MANAGEMENT OF SOIL EROSION IN CONDITIONS OF DIFFERENT CROP ROTATIONS AND SHELTERBELTS FUNCTIONS

Valerii KOLIADA, Pavlo NAZAROK, Oleksandr KRUGLOV, Alla ACHASOVA

National Scientific Center "Institute for Soil Science and Agrochemistry Research named after O. N. Sokolovsky" NAAS, 4 Chaikovska Street, Kharkiv, 61024, Ukraine, Phone/Fax:057/7041669; E-mails: koliadavalerii@gmail.com, pavelnazarok@gmail.com, alex_kruglov@ukr.net, alsisa971@gmail.com

Corresponding author: koliadavalerii@gmail.com

Abstract

The results of modeling of potential soil losses due to surface soil runoff according to the current DSTU 7904: 2015 are considered. "Soil quality. Determination of potential threat of erosion under the influence of rains" on the slope of the field with contour-ameliorative organization of the territory (CAOT) on the lands of SE" DG Donetske" of NSC "Institute of Soil Science and Agrochemistry named after O.N. Sokolovsky" Bahmutsky district of Donetsk region, Ukraine. The main tasks of the work were: determination of potential soil losses on the slope of the fields to choose the more appropriate way of management in terms of using the working areas in the research system for black fallow, field crop rotation (excluding the impact of forest shelterbelts and taking into account the impact of shelterbelts), soil protective crop rotation. The use of working areas A and B under black fallow expectedly led to the excess of permissible soil losses in both areas, modeled according to the current DSTU 7904:2015 in Ukraine. Exceeding the allowable soil losses from erosion also occurred in section A under the conditions of its use for field crop rotation. Under the conditions of use of areas for soil protection crop rotation and in the conditions of functional compliance of forest shelterbelts, soil losses in both plots remain within the norm. In order to prevent the concentration of surface runoff from both working areas (A and B) in the lower part of the landfill, it is recommended to periodically apply the "rehabilitation" period with the organizing of soil protection crop rotation after black fallow.

Key words*: *soil runoff management, modeling, crop rotations, forest reclamation measures, shelterbelts.

INTRODUCTION

Problems of agriculture adaptation to climate change in the intensification of erosion processes attract the attention of scientists worldwide [1, 22, 24, 26, 27, 30]. Agriculture in Ukraine is an economically important sector, the profitability of which largely depends on climatic conditions, especially on lands at risk of water erosion processes, the area of which is 12 million hectares. Due to this fact, the impact of climate change on the productivity of growing certain crops and soil erosion degradation of Ukraine has become widespread in many domestic and foreign publications [3, 8, 9, 23, 28, 29]. According to research by V. Balabukh [2], in Ukraine since the 90s of the twentieth century, there emerged a tendency of increased number of heavy rains and showers, which reached the criteria of dangerous. In the XXI century, this trend has become even more pronounced throughout Ukraine. For example, in May 2020, after a dry, snowless winter, which caused overdrying and extremely low vegetation density, precipitation fell in a short time, which in many eastern and southern regions was twice the long-term norm.
Donetsk region, located in the east of the country and belongs to the Steppe soil-ecological zone is no exception. The annual amount of precipitation in this zone varies from 330 mm in the south to 500 mm in its northern part, and the appearance of water erosion processes is mainly due to the torrential nature of precipitation in the summer. In general, the Steppe of Ukraine features a high degree of vertical and horizontal detachment of the terrain, and the steepness of the slopes and the depth of local erosion bases have repeatedly been the main

reasons for the intensive development of erosion processes [33].

Given this, to combat soil erosion in the most erosive regions of Ukraine in the 70s-80s were organized base farms with contour and amelioration (reclamation) organization of the territory (CAOT), taking into account the division of land into three soil ecological and technological groups according to surface angle, the altered structure of sown areas with a significant share of perennial plantations and periodic introduction of soil-protective crop rotations [28, 29].

Since the contour and amelioration organization of the territory began in the 50s-70s, many elements of the system (such as shafts, terraces, forest shelterbelts) do not function properly nowadays. In addition, the intensification and growth of agricultural production in the region in combination with the rejection of periodic application of soil-protective crop rotations have created the preconditions for soil erosion from sloping areas and the development of erosion processes. On the other hand, the results of contemporary erosion modeling are widely used by land management institutions of Ukraine and relevant divisions of large agricultural enterprises engaged in the development and planning of soil protection measures on agricultural lands. Such modeling involves GIS methods of Earth's remote sensing, which confirmed the high efficiency and met the worldwide existing standards in land use planning [4, 10, 11, 12, 13]. At the same time, the priority of the water regime as an evaluative factor in the study of erosion processes is that oftentimes it limits the fertility of soils in the region [3]. The possibilities of using GIS to study the erosion processes are unprecedented and allow real-time monitoring of areas with a possible risk of erosion or with erosion processes that have already taken place. A number of works are devoted to this issue [6, 11, 32].

