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Modern techniques for monitoring wind soil erosion

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Abstract: The article presents a scientific literature review in the field of modern methods of monitoring wind erosion of soils such as: visual indicators of erosion, erosion bridge, close-range photogrammetry, cesium-137 and remote sensing cover. The brief description of each method, advantages and disadvantages, conditions and limitations of their applicability are given. When choosing the method, it is necessary to take into account the monitoring conditions, the area of the territory under consideration and the scale of research, time frames, financial and labor resources. It has been established that the most relevant, economically justified and promising, especially on large territories, are the remote sensing methods, which allow monitoring on different scales, and not only estimating the erosion activity, but also predicting it, thus providing the parties concerned with the necessary information for making right, prompt and timely economic decisions, aimed both at combating wind erosion and elimination of its consequences, and for organizing preventive measures as well. To improve the effectiveness of these methods it is also necessary to create databases, expand and accumulate soil information that can help verify, refine, process and calibrate the satellite data obtained. In order to understand aeolian processes and dust particle transport mechanisms one should create integrated methods that include remote sensing data, meteorological data, on the basis of which the improved models and maps would be developed, and erosion processes would be predicted. The scientific literature is mostly devoted to the interpretation of wind erosion in arid and semi-arid zones. The possibility of satellite monitoring of soil erosion in arable fields remains poorly studied. There are also practically no research results available on the transport of chemicals with micro-particles due to wind erosion. Both in Russia and abroad the attempts are made in soil erosion modelling, but the quality of the models is very limited by the lack of field data required for their calibration and verification. Eroded soils in the country are still identified using ground-based methods. However, field studies can only be conducted in a very limited area, in a few key points, and as a matter of fact it is quite complicated to conduct field studies on actively used agricultural lands.

Keywords: soil deflation, satellite monitoring, soil degradation, soil research methods.

INTRODUCTION

Soil erosion is currently understood as a complex of interrelated processes of soil separation, transfer and deposition by surface runoff of temporary water flows and wind. The phenomenon of soil wind erosion arises at the border of solid and gaseous media (soil and air), grows in the atmosphere layer adjacent to the Earth and ends on the ground, water or soil surface (Gendugov, Glazunov, 2007; Duniway et al., 2019).

To study soil erosion, its causes and effects, along with the measures to eliminate it is of great national economic and scientific importance. Soil erosion is a constant, often destructive process which is significantly enhanced as a result of human activity and causes great damage to the national economy.

First of all, the costs are associated with a decrease in volume of products and raw materials, with a make-up for nutrient losses by applying increased doses of fertilizers, with an increase in maintenance cost of roads, dams and other infrastructure, with a decrease in soil water-retaining capacity, which, in its turn, leads to higher irrigation norms, and, consequently, to some related expenses, and, finally, significant costs are required by the erosion control measures themselves. In addition, wind erosion reduces the recreational potential of the territory due to poorer water and air quality, the reduction of wild animals' habitats. Despite the fact that erosion is an important natural process, being additionally enhanced by human activity, it can significantly impact the productivity and nature of land use (Gendugov, Glazunov, 2007; Ypsilantis, 2011; Duniway et al., 2019; Webb et al., 2020). The soils of most densely populated regions are the most susceptible to erosion. This favors the generally accepted idea that erosion in human habitats is mainly anthropogenic in nature.

The mechanisms how wind erosion effects soil are very diverse. This includes a decrease in eroded soils fertility, less arable land area as a result of the formation of ravines and sand encroachment, contamination of agricultural soils with harmful substances, including toxic salts, brought by the wind from the surface of alkaline soils and rock dumps, as well as a decrease in photosynthesis as a result of dust contaminating crops leaf surface. On top of that, wind soil erosion is the main reason for filling air with dust, and the volume of soil dust arriving is so great that it begins to affect the thermal balance of the planet (Gendugov, Glazunov, 2007).

The calculated carbon content in a meter layer of soil is $2.5–10^{12}$ tons, which is three times as high as the content in the atmosphere and 4.5 times as high as in living organisms. Erosion leads to carbon loss from soil, firstly, as a result of mechanical removal from eroded soil, and secondly, during accelerated mineralization caused by erosion, both in eroded and in accumulated soils (Gendugov, Glazunov, 2007). The processes leading to this require in-depth study, but now there is no doubt that one of the few possible ways to remove excess carbon from the atmosphere is to store it in the form of specific soil organic matter (Minasny et al., 2017).

Soil is the basis of the human environment and erosion leads to disruption of this soil function. In particular, ordinary soil dust blown up by the wind causes an increase in the incidence of asthma. The life in a huge megalopolis can be completely paralyzed with a high content of soil dust in the air. The situation is so serious that in many countries the limits of permissible atmosphere dust content are introduced by law.

On top of that, dust can cause epidemics as it contains an increased number of spore-bearing aerobic bacteria. Radioactive dust is even more dangerous, which sources are wind-eroded soils of contaminated areas as well as ash dumps of thermal power plants operating on coals which contain radioactive elements and heavy metals.

The frequency and scale of wind soil erosion manifestation, which have become global, along with the rates and tendencies of its spread are threatening. This is evidenced by numerous materials of the latest international forums of scientists and general public, organized by the Dokuchaev Society of Soil Scientists, the International Society of Soil Science (ISSS), the International Soil Conservation Organization (ISCO), the European Society of Soil Conservation (ESSC), the Soil and Water Conservation Organization (SWCO)

In the world soils on the area of 1.643 billion hectares are subject to erosion, of which to an excessive degree – on the area of 250 million hectares. Water erosion is widespread on the area of 1.094 million hectares and wind erosion – on the area of 549 million hectares (GLASOD, 1990) (https://www.isric.org/projects/global-assessment-human-induced-soil-degradation-glasod). Soil areas affected by these two erosion types coincide only partially. According to direct measurements from a satellite, dust storms, as an extreme manifestation of wind soil erosion, occur in all soil and climatic zones, including in the Arctic, but they most oftenly and steadily repeat in the Northern Hemisphere, in the so-called dust belt, stretching from the west of North Africa, through the Middle East, Central and South Asia to China.

The calculations prove that over the past two centuries erosion has destroyed almost 2 billion hectares of arable land in the world. By way of contrast, now agricultural land is cultivated on the area of 1.5 billion hectares (https://agrovesti.net/lib/tech/reclamation-tech/eroziya-pochv-prichiny-vidy-posledstviya-metody-predotvrashcheniya.html).

