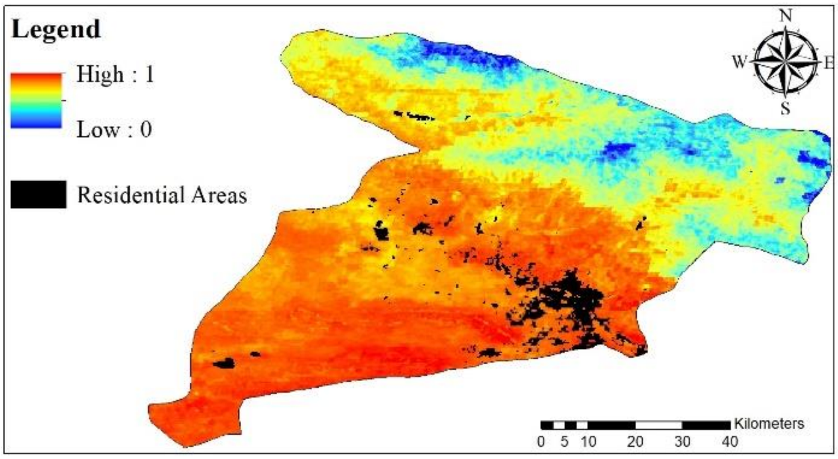

Fig. 5. Fuzzy membership map of EF

Fig (6) indicates the map of the fuzzy membership of the soil crust (SC) factor. According to this map, the northern, central and southern parts of Alborz Province have the minimum amount of this factor, and the northwestern to northeastern parts of Karaj city, as well as its southwestern to southeastern parts have the highest amount of the factor. The map of the fuzzy membership of the vegetation cover (VC) factor (Fig.7) illustrates that the northern areas, especially arid lands located in the southern parts of Alborz Province have the maximum likelihood, and the middle belt where most of the agricultural land is located there have the minimum likelihood of generating wind erosion in terms of vegetation cover.

As mentioned, the modified land use map prepared by the Natural Resources and Watershed Management Organization (https://frw.ir/index.jsp?fkeyid=&siteid=1&pageid=2089) was used to calculate the surface roughness (SR) factor (Fig.8). In general, good to moderate rangelands are located in the north of the province, middle areas include residential and agricultural areas, and the south of the province encompasses arid lands, and in some areas, there are pastures. The Salehieh wetland in the south of the province is a seasonal wetland in Nazarabad. Fig.9

presents the map of the fuzzy membership of the surface roughness (SR) factor. According to this map, many parts of Alborz Province, from south to the center, are the most susceptible areas to wind erosion and dust; however, many of central regions to the north of the province are the least prone areas to wind erosion and dust.