The forecast for erosion processes development is based, basically, on the results of their mathematical modeling. In the future, after modeling different scenarios of erosion processes and their minimization with anti-erosion measures, it is possible to identify actions of a particular group (or their combination) for differentiated implementation on the lands of various agro-technological groups. The use of these satellite systems in modeling soil losses following current standards is one of the modern multifunctional tools for assessing the manifestations of erosion processes. It allows studying the soil, erosion dynamics, prospects for renewal or implementation of new erosion measures [23].

In general, studying erosion by modeling different scenarios of its manifestations land use management can be considered one of the most common and promising areas in recent decades [4, 5, 28, 30].

That is why the main purpose of our research is to assess the potential soil losses as a result of modeling of surface runoff according to the current DSTU 7904: 2015 "Soil quality. Determination of potential threat of erosion under the influence of rains" [7] in different agricultural technical conditions: under black fallow, under field crop rotation without taking into account the effect of forest shelterbelts, under field crop rotation taking into account the effect of shelterbelts, under soil protective crop rotation. The works were planned to determine how they correspond to the minimum allowable soil losses recommended for the region.

MATERIALS AND METHODS

The study of potential manifestations of erosion processes and possible soil losses in the conditions of various crop rotations and limited functioning of shelterbelts was carried out within a separate field with partially functioning forest belts of contour-ameliorative agro-landscape in Bahmutsky district of Donetsk region in 2021.

Soil type - Chernozem ordinary slightly-eroded low-humificated with light loam composition on loess-like loam. The humus content in the arable layer (0–30 cm) – 4.5–4.7%. The reaction of the soil solution is 6.5-6.9 units. Gross reserves of nutrients in the arable layer: nitrogen - 0.24–0.34%; phosphorus - 0.13%; potassium - 1.52%.

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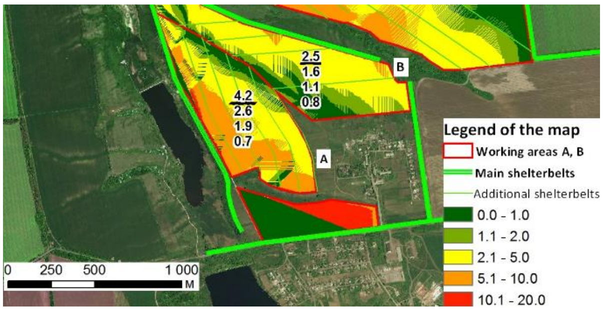
The obtained terrain data were processed and interpreted by analyzing STRM and other time-varying satellite images using GIS programs such as ARC-GIS®, QGIS®.
Topographic maps with an appropriate scale M 1:10 000 were used as a cartographic basis.
GIS technics and approaches to calculate potential soil losses were based on M. F. Hutchinson's works that allowed establishing geomorphological parameters of the studied area by constructing a digital terrain model, followed by calculating steepness and slope length values [14, 15, 16, 17, 18]. The other data related to hydrological and soil indicators, responsible for determining the amount of potential loss, were established according to GIS reference data and other literature sources [19, 20, 21, 25, 31]. Mathematical modeling was performed according to the current DSTU standard in Ukraine, and it included the following scenarios for the use of the work area in the research system: 1) black fallow (open soil surface); 2) field crop rotation (excluding the influence of forest shelterbelts); 3) field crop rotation (taking into account the impact of forest shelterbelts); 4) soil-protective crop rotation. The modeling of potential soil losses provided for the use as a predictive model of soil losses due to water erosion under the influence of rain equation C. Ye. Mirtshulava (described in DSTU 7904-2015), that included parameters: the density of the soil structure; the average frequency of the pulsation velocity; weighted average diameter of waterproof units; runoff coefficient; average rainfall intensity; slope angle degree; a coefficient that takes into account the deviation in the movement pattern of the slope runoff from the movement of an equal layer of water accepted in the calculation scheme, defined as the coefficient of furrowing; roughness factor; slope length; rainfall duration; indelible (permissible) speed at the height of the protrusions of the roughness; free fall acceleration; water density; density of the solid phase of the soil; porosity of structural soil particles.