Wind erosion can cause irreparable damage both over a long period of time and in just a few hours. Dust (black) storms rather quickly destroy soil top layer, sometimes carrying it away for many hundreds of kilometers. Sometimes such dust, settling, buries whole water reservoirs. We can give an example from the 50s of the last century. Then, during the virgin lands campaign in the steppes of

Kazakhstan and the western part of the Altai Territory, moldboard plowing was used. A drought began after sowing and then a strong wind came to the territory from the west. It took away a significant part of the fertile layer. The dust of the Kazakh and Altai steppes settled even in the Krasnoyarsk Territory (https://agrovesti.net/lib/tech/reclamation-tech/eroziya-pochv-prichiny-vidy-posledstviya-metody-predotvrashcheniya.html).

In Russia wind erosion manifests itself mainly within certain boundaries. In the north it is an irregularly shaped line from Voronezh towards the East. The border goes through Samara, Chelyabinsk, Petrozavodsk, Omsk. Further – to Novosibirsk and then to Eastern Siberia, through Khakassia, Buryatia, Tuva, Chita Oblast'. This determines the application of measures protecting from wind erosion on agricultural lands located to the south. In the Volga region, the North Caucasus, the Urals, and Siberia there are high risks for wind erosion. The area at risk is more than 45 million hectares, including 38.7 million hectares of arable land (https://agrovesti.net/lib/tech/reclamation-tech/eroziya-pochv-prichiny-vidy-posledstviya -metody-predotvrashcheniya.html). Thus, the main deflationary-dangerous focus in the country are steppe and semi-arid zones, especially in the regions with high proportion of arable land (Larionov, 1993).

Over 500 million tons of fertile soil is removed from the country's arable slopes every year due to water and wind erosion. The negative result of these processes is that the country experiences the grain shortage estimated at 15.8 million tons per year. The total damage from water and wind erosion in Russia is more than $ 9.7 billion annually (Ivanov et al., 2016).

Therefore, monitoring of eroded soils in Russia is an important and urgent national issue. From a scientific point of view, the process of wind mass transfer from arable lands is still very poorly studied. The geography of these phenomena is very generally determined, while the transfer of chemicals with micro-particles from fields and their influence on fertility of the soils in zones where particles settle along with their ecological state have not been practically studied (Scientific bases…, 2013).

The development of qualitatively new measuring equipment caused an upsurge in scientific and applied research on wind erosion, expressed in an increase in the level of experimental research. So, when registering and tracking dust raised into the air during soil tillage or as a result of erosion, lidars, solar photometers and photon counter were used; when studying soil translocation by wind in the ground-level layer one uses piezo and membrane sensors with a high measurement frequency, isokinetic dust collectors; for physical modelling of wind erosion – improved field and laboratory aerodynamic installations. Simultaneously, with the development of experimental methods for studying wind erosion, the remote sensing systems based on aerospace surveys were improved, which led to the accumulation of a huge amount of experimental material that makes it possible to analyze the phenomenon of wind soil erosion as a whole process, from the stage of blowing to the stage of accumulation. However, there is no evidence of the existence of such projects devoted to associated study of the full-scale one-off phenomenon of wind soil erosion at the micro-, meso- and macro-levels (Gendugov, Glazunov, 2007).

TRADITIONAL TECHNIQUES FOR MONITORING WIND SOIL EROSION

The scientific approach to the study of wind soil erosion and the development of anti-erosion measures was initiated by the works of the classics of soil science such as V.V. Dokuchaev, P.A. Kostychev, N.M. Sibirtsev, V.R. Williams, their collaborators and followers, who paid attention to wind erosion primarily as a factor in soil formation and transformation, as well as the works of the great researchers of Central Asia: N.M. Przhevalsky, N.F. Dubrovin, V.I. Roborovsky, P.K. Kozlov, G.E. Grum-Grzhimailo, M.V. Pevtsov, G.N. Potanin, V.A. Obruchev, who investigated physical, pedological, geological and geographical aspects of wind erosion in places (Gendugov, Glazunov, 2007). On the basis of the predominantly descriptive, comparative-geographical research method they received the first significant up to the present information about the causes, the intensity and the scale of wind soil erosion manifestation and the ways to prevent it. The expansion of methodological base due to the use of stationary and comparative-analytical research methods made it possible to deepen the conception of the mechanisms of wind soil erosion phenomenon, to obtain some quantitative estimates of its distribution and degree of danger, to initiate anti-erosion measures on the scientific basis. Further qualitative and quantitative growth of research on wind soil erosion is associated with the development and application of modelling methods – physical, mathematical, numerical. Experimental methods for studying the mechanisms of wind soil erosion was initiated by the works of a prominent geologist N.A. Sokolov at the end of the 19th century. The most meaningful results in studying the mechanisms of wind erosion were obtained in the second half of the last century by A.I. Znamensky, G.I. Vasiliev, D.S. Bulgakov, L.N. Gavrilenko, A.S. Kalinichenko and others using instrumental methods based on measuring the translocation of soil particles by wind during dust storms in the field. To study the mechanisms of soil particles separation by wind it was necessary to develop methods of physical modelling based on wind tunnels (Gendugov, Glazunov, 2007).

There is a brief description of the main traditional methods for assessing and monitoring wind erosion.

Visual assessment

In 1967 the United States first developed a methodology for assessing the erosional state of 160 million acres of land over the next 5–10 years. It is important to note that for the time being there were no quantitative indicators accumulated that would allow assessing the erosion activity at a particular moment. For this purpose, The Erosion Condition Classification System (Clark, 1980) was developed, based on the properties of soil surface, which the researcher can estimate in the field and which can be represented in digital terms and further used as a basis for identifying five erosion classes. These numerical values which characterize the classes of erosional state were named Soil Surface Factors (SSF) and varied from 1 to 100 (Clark, 1980; Ypsilantis, 2011). Visual assessment boils down to considering certain soil properties: erosional basement, movement of surface particles, sediments, force of wind gusts in grades, etc. Some of these indicators are still considered when assessing the state of land (Pellant et al., 2005; Ypsilantis, 2011). For the assessment one can use the methodology from the corresponding technical reference books

(Ypsilantis, 2011), considering the location, including the ecological region, comparing the actual values of erosion indicators with the reference values, recording the differences in the corresponding document.

Advantages and disadvantages

The main advantages of visual assessment method are: 1) it is a relatively quick process; 2) observations can be made during field survey; 3) potential erosion problems that require monitoring at a specific location (problem locations) can be identified.

The main disadvantages of visual assessment method include: 1) subjectivity, based on the expert's opinion and assessment; 2) quantitative assessments (grades) may differ from different experts without appropriate training; 3) assessments may vary depending on the observation time relative to the moment when the storm broke out; 4) the ecological area must be known, it requires an appropriate technical guide with reference values and methods; 5) this technique can only be performed by a very experienced, competent and skilled specialist.

Data analysis

The differences between visually assessed parameters and their reference values are recorded in specially provided forms. The differences from the reference values are determined for each of these indicators, afterward the final grade is calculated and the characteristic of stability for the study area, its hydrological functionality and biological integrity are provided.