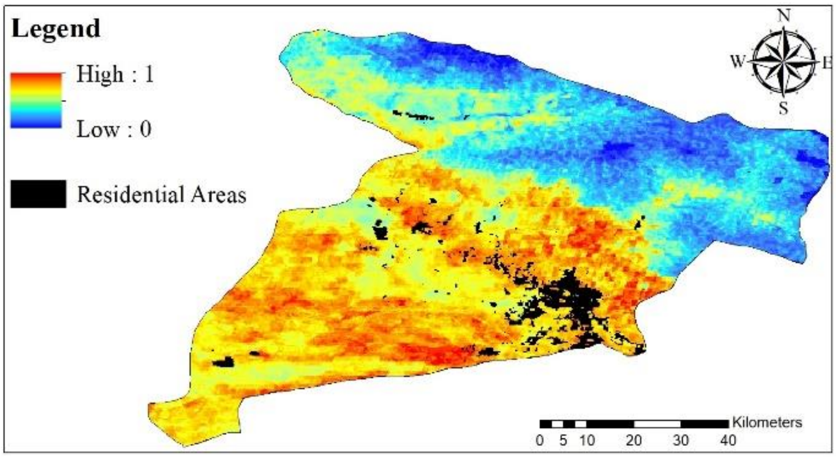

Fig. 6. Fuzzy membership map of SC

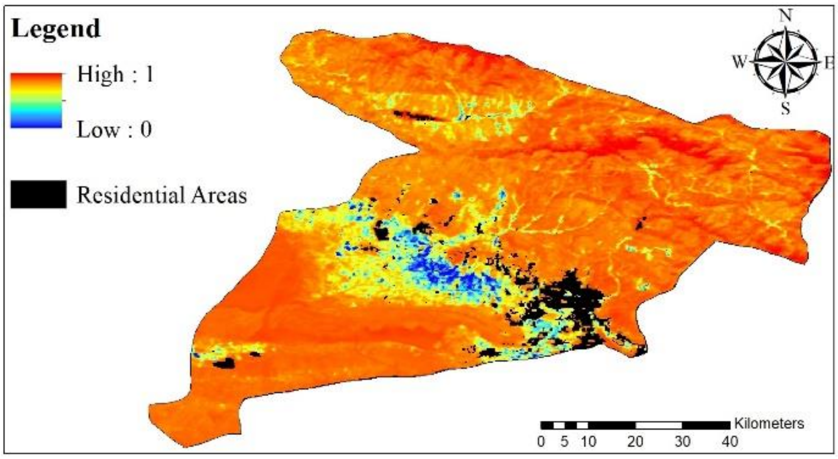

Fig. 7. Fuzzy membership map of VC

ILSWE was calculated using Equation 5 after preparing the fuzzy membership maps of these five factors: climate erosivity, soil erodibility, soil crust, vegetation cover, and surface roughness. Then, it was divided into five classes from very low sensitivity to very high sensitivity to wind erosion using the natural break method in the Arc GIS software (Fig. 10). This method attempts to minimize the variance between data in each class and maximize the variance between classes based on a computational algorithm (Heydari Alamdarloo *et al*., 2021). This algorithm uses the average of each range to create the classes to ensure that the distribution of data over each range is more uniform (Jenks, 1977). The very low sensitivity class covers 34.5% of the area of Alborz Province, most of which is located in its northern parts. Generally, the low sensitivity class is located in the downstream regions of this class toward the south which includes 26.8% of the total area of Alborz Province. Central sections and small parts of the south of this province are in the moderate sensitivity class, including 18.3% of the Alborz area. The high sensitivity class is related to the southern areas of the province.