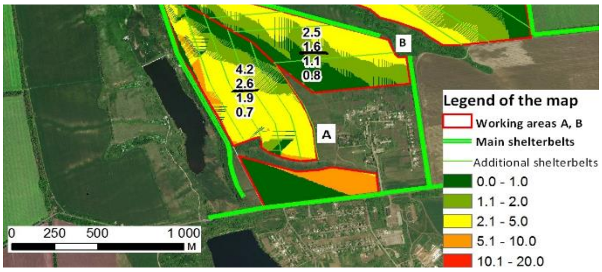
RESULTS AND DISCUSSIONS

This section presents the result of the potentially possible soil losses simulation from the slope in the research system under the conditions of its use under four scenarios of use (black fallow, field crop rotation (excluding the impact of forest shelterbelts), field crop rotation (taking into account the impact of shelterbelts), soil protective crop rotation according to the valid DSTU) obtained a number of values presented in two columns for two fields - working areas in the research system (AB).
Map 1 presents the results of modeling potential soil losses under conditions of their use under black fallow.



Map 1. Potential soil losses after using the working area in the research system for black fallow
Source: Authors' results.

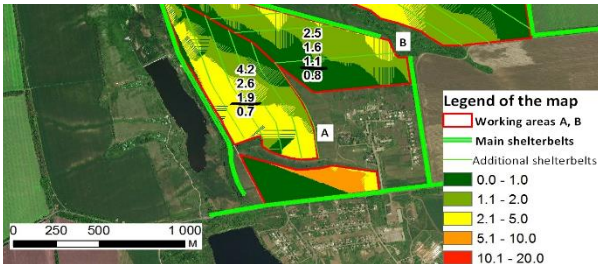
Soil losses from water erosion are the largest because when using the field for black fallow, the field surface is entirely exposed to water denudation and is not protected by any vegetation. In our case, for field A (yellow and orange), it is 4.6 t/ha, and for field B (primarily yellow) it is 2.5 t/ha per year. Along the left edge of field A, the concentration of surface runoff is recorded, followed by its accumulation below this field (red color). The area to outline the runoff build-up is characterized by the value of potential soil losses ranging from 10 to 20 t/ha annually.The following Map 2 presents the results of modeling potential soil losses from erosion with the provision of field crop rotation on two plots, represented by: black fallow, winter wheat, corn dredge, spring barley, sunflower. Thus, in this crop rotation, two crops (wheat, barley) represent cereals of continuous sowing, corn dredge and sunflower - technical row crops with the wide row spacing. Black fallow represents a technical link of crop rotation, during which the field surface remains exposed to water erosion. (Fig. 2). In this case, soil losses resulting from modeling this type of land use reach 2.6 for field A (mostly yellow coloring) and 1.6 t/ha annually for field B (yellow and green colorings).



Map 2. Potential soil losses after using the working area in the research system for field crop rotation (excluding the influence of forest shelterbelts)
Source: Authors' results.

When using the slope area for field crop rotation, preconditions are created for the manifestation of water erosion processes under technical row crops with a wide row spacing (sugar beet, corn for corn, sunflower). However, since their share in crop rotation does not exceed 20 %, the field can be considered protected. The soil losses in the area with runoff accumulation below field A at the level of 5-10 t/ha per year pasted with orange color.

The following Map 3 presents the results of modeling the potential annual soil losses under the conditions of joint soil protection action of field crop rotations and forest reclamation measures in the form of field protective forest shelterbelts on the respective research area.



Map 3. Potential soil losses after using the working area in the research system for field crop rotation (taking into account the impact of forest shelterbelts)
Source: Authors' results.

Under the implementation of this scenario, it can be seen that the amount of eroded soil decreases (both due to the correct selection of agro background in crop rotation (which provides scattering and delay of runoff in the middle of the working area) and due to effective retention of runoff outside the field.

Soil losses are less than in the previous map and are 1.9 t/ha annually for field A (yellow and green colorings) and 1.1 t/ha annually for field B (primarily green coloring).

The last and most effective scenario for the use of the slope area in the research system was the introduction of soil-protective crop rotation with perennial grasses share increase to 60% and leaving the rest of the field for continuous sowing. The surface of the field is then maximally covered with vegetation and protected from water and wind erosion. Annual soil losses then do not exceed 0.7 t/ha for field A (green and dark green colorings) and 0.8 t/ha per year for field B (primarily green coloring). The simulation results of this scenario are presented in Map 4.