Erosion bridge (pin method)

The soil erosion bridge is a simple, functional, lightweight and inexpensive tool for assessing wind erosion in the field. It consists of a 4-foot (approximately 1.2 m) long aluminum-bar (or masonry level) that is mounted on support stakes, and pins are used for microprofiling the soil surface beneath. This structure remains in the field for the entire monitoring period (Shakesby, 1993; Ypsilantis, 2011). The distance from the level to the soil surface is measured at 10 fixed points, located evenly along the entire length of each level, with special pins that are lowered to the ground level. These measurements are used to calculate the average changes in soil surface level (Figure 1).

Fig. 1. Erosion bridge used for quantitative assessment of wind erosion intensity in a burned-out area, 2 years after the fire, Idaho (USA) (Ypsilantis, 2011).

The locations of soil erosion bridges and their orientation are chosen randomly within the study area (Blaney, Warrington, 1983). Each location must be accurately recorded with GPS so that it can be considered as a data input point. It is believed that lowering the soil level by 1 millimeter corresponds to blowing out 5 tons of soil per acre (0.405 ha). Repeated measurements on each pin are taken during every inspection and data logging. These measurements indicate a change in the soil surface level, the top layer blowing out, or, inversely, accumulation (Ypsilantis, 2011).

In Russia, a similar method of recording the changes in soil surface level is called the pin method. A pin is a thin metal core with graduations applied to it. The pin is immersed into the soil to zero point. A change in the level of soil surface near the pin makes it possible to estimate the amount of soil accumulation or the amount of losses. The pin method is used both in the study of water erosion and deflation for a long time. In winter, some movement of the pin in vertical direction is possible due to frost soil heaves, which can be excluded by protecting the pin with a conductor pipe (Kuznetsov, Glazunov, 2020).

There are many methods to measure soil surface level as a soil erosion indicator. The most widely used (due to its simplicity and accessibility) is a micro-leveling method. It implies setting rigidly fixed supports on the study site, on which, as the measurement period approaches, one installs a metal rail at a constant height from the soil surface, and a cart with a measuring needle attached to it moves freely along the rail. The measuring needle is equipped with a vernier and allows measuring the vertical coordinate of the point on the soil surface with an accuracy of 0.1 mm. The horizontal coordinate is determined with an accuracy of 1 mm (using a ruler mounted on a rail housing). Having two profiles of the soil surface obtained in the same section at different times, it is possible to determine the soil layer that has been lost or accumulated due to erosion during this time. The method is suitable for the soil close to equilibrium state, when the soil density has approached a certain constant value for given land and season. In the case of loose (sandy) soil there might take place some errors in determining the washout due to soil shrinkage (Kuznetsov, Glazunov, 2020).

Advantages and disadvantages

The advantages of soil erosion bridge are that it is an inexpensive, fast, objective method to assess erosion activity. However, the survey sites and their orientation should be randomly selected to avoid consistent error.

The disadvantages include the fact that the level can be displaced or translocated by people, equipment or animals, as well as when the ground is swelled during freezing, which makes the measurements useless. In addition, the pins are quite thin and somewhat flexible, so if they do not hit the same point during the measurements the values might be inaccurate. Also, the study area itself and the number of study areas are quite small. Using this method it is almost impossible to obtain data on soil erosion in large territories.

Data analysis

The measurements obtained are used to calculate the average value of the change in soil surface level, which can be converted into the erosion intensity, indicating the time interval when this change occurred. In the future one can use the Student's t-test to calculate the average value and the confidence interval, then compare the obtained values (Blaney, Warrington, 1983; Ypsilantis, 2011).

An approximate estimate of the amount of soil loss from deflation can be made by measuring the depth of seed placement. The seeding depth is known and the depth difference can be used to estimate the size of the lost soil layer. The thickness of the soil layer blown away can also be estimated by individual soil stone-remnants, which are found in a poorly cultivated arable layer. In the case of gravelly soil, the thickness of the soil layer blown away can be determined by the gravel accumulation on the soil surface. For this purpose, it is proposed to collect a two-centimeter soil surface layer from study areas with a size of 0.5×0.5 m^2 and, using a sieve with a mesh size of 2 mm, separate the fine soil from the stones and weigh it (Dolgilevich, 1958). Then it is necessary to determine the stone concentration in the soil arable layer using the same sieve. Knowing the stone concentration in the soil and the number of stones accumulated in the study area, it is possible to calculate the amount of fine soil which contained this amount of stones before the deflation by making a proportion.

Photogrammetric method (close-range photogrammetry)

Close-range photogrammetry is an excellent method to obtain detailed information on erosion in areas ranging from 1 m^2 to the entire slope. The software makes it possible to create a digital model of the earth's surface with a mesh density of 1–2 mm and to detect changes in the level of soil surface with submillimeter accuracy on smaller plots. This method is especially effective for monitoring erosion in vegetation-free areas such as roads, construction sites and vehicle-driven off-roads in the wild. It is also suitable for measuring sediment that accumulates in specially designed and installed accumulation traps aimed at monitoring erosion in the watershed area.

Terrestrial (close-range) photogrammetry is a compilation of photographic materials with their subsequent processing and implies a distance between the camera and the object less than 300 m (Matthews et al., 2006). A digital camera requires preliminary calibration to work in the **x**, **y** and **z** coordinate system. Photogrammetric calibration of digital shooting cameras is carried out in order to determine the element value for internal orientation of shooting cameras, including photogrammetric distortion parameters for the camera lens. In this method photogrammetric calibration of digital cameras is performed using images of a 3D-test object, where the test object is a three-dimension field of marked points. Alternatively, during the calibration the area under study is shot at different angles and with overlap, while alignment marks are placed and coded in a circle, and then the object with known parameters (dimensions) is placed in the view area (Matthews, 2008; Ypsilantis, 2011). It is necessary to set one (or more) fixed points as a reference mark for a conditional reference level (a kind of a benchmark) to monitor changes in ground level. For large areas more points are required – 3 or 4. As a support point you can use a bedrock outcrop or a metal core driven deep enough into the ground so that it remains stable, and the core top should be slightly below the ground surface so that it is not hit or displaced and so, in turn, does not create danger to people. The position of the support points is registered with GPS; when they are moved, the metal detector and the GPS receiver are used for monitoring at other sites.

Subsequently, using a computer and some special software (for example, PhotoModeler® or 3DM Analyst software (ADAM Technology, Australia)), a digital surface model is created (Matthews, 2008; Ypsilantis et al., 2011). Using the photo shoots for the surveyed area, the program creates a mosaic based on a complex automatic recognition of the marked points and similar earth surface parameters in different photographs. Primary photo processing can be done in the field in a few minutes. The 3D digital surface models are then analyzed in ArcGIS using ArcMap and ArcScene. To reveal the changes in soil surface level the initially modeled surface mesh is compared with the meshes obtained in subsequent studies.