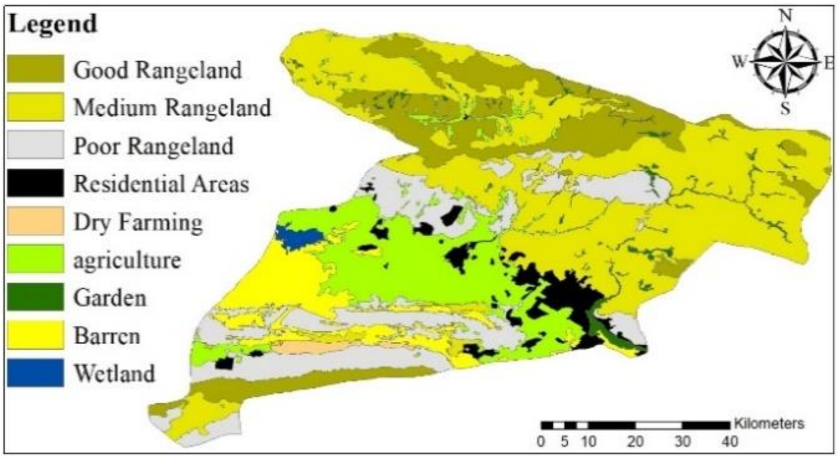

Fig. 8. Land use map applied

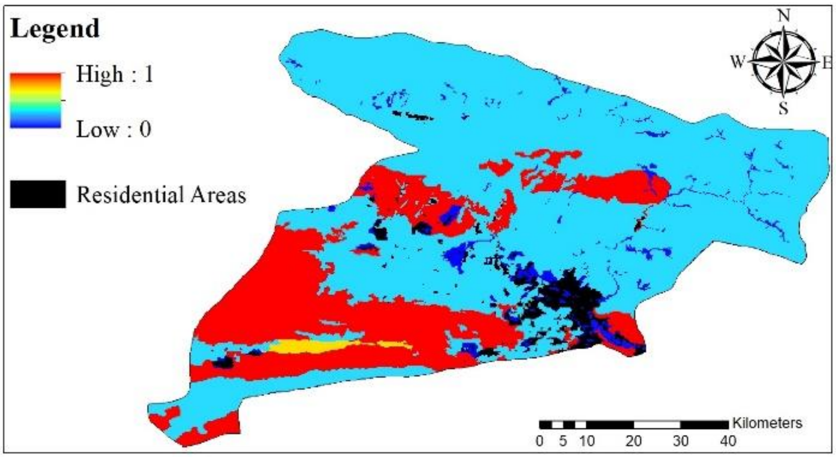

Fig.9 Fuzzy membership map of SR

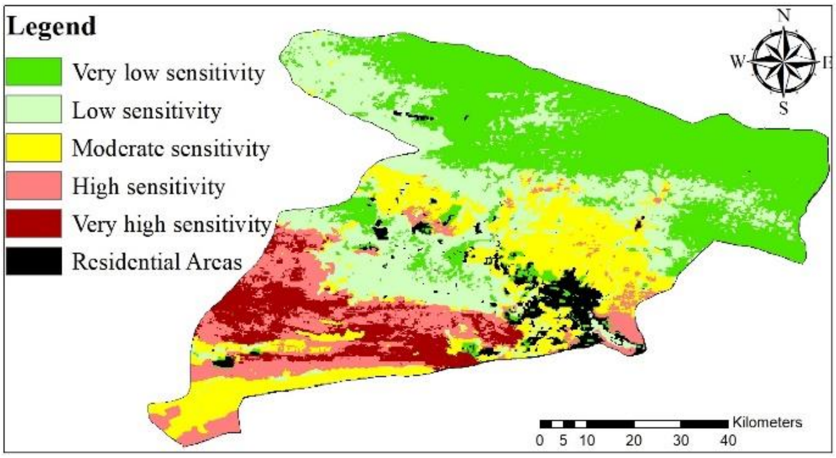

Fig.10 Classified map of ILSWE

Arid lands are generally located in this area, including 12.6% of the province. The very high sensitivity class is also located in the southern regions of the province, and 7.8% of the area of this province belongs to this class. This class is considered the susceptible regions of wind erosion and dust production and was extracted from the sensitivity map (Fig. 11). The northernmost part of susceptible areas of dust production is some parts of the Salehieh wetland, and is spread through the southern parts and includes southern parts of Alborz Province like a belt. The predominant regions susceptible to dust production are arid lands.

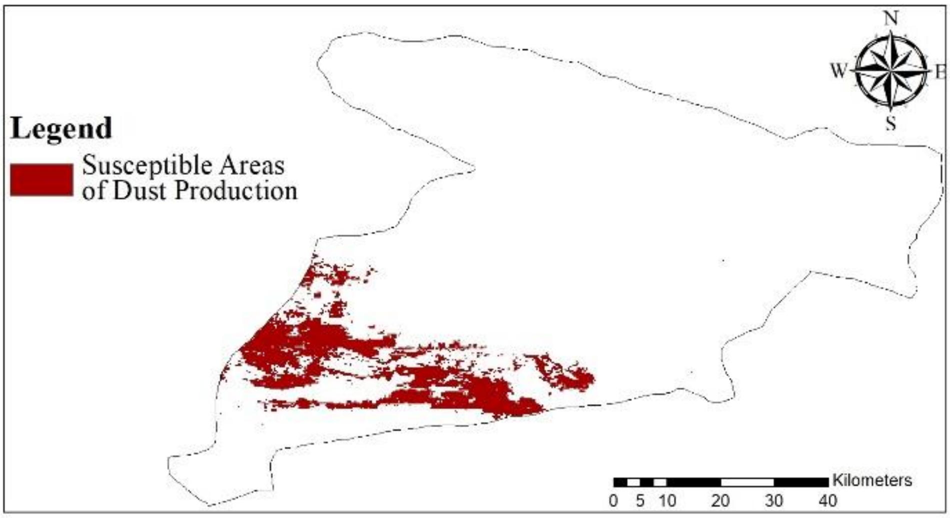

Fig.11 Map of susceptible areas of dust production and wind erosion.

3.2. Determination of areas susceptible to dust production

According to Figure 11, and the map of Karaj rural districts, Najmabad, Ramjin, Chahar Dangeh, Palangabad, Mhammadabad, South Tankaman, and Ahmadabad are areas dealing with dust. Table 1 presents the population and number of the villages of these rural districts based on the information available on the website of the Natinal Statistical Center of Iran (www.amar.org.ir). According to this table, the size of the statistical population is 16584 households, and based on the Cochrane equation, the sample size of the current study became 375 households by assuming 95% reliability, and 400 questionnaires were collected in the implementation of the research to raise the confidence level. Hence, the sample size in each of the 6 selected rural districts was specified proportional to the population of village that its results are presented in Table 1. It is worth mentioning that the content and face validity of the questionnaire was confirmed based on professors and technical experts' opinions. Furthermore, before distributing the questionnaires among the samples, the results of 35 preliminary questionnaires from the statistical population of the research were tested by the Cronbach's alpha test in the SPSS software to determine the reliability of the questionnaires. Accordingly, the Cronbach's alpha coefficient of the mentioned statistical population was 0.85. These results indicate that this questionnaire possesses acceptable reliability.

In the questionnaire used in this study, the general and socio-economic features of farmers, their income, their familiarity with the dust phenomenon, rate of reduction in production caused by the dust phenomenon, and farmers' willingness to pay for protecting the crops against this phenomenon were asked. Table 2 represents the results of assessing some characteristics of the interviewees.