Map 4. Potential soil losses after using the working area in the research system for soil-protective crop rotation
Source: Authors' results.

This can be explained by a more powerful soil protection component of forest reclamation measures in the form of field protective forest shelterbelts, presented in greater larger numbers and at a smaller distance from each other. Annual soil losses below field A in the location of surface runoff accumulation are within 10 t/ha annually. This scenario of field use is characterized by the greatest soil protection effect and can be considered as rehabilitation for these areas under conditions of erosion intensification due to increased rainfall or unsatisfactory quality of the surface vegetation in crop rotation. The expected excess of soil losses was observed when using both working plots for black fallow with no vegetation (scenario 1) and using plot A for field crop rotation (scenario 2). For this area, under conditions of local manifestation of erosion processes after the application of black fallow, a "rehabilitation" period is recommended (scenario 4).

The comparison of the obtained results of modeling of potential soil losses under different scenarios of use with the allowable minimum losses (up to 2.0 t/ha) produced obtained a number of values presented in Table. 1.

Table 1. Options for possible use of working areas A and B with recommendations for further use depending on potential soil losses

Description of possible working sites use scenarios	Gradation of soil losses due to allowable values	Potentially possible soil losses from the field, t/ha
1	2	3
Fully open soil surface for winter crops (black fallow)	A: Unacceptable excessive B: Unacceptable excessive	4.2 2.5
Field crop rotation whiep winter wheat, spring barley, corn (for grain), sunflower	A: Unacceptable excessive B: Maximal allowable	2.6 1.6
Preliminary version of field crop rotation with additional effect of forest shelter belts	A: Maximal allowable B: Average allowable	1.9 1.1
Field rotation without black fallow but with perennial grasses for 1-3 years	A: Minimal allowable B: Minimal allowable	0.7 0.8

Source: Authors' results.

Despite finding potential soil losses within acceptable limits, it is recommended to maintain forest reclamation measures in the form of field forest belts in proper functional condition (scenario 3).

Deterioration of soil protection properties of forest belts can lead to more significant values of soil decline from the working areas, which are already within the limits.

In order to compensate for the proportion of nutrients washed away from the soil under the conditions of local manifestation of erosion processes in all working areas (scenarios 2 and 3), it is also recommended to involve perennial grasses in crop rotations instead of technical row crops. This measure will help reduce the effects of erosion and keep soil losses from the site on a minimal level.

CONCLUSIONS

The use of working plots A and B under black fallow (the first scenario) expectedly led to the excess of permissible soil losses in both areas, modeled according to the current DSTU in Ukraine. Exceeding the allowable losses from erosion also occurred in section A under the conditions of its use for field crop rotation (second scenario). Under the conditions of use of plots for soil protective protection crop rotation and in the conditions of functional compliance of forest belts (scenarios three and four), soil losses in both plots remain within the norm. In order to quickly manage the erosion situation on the slopes in the research system, it is recommended to apply a "rehabilitation" period with the introduction of soil-protective crop rotation after the application of black fallow (scenario 4). Otherwise, as a result of the concentration of surface runoff from both sites in the lower part of the landfill there is a high probability of increasing soil losses to the level of more than 10 tons annually.

REFERENCES

[1]Bagdatli, C., Belliturk, K., 2016, Negative effects of climate change in Turkey. 111 Advanced Plants and Agriculture Research. Vol. 3 (2), 44–46.

[2]Balabuh, V. O., 2008, Minlyvist duzhe syl'nyh doshiv i syl'nyh zlyv v Ukrajini (Variability of very heavy rains and heavy rains in Ukraine). Naukovi pratci UkrNDGMI. 2008. Vol. 257, 61-72.(Ukrainian)

[3]Belolipskii, V.A., Bulygin, S.Y., 2009, An Ecological and Hydrological Analysis of Soil- and Water-Protective Agrolandscapes in Ukraine. Eurasian Soil Science, Vol. 42(6), 682-692.

[4]Bolstad, P.V., Stowe, T., 1994, An evaluation of DEM accuracy: elevation, slope and aspect. Photogrammetric Engineering and Remote Sensing 60: 1327-1332.