Advantages and disadvantages

The advantages of this method are the following:

1) erosion activity can be measured directly in the field with high accuracy in a fast and efficient way, while the size of the study areas can vary significantly (from 1 m^2 to the entire slope area);

2) low equipment cost for work in the field;

3) thousands of data input points are received for each study area;

4) the possibility to hide control surveyor's points (cores) below the ground level excludes their displacement, it also allows carrying out recreational activities in the investigated area (cycling, walking, horse riding, etc.) from the safety point of view;

5) detailed maps of soil erosion spatial distribution are created for the entire study area;

6) the photographs themselves and the set of associated data are stored in electronic form.

In addition, this method can be used to validate erosion models.

The disadvantages include the following:

1) currently expensive software required for data processing on large-scale study areas;

2) vegetation can block ground surface, thereby making it difficult to carry out measurements in this part of the study area;

3) at the moment there are very few good experts and competent organizations capable of conducting this kind of monitoring.

Another disadvantage of the method is that any movement of litter, stones and other objects along the ground surface during data processing can be interpreted by the program as soil washout or accumulation. In this case, the analysis results can be significantly distorted if such points are not removed from the database. But incorrect (false) data input points can be deleted from the database during the processing.

Data analysis

ArcGIS (or any other GIS package) is used to determine the volume of soil mounds and excavations during earthworks, as well as the topsoil removal for a surface grid within the site. The total amount of soil loss or gain is divided by the study area to determine soil loss or accumulation per unit area or to express them in tons per unit of eroded area. Terrestrial photogrammetry allows determining the soil loss intensity or accumulation with a centimeter accuracy over large areas (for example, for a slope as a whole) and with a millimeter accuracy for small areas of 1 m^2.

Software (such as ADAM Technology 3DM) typically processes digital photogrammetric information quickly and efficiently to create a project. The method of terrestrial (close range) photogrammetry is very promising and has great potential for direct erosion measurement caused by various factors and human activities.

Dust collectors applying

The methods listed above make it possible to estimate soil losses, i. e. the consequences of erosion. However, they are not informative in the case of studying erosion mechanism and if we do not understand this, it is difficult to control erosion processes and all the more to predict their occurrence. In a simplified form, the processes of wind erosion are the movement of soil mass influenced by air currents. To identify the reasons why this mass moves, it is necessary to be able to measure this movement – to measure the solid phase (i. e. soil) flow during erosion (Kuznetsov, Glazunov, 2020). Currently all kinds of dust and sand collectors, filters, piezoelectric devices are used for this purpose to record the movement of soil particles and so on. (Kuznetsov, Glazunov, 2020). These devices, being placed in the flow, violate its physical characteristics to some extent, which affects the measuring efficiency for the solid phase flow. The less disturbed the suspension flow in the area of the receiving hole or the mouth of such an instrument or device is, the more accurately the solid phase flow is measured. (Kuznetsov, Glazunov, 2020). The main difficulty in measuring the soil phase flow during deflation is a large thickness of the flow carrying soil particles: a continuous dust front during dust storms is often several hundred meters thick. However, the bulk of the soil is translocated in a layer up to 1 m, which greatly simplifies the task and opens up opportunities for measuring soil translocation by wind using simple and affordable methods (Kuznetsov, Glazunov, 2020).

Dust or sand collectors are the most widely used in the study of deflationary processes, which are a box in the form of a parallelepiped, with one of its faces serving as a receiving hole. As an example we will focus on the operation principles of two dust collectors described in the work of M.S. Kuznetsov, G.P. Glazunov (2020):

"… The box is placed on the soil surface so that the receiving edge is perpendicular to the flow. To reduce the resistance to the flow, the box is made flat. Thus, the Bagnold sand collector receiving slit is 110 cm high and 1 cm wide. The dust collector is mounted on a rotating axis and equipped with a wind vane, which ensures the optimal position of the receiving hole relative to the flow – the level of the receiving opening is perpendicular to the wind direction. Soil particles fallen into the dust collector mouth settle into a receiving vessel, which is located under the receiving box below the soil surface level. Often, the inlet slit of the dust collector is equipped with partitions, which makes it possible to assess separately soil transfer in different layers. Dust collectors of the specified type do not let the air flow through them. This enables a significant part of particles, especially small ones, bypass the dust collector. Therefore, the dust collectors of this type have to be calibrated. ...

There is another type of dust collectors, which has an outlet in the back of the storage tank. The dusty flow, entering the storage tank through the receiving opening, is freed from dust there and goes out cleaned through the opening in its back part. An example of a simple device of this kind is a glass flask with a rubber stopper in which two L-shaped glass tubes are inserted. The flask is attached to a bar at a fixed height from the soil surface so that the end of one of the glass tubes is open towards the flow. Soil particles trapped in the mouth of this tube roll into the flask. The flow rate in the receiving opening of the dust collectors of this design will definitely differ from zero, but it will also differ from the speed in the free flow. For greater efficiency of the dust collector it is necessary that, firstly, the flow rate in its inlet is equal to the flow rate at its absence in the given point and, secondly, the flow entered the collector is completely cleared of the soil phase. … Devices with forced air intake, like household vacuum cleaners, meet these requirements. They are equipped with sensors for measuring the flow rate in the nozzle of the intake opening and in free flow at the same height from the surface, on which the measuring device is installed. The sensors make it possible to achieve equal speed in the intake opening and in the free flow…" (Kuznetsov, Glazunov, 2020).

Cesium-137

In recent decades cesium-137 has been widely used to monitor soil erosion (Sac et al., 2008; Ypsilantis, 2011; FAO, 2017; Loughran et al., 2002; Mabit et al., 2008a; Mabit et al., 2008b). Cesium-137 is an artificial radionuclide with a half-decay period of about 30 years. The radioactive contamination with cesium-137 during the nuclear weapon tests in the mid-1950s and 1960s was global, the radionuclide dropped out of the contaminated atmosphere along with precipitation (mainly showers). In addition, the emissions from nuclear enterprises and major accidents (including at the Chernobyl nuclear power plant) were the most significant source of environmental pollution. When ^{137}Cs enters the soil it is immediately quickly absorbed and firmly bound by ion-exchange parts of soil particles and predominantly turns into a non-exchange state in most media (Ritchie et al., 2003; Ypsilantis, 2011). Physical processes of wind and water erosion are the main factors in the movement of the soil particles labeled with ^{137}Cs radionuclide within the same landscape or between landscapes (Ritchie et al., 2003; Ypsilantis, 2011). From the above, it follows that this method makes it possible to estimate the transfer of soil mass as a whole, however, the transfer factors can be any, therefore, the method can be used in limited areas, where only the wind acts as a driving force and other factors (water erosion, plowing of land, etc.) are absent, for monitoring wind erosion.