Table 1. Statistical population and the sample under study

County	District	Rural districts	Number of village	Number of households	Population	Number of sample
Karaj	Central	Mohammadabad	4	1983	6704	56
Savojbolagh	Chahar Bagh	Chahar Dangeh	8	1696	5166	39
		Ramjin	17	7347	23348	176
Nazarabad	Central	Ahmadabad	16	1873	6036	42
		Najmabad	13	1983	6704	50
	Tankaman	South Tankaman	9	1026	3241	24
Eshtehard	Palangabad	Palangabad	3	368	1196	10
	Total		70	16584	53140	400

Table 2. Some characteristics of the interviewees

Variable (feature)	Average	Minimum	Maximum	Standard deviation
Age (year)	49.3	20	82	11.75
Family members (No.)	4.21	1	8	3.21
No. of years of study	14.2	0	22	4.31
Working population	2.1	1	4	1.01
Monthly income of agricultural households (million Rials)	41.3	20	80	1.7

Each US dollar is equal to 300000 Rials

By evaluating the interviewees' characteristics, it can be observed that their mean age is 49.3. In addition, these people have on average a family of 4.21 persons, and their average monthly income is approximately 41.3 million Rials. The examination of the respondent' education level also indicates that their average years of study are approximately 14.2 years; in other words, most of them have a diploma or a higher degree. Out of three bids, 38.42% accepted the bid of 2 million Rials annually. The importance of protecting the corps and farmers' concerns about the damage to agriculture caused by the dust phenomenon and reduction in agricultural production has been investigated in another part of this research, which was introduced to the model under the title of environmental index and was examined. The factors influencing the willingness to pay have been estimated using the logit model, the results of which are presented in Table 3.

The results indicated that in the agricultural sector of the region under study, variables of age, working population, education, and income positively and significantly affect the farmers' willingness to pay for protecting crops against dust. The environmental index became significant at a level of 5%. The positive sign of the environmental index represents that as the familiarity of farmers with the damage caused by dust to crops and the importance of protection against this phenomenon increase, the probability of accepting the bids increases significantly. After estimating the parameters of the logit model using the maximum likelihood method, the expected value rate of WTP was calculated using Equation 10 by the numerical integration in the range of 0 to the maximum bid (2 million rials), which was equal to 1654231 Rials (almost $5.5). According to the population under study (16584 people), the total value of protecting the crops against dust is 27433766904 Rials ($91445.89) per year.

Table 3. Estimation results of the logit model.

Variable	Coefficient of estimation	T statistics	Elasticity in mean	Final effect
Intercept	-1.05	-3.5*	-0.63	-
Offer (bid)	-0.049	-4.82**	-0.31	-0.0004
Age	0.051	2.27*	0.18	0.0054
Family members (No.)	-1.2	-1.99*	-0.37	-0.0008
Working population	0.53	1.54*	0.35	0.087
Education	0.0052	4.12*	0.74	0.067
Income	0.0016	2.5**	0.23	0.00014
Environmental index	0.29	1.19*	0.59	0.0012

Percentage of right predictions=0.73
Likelihood ratio test= 38.5
Mcfadden R-square= 0.07
Maddala R-square=0.089

4. Discussion

Dust storms cause air pollution and consequently cause respiratory diseases, damage to vegetation cover and crops, soil degradation, changes in precipitation patterns and so forth (Moghaddam *et al*., 2018).

Identification of the source of dust storm is considered the key parameter of the accurate prediction of measures aiming at reducing, adapting and understanding the adverse effects of dust on human health and the environment (Cao *et al*., 2015). One of the aims of this study is to determine the susceptible areas of dust production and sensitive to wind erosion using ILSWE. The results indicated that the southern areas of Alborz Province were the regions susceptible to dust production and wind erosion. Rayegani *et al*. (2020), in one study conducted in Alborz Province to specify the centers of dust production, achieved results similar to those of the present study, so that most areas regarded as dust emission sources were also among the susceptible areas in this research. Thus, this result indicates that ILSWE has high efficiency to determine areas susceptible to dust production. This research, like the study conducted by Rayegani *et al*. (2020), indicated that the Salehieh wetland had the potential of dust production and wind erosion when it was dry. The available evidence confirms this issue. Fentat *et al*. (2020) also concluded that assuming the classification of ILSWE was correct; the overall accuracy of this index is 70% and it corresponds well to the frequency of dust storms. It should be noted that the way of classification and the extent of each class play a crucial role in determining the general accuracy of the model.