[5]Borrelli, P., Alewell, C., Alvarez, P., Anache, J.A.A., Bartman, J., Ballabio, C., Bezak, N., Biddoccu, M., Cerda, A., Chalise, D., Chen, S., Chen, W., De Girolamo, A.M., Gessesse, G.D., Deumlich, D., Diodado, N., Efthimiou, N, Erpul, G., Fiener, P., Freppaz, M., Gentile, F., Gericke, A., Haregeweyn,

I.N., Hu, B., Jeanneau, A., Kaffas, K., Kiani-Harchegani, M., Villuendas, I.L., Li, C., Lombardo, L., Lopez-Vicente, M., Lucas-Borja, M.E., Marker, M., Matthews, F., Miao, C, Mikos, M., Modugno, S., Moller, M., Naipal, V., Nearing, M., Owusu, S., Panday, D., Patault, E., Patriche, C.V., Poggio, L., Portes, R., Quijano, L., Rahdari, M.R., Renima, M., Ricci, G.F., Rodrigo-Camino, J., Saia, S., Samani, A.N., Schillaci, C., Syrris, V., Kim, H.S., Spinola, D.N., Oliveira, P.T., Teng, H., Thapa, R., Vantas, K., Vieira, D., Yang, J.E., Yin, S., Zema, D.A., Zhao, G., Panagos, P., 2021, Soil erosion modelling: a global review and statistical analysis. Science of the Total Environment, 780, 146494 https://doi.org/10.1016/j.scitotenv.2021.146494 24, Accessed on 22.12.2021.

[6]Desprats, J., Raclot, D., Rousseau, M., Cerdan, M., Garcin, Y., Le Bissonnais, A., Slimane, B., Fouche, J., Mont-Climent, D., 2013, Mapping linear erosion features using high and very high resolution satellite imagery. Land Degradation and Development. Vol. 24(1), 24–32.

[7]DSTU 7904:2015. Yakist' gruntu. Vyznachennya potentcijnoi zagrozy eroziji pid vplyvom doshiv (Soil quality. Determining the potential threat of erosion under the influence of rain). [Valid from 2016-07-01].Vyd. Ofitc. Kyiv, 2016. 12 p. (Ukrainian)

[8]Fileccia, T., Guadagni, M., Hovhera, V., Bernoux, M., 2014, Ukraine: Soil fertility to strengthen climate resilience preliminary assessment of the potential benefits of conservation agriculture // Food and Agriculture Organization of the United Nations. – Rome, 2014, 96 p.

[9]Fileccia, T. Hovhera, V., 2014, Ukraina: rodjuchist' gruntiv jak zaporuka stijkosti do zmin klimatu (Ukraine: soil fertility as a guarantee of resilience to climate change). Report No. 9 (June 2014). FAO Investment Centre. Food and Agriculture Organization of the United Nations, Rome. 2014. 18 p. (Ukrainian)

[10]Garbrecht, J., Starks, P., 1995, Note on the use of USGS level 1 7.5-minute DEM coverages for landscape drainage analyses. Photogrammetric Engineering and Remote Sensing Vol. 61, p. 519-522.

[11]García-Rodríguez, J. L., Giménez-Suárez, M. C., 2010, Comparison of mathematical algorithms for determining the slope angle in GIS environment. Revista AquaLAC. Sep. Vol. 2. p.78-82.

[12]Giles, P.T., Franklin, S.E., 1996, Comparison of derivative topographic surfaces of a DEM generated from stereographic SPOT images with field measurements. Photogrammetric Engineering and Remote Sensing, Vol. 62, p. 1165-1171.

[13]Hunter, G.J., Goodchild, M.F., 1995, Dealing with error in spatial databases: a simple case study. Photogrammetric Engineering and Remote Sensing, Vol. 61, p. 529-537.

[14]Hutchinson, M.F., 2008, Adding the Z-dimension. In: Wilson, J.P. and Fotheringham, A.S. (eds), Handbook of Geographic Information Science. Blackwell, p. 144-168.

[15]Hutchinson, M. F., 1996, A locally adaptive approach to the interpolation of digital elevation models. Third International Conference/Workshop on Integrating GIS and Environmental Modeling. NCGIA, University of California, Santa Barbara, http://www.ncgia.ucsb.edu/conf/SANTA_FE_CD-ROM/sf_papers/hutchinson_michael_dem/local.html. Accessed on 21.12.2021, and http://www1.gsi.go.jp/geowww/globalmap-gsi/gtopo30/papers/local.html, Accessed on 21.12.2021.

[16]Hutchinson, M.F., 1989, A new method for gridding elevation and streamline data with automatic removal of pits. Journal of Hydrology, №106, p. 211-232.

[17]Hutchinson, M.F., 1988, Calculation of hydrologically sound digital elevation models. Proceedings of the Third International Symposium on Spatial Data Handling, August 17-19, Sydney. International Geographical Union, Columbus, Ohio, p. 117-133.