Soil samples are taken with a hole bore in the study and control areas, which implies the absence of erosion activity. Drill soil samples can be studied layer by layer to reveal the nature of ^{137}Cs vertical distribution along the soil profile. The samples are dried first to an air-dry state, then in the drying oven to an absolutely dry state and then sieved through the holes with a diameter of 2 mm. Test samples are placed in Marinelli vessels or small plastic cups and analyzed on a gamma spectrometer. ^{137}Cs accumulation and removal for each study area can be assessed by comparing the measurement results from this and control area. Soil accumulation/removal assessment for each study area can be carried out using various models, for example, the ^{137}Cs profile distribution model, etc.

There are portable installations for measuring gamma radiation directly in the field, the accuracy of such installations is inferior to laboratory ones, but they are excellent for reconnaissance studies in order to assess general erosion activity and identify especially problematic areas (FAO, 2017).

Advantages and disadvantages

The main advantage of ^{137}Cs method for erosion monitoring is that it is suitable for long-term erosion studies at the scale of the entire watershed or the entire landscape (Ypsilantis, 2011; FAO, 2017). The method is also relevant when assessing wind erosion in large areas, while only one field expedition for sampling is enough, and sampling points can be selected with any density and location in space to ensure the required spatial resolution of the finished project (Sac et al., 2008).

The main disadvantage of the method is that it is not suitable for relatively short-term studies, for example, for assessing the effectiveness of anti-erosion measures. Moreover, the cost of laboratory analyzes with a large number of soil samples can be quite high. One more disadvantage is low concentrations of ^{137}Cs in the majority of regions with wind erosion, which leads to high error in results of soil erosion estimations.

Data analysis

An important part is the conversion of the data obtained on cesium-137 into the indicators of soil washout or accumulation intensity. Despite the fact that the amount of eroded soil is directly proportional to the redistribution of ^{137}Cs activity, the quantitative mathematical expression of this ratio is complex. Soil accumulation and washout assessment in each study area can be carried out with different models.

There are two modelling types: empirical and theoretical models.

The first is based on the calibration of ^{137}Cs activity according to erosion activity data obtained in the experimental field plots empirically, i. e., by physical methods. The resulting equations (statistical models) in the form of exponential equations with constants, as a rule, work only for a specific territory and at a specific time.

It became possible to overcome the shortcomings of empirical models by creating theoretical ones (the second type of modelling), which are based on logical assumptions and algorithms for calculating soil redistribution intensity. In this type the models are divided into two categories: the models for virgin lands and the models for cultivated lands. For virgin lands Profile Distribution Model and Diffusion and Migration Model have been developed.

For cultivated land Proportional Model, Mass Balance Model 1, Mass Balance Model 2, Mass Balance Model 3 are used (Mabit et al., 2014; FAO, 2017).

In the future one can obtain three-dimensional images of ground surface (Digital Elevation Model) and build maps of eroded areas using the software.

Wind erosion modelling

Wind erosion modelling began in the early 60s for a semi-quantitative assessment of soil loss. Wind erosion modelling has been primarily a semi-empirical method and the models are relevant only for specific sites where research is carried out, there is no universal reliable model. Empirical models are the simplest and based on observations/experimental data, that is, they reflect facts and help predict what will happen in the future. Such models have some limitations and disadvantages, which include the lack of information on the spatial distribution of erosion, however, these disadvantages can be overcome with GIS technologies. Physical models are based on the knowledge of fundamental erosion processes and the implementation of the law of conservation of matter and energy. The required parameters can be measured in theory, in practice, however, a significant number of parameters require constant calibration. These include models such as Soil and Water Assessment Tool (SWAT) (https://swat.tamu.edu/), Erosion Model for Mediterranean regions (SEMMED) (Jonga et al., 1999), Water Erosion Prediction Project (WEPP) (http://www.fao.org/land-water/land/land-governance/land-resources-planning-toolbox/category/details/en/c/1236427/), USLE, MUSLE, RUSLE and many others (Karydas et al., 2014; Pandey et al., 2016). The mechanism of the model operation as well as the preparation of the input data are often complex, this, as a rule, requires investment of money and time since it includes the data limited by the opinion and competence of the expert and by a set of field research results. In addition, the models are designed for monitoring small areas. These limitations can be overcome by using satellite data in combination with GIS, which allow tracking erosion in dynamics, controlling changes in erosion processes in time and space, which is the basis for assessing, controlling and predicting erosion.

The main example is wind erosion equation (WEQ – Wind Erosion Equation) (Woodruff, Siddoway, 1965; Shrestha, 2008). It has been tested in different places and Klik's works (2008) report that in combination with GIS this equation gives quite adequate results in identifying areas (territories) with wind erosion risk.

Wind erosion equation (WEQ) allows predicting soil loss depending on a number of factors:

$$Q = f(E, I, K, C, L, V),$$

where Q – possible soil loss from wind erosion per year from a surface unit;
E – soil wind erodibility dependent on its lumpiness (A) and a soil crust, assessing with coefficient F_s;
I – slope;
K – coefficient of furrow roughness;
C – climatic index of soil wind erosion, dependent on the average wind speed V_z and soil moisture W;

L – length of unprotected field part down the wind;
V – soil-protective equivalent of vegetation cover and crop residues:

$$V= RSK_0,$$

where R – mass of vegetation cover or crop residues per unit area;
S – coefficient assessing total surface of plant elements;
K_0 – coefficient assessing spatial plant distribution.

GIS models for erosional process development was built with growing computer technologies. For example, wind erosion equation (WEQ) is widely used to estimate wind erosion in Mongolia (Mandakh et al., 2016) in the ArcGIS environment, the model includes meteorological data, the normalized difference vegetation index (NDVI) values obtained with MODIS, a digital relief model and a soil map of Mongolia. In the United States they have carried out the studies on wind erosion modelling both at the field scale and at the regional level. A modified equation was used for this purpose – revised wind erosion equation (RWEQ), GIS and Landsat images (Zobeck et al., 2000). GIS wind erosion models were developed within the framework of the WEELS projects, Wind Erosion Prediction System (WEPS) and GIS-RWEQ (Borrelli et al., 2017), sponsored by a number of European countries – EUROPEAN SOIL DATA CENTER (ESDAC).

The WEELS model provides a forecast of erosion advancing at three scale levels (Thiermann et al., 2002). At the regional level it enables to identify problem areas which require more detailed study. The next level is to determine wind erosion risk at the level of a particular site based on such initial parameters as topsoil characteristics, field length, prevailing wind directions and wind barriers. The third level, which requires the most detailed data, provides the modelling of wind erosion impact for a 30-year period and the forecasting based on possible climate change scenarios and various land use options. The procedure above for identifying problem areas and fields with potential erosion risk provides a search for “hot spots” of wind erosion at the regional level. The required initial data are available in most European countries. For more detailed studies at the level of specific fields it is necessary to have appropriate data on the topsoil, data on the field shape and the wind barriers. In many European countries these data, completed to different degree, can be obtained from existing digital datasets. If such data is absent then it is necessary to carry out field studies and their results should be digitized.