In another part of this study, to avoid or prevent and reduce the negative impacts of dust on the agriculture, individuals’ willingness to pay (WTP) was calculated approximately $5.5 using the contingent valuation method (CVM). Overall, measurement of dust storms-related costs requires the awareness of severity and probability of this phenomenon occurrence and its impacts on different sectors like agriculture (Al-Hemoud *et al*., 2019). In other words, individuals’ willingness to pay (WTP) to avoid or prevent and reduce the negative impacts of dust depends on the temporal and spatial conditions and features. The increase in the average temperature and the length of the warm season (Heydari Alamdarloo *et al*., 2021) as well as high probability of drought occurrence in Alborz Province (Heydari Alamdarloo *et al*., 2020) indicate the possibility of raising the occurrence number of the dust phenomenon in this province in the future. Accordingly, it can be stated that WTP will be increased to reduce the impacts of dust. Moreover, the variables of age, working population, education, income, and environmental index positively and significantly affect farmers' willingness to pay for protecting crops against dust. In corresponding researches like the research conducted by Zhang *et al*. (2019), similar results have generally been achieved. It is suggested that first farmers' knowledge and awareness about negative effects of dust on agriculture should be increased to control and stabilize dust emission sources in Alborz Province of Iran by training courses, advertising and so forth; therefore, farmers' willingness to pay (WTP) will be increased. Then, the programs and plans controlling and stabilizing dust emission sources should be designed and implemented with the participation of farmers themselves in the form of non-governmental organizations and/or participatory designs with the government.

5. Conclusion

According to the results of his research and the evaluations conducted in this field, it can be stated that ILSWE is generally an appropriate regional model to determine the susceptible areas and dust emission sources, which can be effectively used in designs of determining centers of dust and wind erosion owing to limitations of time, large area and cost. To enhance the accuracy of the results related to ILSWE, it is recommended that ground data be employed to measure the soil properties used in this index. Therefore, the accuracy of this index can also be assessed on a local scale. Since the calcium carbonate percentage of the soil collected from the Harmonized World Soil Database is not available everywhere in Iran, remote sensing indicators can be used in this regard, and the soil erodibility factor (EF) can be modified accordingly. Furthermore, in terms of calculating the surface roughness (SR) factor, which requires scoring table land use and cover, due to specific and certain conditions and features of Iran, this table should be reviewed and modified. However, it should be noted that more studies are needed to better assess this index in Iran.

It is also suggested that first farmers' knowledge and awareness about negative effects of dust on agriculture should be increased to control and stabilize dust emission sources in Alborz Province of Iran by training courses, advertising and so forth; therefore, farmers' willingness to pay (WTP) will be increased. Then, the programs and plans controlling and stabilizing dust emission sources should be designed and implemented with the participation of farmers themselves in the form of non-governmental organizations and/or participatory designs with the government

References

Albugami, S., S. Palmer, J. Cinnamon, J. Meersmans, 2019. Spatial and temporal variations in the incidence of dust storms in Saudi Arabia revealed from in situ observations. Geosciences, 9(4), pp. 1-20.

Al-Hemoud, A., A. Al-Dousari, R. Misak, M. Al-Sudairawi, A. Naseeb, H. Al-Dashti, N. Al-Dousari, 2019. Economic impact and risk assessment of sand and dust storms (SDS) on the oil and gas industry in Kuwait. Sustainability, 11(1), pp. 1-19.

Alizadeh-Choobari, O., P. Ghafarian, E. Owlad, 2016. Temporal variations in the frequency and concentration of dust events over Iran based on surface observations. International Journal of Climatology, 36(4), 2050-2062.

Ardakani, A. F., 2016. Estimating willingness to pay in order to prevent external intangible effects of dust in Yazd-Ardakan plain. International journal of environmental science and technology, 13(6), 1489-1496.

Ashrafi, K., M. S. Motlagh, S. E. Neyestani, 2017. Dust storms modeling and their impacts on air quality and radiation budget over Iran using WRF-Chem. Air Quality, Atmosphere & Health, 10(9), 1059-1076.

Bishop, R. C., T. A. Heberlein, 1979. Measuring values of extramarket goods: Are indirect measures biased?. American journal of agricultural economics, 61(5), 926-930.

Borrelli, P., C. Ballabio, P. Panagos, L. Montanarella, 2014. Wind erosion susceptibility of European soils. Geoderma, 232, 471-478.

Borrelli, P., P. Panagos, L. Montanarella, 2015. New insights into the geography and modelling of wind erosion in the european agricultural land. Application of a spatially explicit indicator of land susceptibility to wind erosion. Sustainability, 7(7), 8823-8836.

Borrelli, P., P. Panagos, C. Ballabio, E. Lugato, M. Weynants, L. Montanarella, 2016. Towards a pan-European assessment of land susceptibility to wind erosion. Land Degradation & Development, 27(4), 1093-1105.