[18]Hutchinson, M.F., 2000, Optimising the degree of data smoothing for locally adaptive finite element bivariate smoothing splines. Australian & New Zealand Industrial and Applied Mathematics Journal №42 (E): p. 774-796.

[19]Hutchinson, M. F., Dowling, T. I., 1991, A continental hydrological assessment of a new grid-based digital elevation model of Australia. Hydrological Processes №5, p. 45-58.

[20]Hutchinson, M.F., Gallant, J.C. 2000, Digital elevation models and representation of terrain shape. In: Wilson J.P. and Gallant J.C. (eds), Terrain Analysis: Principles and Applications, Wiley, New York, Chapter 2, p. 29-50.

[21]Hutchinson, M. F., Gallant, J. C. 1999. Representation of terrain. In: Geographical Information Systems: Principles, Technical Issues, Management Issues and Applications. Second Edition. Edited by Longley, P.A., Goodchild, M.F., Maguire, D.J. and Rhind, D.W. Wiley, New York, Chapter 9, pp 105-124.

[22]Klik, A., Eitzinger, J., 2010, Impact of climate change on soil erosion and the efficiency of soil conservation practices in Austria. Journal of Agricultural Science. October Vol.148 (05), 529 - 541.

[23]Koliada, V. P., Kruglov, O. V., Achasova, A. O., Nazarok, P. G., Tiutiunnik, N. V. 2021, Zminy lisomelioratyvnogo skladnyka protyerozijnyh zahodiv na prykladi diljanky z konturno-melioratyvnoyu organizatsiyeyu terytoriji (Changes of the forest-ameliorative component of erosion preventive measures on the example of the field with the contour-ameliorative organization of territory). Agrarian Innovations, Vol. 7, 60-64. (Ukrainian).

[24]Prokopenko, K.O., Ulova, L.O., 2017, Sil'ske gospodarstvo Ukrajiny: vyklyky i shljahy rozvytku v umovah zmin klimatu (Agriculture of Ukraine: challenges and ways of development in the conditions of climate change). Ekonomika i prognozuvannya, Vol. 1, 92-107. (Ukrainian)

[25]Qin, A.-X., Zhu, T., Pei, B., Li, C., Zhou, L. Yang, 2007, An adaptive approach to selecting a flow-partition exponent for a multiple-flow-direction algorithm, International Journal of Geographical Information Science, 21(4), 443-458.

[26]Soil erosion: the greatest challenge to sustainable soil management. 2019. FAO, Rome. 100 pp.

[27]Stefanidis, S., Stathis, D., 2018, Effect of Climate Change on Soil Erosion in a Mountainous Mediterranean Catchment (Central Pindus, Greece). Water. Vol. 10, Art. 1469. p. 12.

[28]Tarariko, O.G., Ilenko, T.V., Sirotenko, O.V., Kuchma T.L., 2015, Formuvannya zbalansovanyh agrolandshaftiv na pryntcipah gruntozahysnoji konturno-melioratyvnoji systemy zemlekorystuvannya (Formation of balanced agrolandscapes on the principles of soil protection contour-reclamation system of land use). Zemlerobstvo. Kyiv, Vol. 1, 13-18. (Ukrainian).

[29]Tarariko, A., Kuchma, T., Ilyenko, T., Demyanyuk O., 2017, Soil erosion degradation of Ukraine under the impact of climate change. Agroecological journal. Tissue № 1, 7-15. (Ukrainian).

[30]Van der Linden, P., Mitchell J.F.B., 2009, ENSEMBLES: Climate change and its impacts: summary of research and results from the ENSEMBLES project. 2009, MetOffice Hadley Centre. 160 pp.

[31]Wise, S.M., 1998, The effect of GIS interpolation errors on the use of digital elevation models in geomorphology. In: Lowe, S.N., Richards, K.S. and Chandler, J.H. (eds), Landform Monitoring, Modelling and Analysis. Wiley, New York, p. 139-164.

[32]Yermolaev, O. P., 2017, Geoinformation mapping of soil erosion in the Middle Volga region. Eurasian Soil Science, Vol. 50(1), 118–131.

[33]Zubov, A.R., Tarariko, I.G., 2009, Formirovanie erozionno ustoichivyh agrolandshaftov v basseine Severskogo Dontsa (Formation of erosion-resistant agrolandscapes in the Seversky Donets basin). GNU VNIALMI, Volgograd, 240 p.(Russian).