The approach focused on identifying areas with potential wind erosion risk at different territorial levels allows focusing attention and financial resources on the most vulnerable areas. Further, it is justified to carry out detailed modelling and create a forecast of wind erosion real risk in the identified "problem" fields (Thiermann et al., 2002).

Soil susceptibility to erosion depends on many factors, these dependences are far from linear and cannot be described with classical statistical approaches accurately enough. Over time, models undergo changes and improve. For example, a combined method is used to predict wind erosion – a combination of a genetic algorithm and an artificial neural network (hybrid Genetic algorithm – Artificial neural network method GA-ANN method) (Kouchami-Sardoo et al., 2020). Factors such as gravel amount on the soil surface, soil crust, very fine and very coarse sand, aggregate stability, calcium carbonate equivalent were identified in the course of genetic analysis and added to the model as the most significant parameters affecting soil susceptibility to wind erosion (in the conditions of Iran). Further, a neural network was developed which allows predicting erosional changes in response to the spatial variability of the selected factors listed above.

SATELLITE MONITORING

Remote sensing data (aerial and satellite images) are widely used in mapping and monitoring soil erosion (Andronikov, 1979; Vrieling, 2006; Vrieling et al., 2007; Alewell et al., 2008; Kosmadakis et al., 2015). Recently satellite data have been especially actively used, they allow studying and mapping soil erosion in large areas by direct deciphering the areas of eroded soils (Vrieling et al., 2008) and the erosion consequences, also they make it possible to assess and model the risk of soil erosion (Siakeu, Oguchi, 2000; Jain et al., 2002; Gitas et al., 2009). The use of satellite data is distinct in less involvement of expert opinion, less efforts and time, these data can serve as a basis for both empirical and physical models when assessing erosion degree.

A number of works have shown that satellite data can be used to map wind erosion, detect the areas affected by wind erosion and record the time it takes to recover the areas affected by wind erosion. For example, Collado et al. (2002) applied a dynamic or multi-temporal comparison approach to map areas during desertification in Argentina using Landsat TM images over different shooting time. Remote sensing digital image analysis has been used to monitor desertification in San Luis province, where signs of severe landscape degradation can be observed in recent decades. Two Landsat images (from 1982 and 1992) were compared to assess the potential for using remote sensing data analysis to monitor desertification. After geometric and radiometric corrections, the multi-temporal comparison was used to identify the areas with greatest degradation degree. Spectral decomposition simplifies the analysis of the areas with heterogeneous cover, the difference between the "decomposed" images of sand or water allows determining the movement of dunes, trends in vegetation recovering, changes in water bodies due to changed precipitation and land use patterns (Collado et al., 2002).

Remote sensing is used to study erosion in order to obtain initial data for erosion models, for indirect soil erosion assessment by analyzing the vegetation cover, as well as for direct determination of erosional landforms and erosion stages. The basic principle of eroded and accumulated soil identification is based on the assumption that the spectral characteristics of the reflection of accumulated and non-eroded "healthy" soils are different. These differences are explained by the changes in chemical and physical properties of topsoil, triggered by soil particles transport and their accumulation (Žížala et al., 2019).

Thus, the soil properties changed by erosion processes, which find a spectral response in general spectral soil characteristics, at the same time can be used as spectral indicators of soil erosion. These are the properties that have undergone changes either as a result of selective alienation or movement of light surface particles, for example, organic matter content and granulometric soil composition (Schmid et al., 2016; Žížala et al., 2019), or as a result of the upper fertile soil layer washout or its mixing with the underlying horizons, such as carbonate, iron oxides and coarse material content (Žížala et al., 2019). The possibility and accuracy of identifying eroded soils using spectral images largely depends on the intensity of erosion processes, on the one hand, and on the corresponding changes in the spectral characteristics of disturbed soils, on the other.

The remote sensing methods traditionally used to locate eroded lands usually involve visual interpretation of the images based on the interpretation of soil color and its change caused by erosion processes (Sepuru, Dube, 2018; Žížala et al., 2019).

In recent years, satellite data quality and the use of remote sensing, including preliminary (primary) computer image processing, and advancing automatic classification methods have made it possible to analyze large areas for less time, as well as with a quantitative accuracy assessment of these classifications. The classification methods based on pixel-by-pixel spectral analysis are rapidly introduced. However, their application can be problematic in cases with significant spectral variability within the same class or with a complex effect from different surfaces, especially in conditions of high soil cover heterogeneity. The literature notes the need for additional auxiliary information to accurately classify the types of erosion manifestation, as well as for a combined approach to automatic classification and visual interpretation. The use of non-persistent (vague) classification, mixed spectrum analysis (subpixel analysis) or objective-oriented classification ("space-contextual" image classification) can be useful in solving the aforementioned problems associated with the methods based on minimum image elements (pixels). At the same time, the use of data with a higher resolution in the spectral range (hyperspectral data) is very promising in improving the accuracy of eroded soils classification (Schmid et al., 2016; Žížala et al., 2017). Further development and wider application of this method is expected when using data from hyperspectral sensors such as EnMAP (Germany), PRISMA (Italy), HISUI (Japan), SHALOM (Israel, Italy) or TianGong-1 (China). At the moment the most commonly used multispectral data from the Landsat and SPOT series or the high-resolution data obtained with IKONOS and QuickBird are used to study soil erosion (Sepuru, Dube, 2018). Relatively recently launched Landsat-8 and Sentinel-2 satellites with improved radiometric and spatial characteristics provide free access to multi-temporal data suitable for constructing erosion processes maps. At the moment it is required to verify their applicability.

Despite the advances in digital image analysis techniques and the development of new satellite sensors, there are still gaps in knowledge which limit the application of these techniques to assess eroded soils.

There are several main limitations:

1) Assessment of large areas with fields which are distinct in the variability of soil conditions (soil moisture, uneven soil surface, soils covered with vegetation, litter, dust, soil crust). To reduce these effects, it is necessary to use appropriate methods and a multi-temporal approach. Until now most research has focused on the erosion assessment at local scale, while regional and global levels require significantly advanced research.
2) Need for accurate atmospheric corrections and masking of clouds and their shadows.
3) Differences in environmental state, especially heterogeneity of soil cover structure (different soil types and parent material, anthropogenic disturbances) (Žížala et al., 2019).
4) Specific character associated with washout/accumulation. Erosion as well as accumulation of soil material can lead to similar indicators of surface soil properties inherent in both washed out and accumulated soils.
5) Lack of the satellite data for previous years and the associated difficulties in determining the initial thickness of fertile soil layer, soil properties and erosion influence even at the local level.