Cao, H., F. Amiraslani, J. Liu, N. Zhou, 2015. Identification of dust storm source areas in West Asia using multiple environmental datasets. Science of the Total Environment, 502, 224-235.

Darand, M., M. M. Sohrabi, 2018. Identifying drought-and flood-prone areas based on significant changes in daily precipitation over Iran. Natural Hazards, 90(3), 1427-1446.

Deiravi Pour, M., H. Mohammadasgari, S. Farhadi, I. Najafi, 2019. Dust storm detection in the Southwest of Iran using NDDI and BTD indexes and neural network. Scientific-Research Quarterly of Geographical Data (SEPEHR), 28(111), 217-234.

Deiravipour, M., H. Mohammad Asgari, S. Farhadi, 2022. Detection of dust storms overnight in the South West of Iran using satellite images. Desert, 27(1), 35-53.

Department of Environment, 2014. The environment of Alborz Province, threats, opportunities and proposed solutions. Department of Environment Karaj, Iran.

Duffield, J. W., D. A. Patterson, 1991. Inference and optimal design for a welfare measure in dichotomous choice contingent valuation. Land Economics, 67(2), 225-239.

Ebrahimi Khusfi, Z., F. Roustaei, M. Ebrahimi Khusfi, S. Naghavi, 2020. Investigation of the relationship between dust storm index, climatic parameters, and normalized difference vegetation index using the ridge regression method in arid regions of Central Iran. Arid land research and management, 34(3), 239-263.

Ebrahimpour, M., J. Rahimi, A. Nikkhah, J. Bazrafshan, 2015. Monitoring agricultural drought using the standardized effective precipitation index. Journal of Irrigation and Drainage Engineering, 141(1), 04014044.

Effati, M., H. A. Bahrami, M. Gohardoust, E. Babaeian, M. Tuller, 2019. Application of satellite remote sensing for estimation of dust emission probability in the Urmia Lake Basin in Iran. Soil Science Society of America Journal, 83(4), 993-1002

FAO., (1979). A provisional methodology for soil degradation assessment. Food and Agriculture Organization, Rome, Italy.

FAO/IIASA/ISRIC/ISSCAS/JRC., 2012. Harmonized World Soil Database (version 1.2). FAO, Rome, Italy and IIASA, Laxenburg, Austria. (accessed 17 May 2019). http://www.fao.org/3/aq361e/aq361e.pdf.

Fenta, A. A., A. Tsunekawa, N. Haregeweyn, J. Poesen, M. Tsubo, P. Borrelli,... Y. Kurosaki, 2020. Land susceptibility to water and wind erosion risks in the East Africa region. Science of the Total Environment, 703, 135016.

Feuerstein, S., K. Schepanski, 2019. Identification of dust sources in a Saharan dust hot-spot and their implementation in a dust-emission model. Remote Sensing, 11(1), 4.

Fryrear, D. W., J. D. Bilbro, A. Saleh, H. Schomberg, J. E. Stout, T. M. Zobeck, 2000. RWEQ: Improved wind erosion technology. Journal of Soil and Water Conservation, 55(2), 183-189.

Fryrear, D. W., C. A. Krammes, D. L. Williamson, T. M. Zobeck, 1994. Computing the wind erodible fraction of soils. Journal of Soil and Water Conservation, 49(2), 183-188.

Fryrear, D.W., A. Saleh, J. D. Bilbro, H. M. Schomberg, J. E. Stout, T.M. Zobeck, 1998. Revised Wind Erosion Equation (RWEQ). Wind Erosion and Water Conservation Research Unit, USDA-ARS, Southern Plains Area Cropping Systems Research Laboratory. Technical Bulletin No. 1. pp. 185. (accessed 2019). https://www.csrl.ars.usda.gov/wewc/rweq/rweq.pdf.

Funk, R., H. I. Reuter, 2006. Wind erosion. In Soil erosion in Europe, Boardman J, Poesen J. (eds). Wiley: Chichester; 563–582.

Hansen, F. V. 1993. Surface roughness lengths. ARL Technical Report U. S. Army, White Sands Missile Range, NM 88002-5501, pp. 51. (accessed 4 December 2018).

Hengl, T., J. Mendes de Jesus, G. B. Heuvelink, M. Ruiperez Gonzalez, M. Kilibarda, A. Blagotić, ... B. Kempen, 2017. SoilGrids250m: Global gridded soil information based on machine learning. PLoS one, 12(2), e0169748

Heydari Alamdarloo, E., H. Khosravi, P. Dehghan Rahimabadi, M. Ghodsi, 2021. The Effect of Climate Fluctuations on Vegetation Dynamics in West and Northwest of Iran. Desert Ecosystem Engineering Journal, 3(2), 19-28.