As an example of such studies we can use the data published in 2019, based on study materials on erosional degradation of agricultural land in the southeast Moravia (the Czech Republic). The purpose was to assess the possible joint use of a) time-series of optical multispectral images obtained from the recently launched Sentinel-2 satellites, b) time-series of orthographic images obtained from the air, as well as c) results of field surveys to identify spatial erosion spread and delimitation of the soils eroded on the regional level. The study uses an approach based on multi-temporal classification of satellite data to assess the spatial distribution of erosion-degraded soils over a significantly greater spatial distance than in previous studies. In the long term, it is planned to develop a methodology based on this approach, suitable for regular monitoring of soil degradation on large areas.

The study showed that the satellite data analysis can accurately distinguish between non-eroded and heavily eroded soils. However, the application of the method for a more detailed classification of various erosion stages, including transitional (for example, moderately eroded soils) has not shown satisfactory results. The overall accuracy level with automatic independent classification reaches 55.2% to identify eroded (strong and moderate) and non-eroded soils, and 80.9% for distinguishing only one eroded class. The classification accuracy increased to 86.9% after visual clarification based on orthographic images. A lot of limitations remain when using this method despite its high accuracy. Many of these limitations and gaps have been found in automatic classification. Some problems are associated with variability of soil cover, masking effects of various objects (clouds, vegetation, litter), as well as the spectral distinction of certain classes. The application of this method is limited by soil and geological homogeneity of studied areas. With the help of this approach, in long-term perspective it will be possible to obtain valuable and accurate information on soil erosional degradation. However, it requires follow-up revision and enhancement of the method.

Earlier studies (Shrestha, 2008) provide an example of remote sensing use and the approach described in the Global Assessment of Soil Structure Degradation (GLASOD) for monitoring wind erosion (https://www.isric.org/projects/global-assessment-human- induced-soil-degradation-glasod).

The interpretation of satellite images was carried out monoscopically using combined color images of the appropriate scale. To create a combination of false color images one normally uses a combination of channels: Landsat TM channel 4 (red), TM channel 5 (green) and TM channel 3 (blue). For ASTER and SPOT images the ideal combination was channel 3 (red), channel 2 (green) and channel 1 (blue). Once obtaining the color image it was used to assess and monitor wind erosion, following the GLASOD guidelines (https://www.isric.org/projects/global-assessment-human-induced-soil-degradation-glasod).

If a stereo pair of satellite images is available (for example, an

ASTER or SPOT stereo pair) data interpretation can be carried out with a stereoscope or directly on a computer. A stereo pair can also be generated if digital topography models (DTMs) or terrain contour data are available. To obtain a stereoscopic site image from a satellite image, for example DEM and GIS-system, you can use the ILWIS software (https://www.itc.nl/ilwis/). But such approaches can be used only for a very large scale of erosion processes.

Advantages and disadvantages

Satellite monitoring of wind soil erosion is a relatively economical, fast and impartial way to obtain information about the surface over large areas, including in hard-to-reach places. Compared to terrestrial methods, fewer people are required for satellite monitoring, in addition, satellite images contain a large amount of extra information. When using satellite images, images of the same territory can be obtained at certain time intervals, thus making it possible to track the dynamics of changes in the observed processes. Moreover, digital images are constantly available for further analysis using various techniques and for evaluating various parameters and characteristics. Satellite data have great potential for timely, cost-effective and reliable assessment of soil erosion over large areas, as well as in the areas where field research is impossible or difficult.

The use of satellite images has significantly expanded the ability to quantify and monitor soil erosion at the local, national and regional levels. In fact, this is the only method for mapping soil erosion since it allows exploring large areas, as well as considering the size and shape of erosion phenomena (Sepuru, Dube, 2018).

The disadvantage is that multispectral data are proxy data, that is, they are in the form of spatial relations and dependencies or spectral characteristics of certain properties rather than in the form of direct measurements of soil erosion indicators. Therefore, it is necessary to double-check the received information on-site (verification, calibration). Low spectral resolution of the sensors is also a limiting factor. Satellite images can only determine surface soil properties if this is not impeded by vegetation cover (Sepuru, Dube, 2018).

Data analysis

Analyzing “raw” satellite data is a very time-consuming process if it is not automated. Fortunately, the advances made in recent years in the field of automation of satellite image processing can significantly reduce effort and time costs.

PROMISING DIRECTIONS IN DEVELOPING METHODS FOR MONITORING WIND SOIL EROSION

The USGS has developed a simple method to estimate wind erosion using digital multispectral satellite data (http://terraweb.wr.usgs.gov/projects/RSDust/). This simple model allows creating images which highlight areas of low vegetation and soil density and high reflectance coefficient. Typically, it automatically highlights two important parameters of wind erosion (namely, vegetation cover / density and general soil surface type). Using this algorithm, it is possible to create an image which shows the areas where these two states are observed simultaneously. In this image map of exposure to the first-order aeolian erosion different color shades indicate different levels of low vegetation density and high soil reflectance coefficient, they serve as a guide to the relative level of potential/exposure to wind erosion and can be used to derive the value of erosion mapping index (EMI) at each pixel.

Wind erosion and dust emissions are influenced by climatic, soil properties and vegetation cover characteristics, which largely determines the territory potential and its ecological state and stability (Webb et al., 2017). The ecological state can be characterized by vegetation cover structure (for example, such ratios as the area covered with vegetation and open soil spaces; the distribution of open areas between plants and the height of vegetation cover), determined by different plant communities. The structure of vegetation cover significantly affects the aeolian process, for example, the distribution of open spaces between plants where we can observe a non-linear increase in wind erosion. A model based on these statements has been developed that reflects surface elements which are not subject to erosion, which uses the size and the distribution of open spaces between plants (areas subject to erosion forces) to obtain a ratio between the maximum shear force and the average particles shear force on the studied surface (Okin et al., 2006).

Chappell and Webb propose to improve wind erosion modelling, mapping and monitoring using surface albedo data. In the work (Chappell, Webb, 2016) the ratio of closed areas to the proportion of shaded areas in the studied territory is established, direct dependences between the measurements of shaded areas and wind tunnel data are shown, thus providing direct calibration of key aerodynamic properties. The estimation of aerodynamic properties by albedo makes it possible to assess wind erosion in various territories and on all platforms: from field studies to data obtained from the air or satellite data available to the public. This approach demonstrates overflow and complexity of existing models and suggests using a simpler but at the same time more accurate model. This model estimated the temporality of predicted horizontal mass flow at various points in Australia, and as a result, it found the variations between different land cover types that would not have been possible to detect by traditional models. The new approach opens up new opportunities in studying wind erosion dynamics in time and space and also sheds light on aeolian processes at various scales (Chappell, Webb, 2016).