Heydari Alamdarloo, E., H. Khosravi, S. Nasabpour, A. Gholami, 2020. Assessment of drought hazard, vulnerability and risk in Iran using GIS techniques. Journal of Arid Land, 12(6), 984-1000.

Heydari Alamdarloo, E., E. Moradi, M. Abdolshahnejad, Y. Fatahi, H. Khosravi, A. M. Da Silva, 2021. Analyzing WSTP trend: a new method for global warming assessment. Environmental monitoring and assessment, 193(12), 1-15.

Hojan, M., M. Rurek, M. Więcław, A. Krupa, 2019. Effects of extreme dust storm in agricultural areas (Poland, the Greater Lowland). Geosciences, 9(3), 106.

Huang, M., G. Peng, J. Zhang, S. Zhang, 2006. Application of artificial neural networks to the prediction of dust storms in Northwest China. Global and Planetary change, 52(1-4), 216-224

Iran Meteorological Organization, 2014. Review of climatic characteristics of Alborz Province. Meteorological Organization of Alborz Province, Karaj, Iran.

Jebali, A., M. Zare, M. R. Ekhtesasi, R.Jafari, 2021. Detection of areas prone to wind erosion and air pollution using DSI and PDSI indices. Natural Hazards, 1-15.

Jenks, G. F., 1977. Optimal data classification for choropleth maps. Department of Geographiy, University of Kansas Occasional Paper.

Jeong, D. Y., 2008. Socio-economic costs from yellow dust damages in South Korea. Korean Soc. Sci. J, 35, 1-29

Ji, S., Y. Choi, C. K. Lee, J. W. Mjelde, 2018. Comparing willingness-to-pay between residents and non-residents using a contingent valuation method: case of the Grand Canal in China. Asia Pacific Journal of Tourism Research, 23(1), 79-91.

Jin, M., Y. Juan, Y. Choi, C. K. Lee, 2019. Estimating the preservation value of world heritage site using contingent valuation method: The case of the Li River, China. Sustainability, 11(4), 1100

Khosravi, H., E. Haydari, G. Zehtabian, J. Bazrafshan, 2016. Analysis of spatial and temporal trends of groundwater index (GRI)(case study: Yazd-Ardakan plain). Iranian Journal of Range and Desert Research, 22(4).

Kim, H. M., I. G. Kim, B. Lim, S. H. Yoo, 2021. Estimating the Economic Value of Improving the Asian Dust Aerosol Model in the Korean Household Sector: A Choice Experiment. Sustainability, 13(21), 12054.

Komleh, S. P., A. Keyhani, S. H. Rafiee, P. Sefeedpary, 2011. Energy use and economic analysis of corn silage production under three cultivated area levels in Tehran province of Iran. Energy, 36(5), 3335-3341.

Lee, C. K., S. Y. Han, 2002. Estimating the use and preservation values of national parks' tourism resources using a contingent valuation method. Tourism management, 23(5), 531-540.

Maghsood, F. F., H. Moradi, R. Berndtsson, M. Panahi, A. Daneshi, H. Hashemi, A. R. M. Bavani, 2019. Social acceptability of flood management strategies under climate change using contingent valuation method (CVM). Sustainability, 11(18), 5053.

Manesh, M. B., H. Khosravi, E. H. Alamdarloo, M. S. Alekasir, A. Gholami, V. P. Singh, 2019. Linkage of agricultural drought with meteorological drought in different climates of Iran. Theoretical and Applied Climatology, 138(1), 1025-1033.

Mansouri, Z., H. M. Asgari, 2021. Dust Distribution and Emission Modeling (Study Area: Khuzestan province). Desert (2008-0875), 26(1).

Mehrabi, S., S. Soltani, R. Jafari, 2015. Analyzing the Relationship Between Dust Storm Occurrence and Climatic Parameters. Journal of Water and Soil Science. 19 (71) :69-81

Mei, D., L. Xiushan, S. Lin, W. A. N. G. Ping, 2008. A dust-storm process dynamic monitoring with multi-temporal MODIS data. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 37, 965-970.

Middleton, N., U. Kang, 2017. Sand and dust storms: impact mitigation. Sustainability 9, 1053.

Mirmousavi, S. H. (2016). Regional modeling of wind erosion in the North West and South West of Iran. Eurasian Soil Science, 49(8), 942-953

Moghaddam, M. H. R., A. Sedighi, S. Fasihi, M. K. Firozjaei, 2018. Effect of environmental policies in combating aeolian desertification over Sejzy Plain of Iran. Aeolian research, 35, 19-28.

Mohammad Asgari, H., H. Mojiri-Forushani, M. Mahboubi, 2023. Temporal and spatial pattern of dust storms, their polycyclic aromatic hydrocarbons, and human health risk assessment in the dustiest region of the world. Environmental Monitoring and Assessment, 195(1), 76.

Nasabpour, S., H. Khosravi, E. Heydari Alamdarloo, 2017. National assessment of climate resources for tourism seasonality in Iran using the tourism climate index. Desert, 22(2), 175-186.

Papi, R., S. Attarchi, A. Darvishi Boloorani, N. Neysani Samany, 2022. Characterization of Hydrologic Sand and Dust Storm Sources in the Middle East. Sustainability, 14(22), 15352.

Qu, J. J., X. Hao, M. Kafatos, L. Wang, 2006. Asian dust storm monitoring combining Terra and Aqua MODIS SRB measurements. IEEE Geoscience and remote sensing letters, 3(4), 484-486.

Rayegani, B. 2019. Identification of potential dust sources using remote sensing data (Case Study: Alborz Province). Journal of Natural Environmental Hazards, 8, 1-20.

Rayegani, B., S. Barati, H. Goshtasb, S. Gachpaz, J. Ramezani, H. Sarkheil, 2020. Sand and dust storm sources identification: A remote sensing approach. Ecological Indicators, 112, 106099.

Rayegani, B., S. Barati, T.A. Sohrabi, B. Sonboli, 2016. Remotely sensed data capacities to assess soil degradation. The Egyptian Journal of Remote Sensing and Space Science, 19, 207-222.

Rayegani, B., G. Zehtabian, H. Azarnivand, S.K. Alavipanah, S.J. Khajeddin, 2015. LADA method Performance evaluation on soil degradation assessment in the East of Esfahan. Journal of Range and Watershed Managment, 68, 109-129.

Raygani, B., Z. Kheirandish, F. Kermani, M. Mohammdi Miyab, A. Torabinia, 2017. Identification of active dust sources using remote sensing data and air flow simulation (Case study: Alborz province). Desert Management, 4, 15-26

Sarmadian, F., R. Taghi Zadeh Mehrjerdi, 2010. A comparison of interpolation methods for preparing soil quality maps: case study:(Agricultural faculty experimental field). Iranian journal of soil and water research, 40(2).

Shao, Y., 2008. Physics and modelling of wind erosion (Vol. 37). Springer Science & Business Media.

Shao, Y., M. Klose, K. H. Wyrwoll, 2013. Recent global dust trend and connections to climate forcing. Journal of Geophysical Research: Atmospheres, 118(19), 11-107.

Sorkheh, M., H. M. Asgari, I. Zamani, F. Ghanbari, 2022. The relationship between dust sources and airborne bacteria in the southwest of Iran. Environmental Science and Pollution Research, 29(54), 82045-82063.

Stefanski, R., M. V. K. Sivakumar, 2009. Impacts of sand and dust storms on agriculture and potential agricultural applications of a SDSWS. In IOP Conference Series: Earth and Environmental Science (Vol. 7, No. 1, p. 012016). IOP Publishing.

Tajiki, F., H. M. Asgari, I. Zamani, F. Ghanbari, 2021. Assessing the relationship between airborne fungi and potential dust sources using a combined approach. Environmental Science and Pollution Research, 1-12.

TA-Luft., 2001. Erste Allgemeine Verwaltungsvorschrift zum Bundes-Immissionsschutzgesetz. Technische Anleitung zur Reinhaltung der Luft – TA-Luft Stand 12.06.2001.

Tussupova, K., Berndtsson, R., Bramryd, T., & Beisenova, R. (2015). Investigating willingness to pay to improve water supply services: application of contingent valuation method. Water, 7(6), 3024-3039.

Wever, N., 2012. Quantifying trends in surface roughness and the effect on surface wind speed observations. Journal of Geophysical Research: Atmospheres, 117(D11).

Xuan, J., I. N. Sokolik, J. Hao, F. Guo, H. Mao, G. Yang, 2004. Identification and characterization of sources of atmospheric mineral dust in East Asia. Atmospheric Environment, 38(36), 6239-6252.

Zhang, K., S. Li, W. Peng, B. Yu, 2004. Erodibility of agricultural soils on the Loess Plateau of China. Soil and Tillage Research, 76(2), 157-165.

Zhang, L., H. Fukuda, Z. Liu, 2019. Public willingness to pay for sand and dust weather mitigation: A case study in Beijing, China. Journal of cleaner production, 217, 639-645

Zobeck, T. M., 1991. Soil properties affecting wind erosion. Journal of Soil and Water Conservation, 46(2), 112-118.