In the United States various services regularly determine the content of aerial suspension and solid particles in the air, mainly for assessing air quality and predicting dust content not only in the cities but in the national parks and other wild areas either (services such as IMPROVE (https: / /airquality.ucdavis.edu/improve)). However, such services of a national scale do not allow establishing a connection between air quality indicators and decision-making strategies in regions with developed erosion. Existing agencies AERONET (https://aeronet.gsfc.nasa.gov/) and EPA (https://cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/display.abstractDetail/abstract/887) collect and provide information for various dust prediction models. These models are relevant for assessing dust content in the air from the point of view of health threats or limiting traffic load, but among other things they are restricted by a rather coarse spatial resolution (N 1–100 km) and low sensitivity to changes in soil and plant conditions (Webb et al., 2017). However, there is room for improved monitoring and assessment of wind erosion based on the combined use of different approaches, models, datasets, remote sensing techniques, etc. First, advanced models are needed that reflect the dependence between land use, soil type, vegetation and wind erosion. Secondly, these models need testing in different conditions (in landscapes and at different economic uses). For this reason, some long-term standardized measurements (meteorological observations, satellite data, wind tunnel and dust collector data, etc.) of wind erosion, dust emissions and factors influencing them are also necessary to extend and improve these models. Thirdly, all these actions must be well coordinated and complementary to achieve successful results, which is expressed, for example, in the public access to information among the participants of this kind of collaboration. An example of such a project is the National Wind Erosion Research Network created in 2014 in the USA, the purpose of which is to compile and analyze the necessary data for forecasting and assessing wind erosion, understanding the main processes of wind erosion at various scales and at various levels, as well as in the formation of recommendations for making any economic decisions with various risks of wind erosion (Webb et al., 2017).

However, in the overwhelming majority of cases we are talking about deciphering wind erosion in arid and semi-arid zones. There are practically no studies on the possibility of satellite monitoring of wind soil erosion in arable fields. At the same time there are practically no studies on the transfer of chemicals with micro-particles as a result of wind erosion.

In recent years some global products for detecting dust emissions from satellite data have appeared (for example: https://gmao.gsfc.nasa.gov/reanalysis/MERRA-2/). MERRA-2 is the first global product of repeatable analysis, which, in addition to standard meteorological analysis, assimilates satellite observations of suspended particles in the atmosphere and provides information on their relation with other physical processes that are considered in the framework of climate research. They allow obtaining data on dust content in the atmosphere with a frequency of several hours (3 hours – Gelaro et al., 2017). The GOCART model in combination with the GEOS atmospheric model allows tracing the life cycle of 5 types of suspended particles mixed in the external environment: dust, sea salt, black carbon, organic carbon and sulfate. Regional aspects of global distribution of suspended particles were investigated using MERRA-2 for the main territories producing this or that aerosol type. Seasonal variations in dust and biomass combustion (carbon-based) were found in all regions. A significant increase in sulfates is noted in regions where volcanic eruptions have taken place. In the Asian region a high carbon content was recorded in Siberia after the 2003 fires. Dust dominates in North Africa and periods of intense dust transport (as, for example, in 2010) are also recorded. This information can potentially be a good source of data on wind erosion of arable soils, however, the studies on the possibility to use it for monitoring wind soil erosion have not been carried out yet.

FINDINGS

Each of the considered methods for assessing and monitoring wind erosion has both advantages and disadvantages, therefore, when choosing a method, the monitoring conditions, the area of studied territory and the scale of research, the time frame, the financial and labor resource should be considered.

The method of visual assessment is not a direct measurement of wind erosion, it is based on the determination of indirect indicators, which, with a comprehensive examination of a specialist, allow the territory to be attributed to one or another erosion class. It is applicable at various levels: local, regional and national (Ypsilantis, 2011). The method is inexpensive and fast, the assessment accuracy and correspondence depends on the specialist's training level, the conclusions of different experts may differ. In general, the method provides an overall assessment of the state ("health") and erosion degree of lands both in short and long terms. However, with the expansion of research territory the method becomes too time-consuming.

The erosion bridge or pin method is a direct measurement of erosion activity, inexpensive and fast (Ypsilantis, 2011), accurate enough if there was no pins displacement but time-consuming; the result reliability depends on the samples numbers. The application is possible only at the local level (locally), the method is effective and is often used in areas after fires. In addition, the method is unacceptable on farmland since the bridge structures create obstacles for the operation of agricultural equipment or may simply be displaced, in which case the results become invalid.

Close range photogrammetry is also a direct measurement, the application is limited to the local level, not suitable for monitoring large areas. The method is very accurate, reliable and fast, however, the data analysis requires expensive software and precise camera pre-settings and calibration. It is characterized by high efficiency and is often used for monitoring erosion on burnt-out lands and for long-term observations. This method is the most promising among the methods based on the changes in soil surface level. The advantages of the method also include the simplicity of obtaining photographs of the studied surface. The disadvantages are its high cost and sophisticated equipment for extracting the required information from these photographs.

The radioactive cesium method is accurate, reliable and fast and is used to monitor erosion at the local and regional level. As some drawbacks we can note expensive laboratory tests and research, especially with a large number of samples taken. It is used mainly for long-term monitoring of erosion processes (40 years and more). It is suitable for monitoring wind erosion only if there are no other factors for soil particles transfer (water erosion, agro-technical treatments, etc.).

Satellite monitoring is based on the measurement of indirect parameters, it is applicable at the local, regional and global levels, fast and inexpensive, quite reliable and accurate. The satellite monitoring method makes it possible to track the state and the trends in erosion advancing, reflects the susceptibility of lands to erosion degradation.

Thus, the most relevant, cost-effective and promising, especially in large areas, are the remote sensing methods that allow monitoring at various scales, assessing erosion activity as well as predicting it, thus providing the interested parties with the necessary information for making correct, time-efficient and relevant economic decisions aimed both at combating wind erosion, eliminating its consequences and organizing preventive measures. For higher efficiency of these methods it is also necessary to create databases, expand and accumulate the soil information, which makes it possible to verify, clarify, process and calibrate the received satellite data.

To understand aeolian processes and mechanisms of dust particle transport one should develop complex methods, including remote sensing data, meteorological information, which are the basis for necessary model advancing, map creation and erosion processes prediction.

The scientific literature is mostly devoted to the interpretation of wind erosion in arid and semi-arid zones. The possibility of satellite monitoring of soil erosion in arable fields remains poorly studied. There are also practically no research results available on the transport of chemicals with micro-particles due to wind erosion.

Both in Russia and abroad there are some attempts to model erosion but the quality of the models is very limited by the lack of field data required for their calibration and verification.

Eroded soils in the country are still identified using ground-based methods. However, field studies can only be conducted in a very limited area, in a few key points, and as a matter of fact it is impossible to conduct field studies on actively used agricultural lands.

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