Advances in Biology & Earth Sciences
Vol.10, No.1, 2025, pp.148-157
https://doi.org/10.62476/abes.101148

ECOLOGICAL SUSTAINABILITY OF AGROECOSYSTEM AND PRODUCTIVITY ASSESSMENT IN THE BARDA AREA USING NDVI AND SAVI

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Abstract. Barda district is located in the Aran economic region of Azerbaijan and is a territory with great agricultural potential. The region's agricultural sector plays an important role in the local economy in terms of meeting domestic demand and contributing to export potential. The article presents the features of biodiagnostics of ecological sustainability of agroecosystems based on biological diversity of organic matter of agrocenoses. The use of green manure crop biomass in fallow and stubble sowing, as well as barley straw in variants with green manure fallow, led to an increase in the number of weeds by 13-15% compared to crop rotation with occupied fallow and their mass - by 14-16%, respectively. This study assesses crop health and soil condition by analyzing agricultural productivity in Barda district, particularly using remote sensing techniques such as NDVI (Normalized Difference Vegetation Index) and SAVI (Soil-Adjusted Vegetation Index). By integrating GIS-based mapping and precision farming technologies, productivity can be increased and land use optimized. The results of this study provide information on sustainable agricultural practices and strategies to increase Barda's export potential.

Keywords: *Green manure crops, export potential, remote sensing, agricultural productivity, NDVI, SAVI.*

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Received: *14 January 2025;* ***Accepted:*** *27 March 2025;* ***Published:*** *15 April 2025.*

1. Introduction

The agricultural sector of the Barda district is one of the main factors of economic development (Boschetti *et al*., 2015). Fertile soils and favorable climatic conditions of the region allow growing various crops, including wheat, barley, cotton, vegetables and fruits (Chaves *et al*., 2020). The development of agriculture in the Barda district using modern technologies is also of great importance (Doran *et al*., 2020). The implementation of various infrastructure projects, especially the improvement of roads, communication systems and irrigation systems, contributes to the expansion of economic activity. In addition to increasing agricultural production, these projects also provide an opportunity to improve the quality of these products and bring them to wider markets (Gong *et al*., 2021). But challenges such as soil salinity, irrigation problems and

How to cite (APA):
Macnunlu, K.K., Hasanova Baba-zade R.A. & Hasanova, T.A. (2025). Ecological sustainability of agroecosystem and productivity assessment in the Barda area using NDVI and SAVI. *Advances in Biology & Earth Sciences, 10*(1), 148-157 https://doi.org/10.62476/abes.101148

climate change require innovative approaches to sustainable agriculture (Hasanova *et al*., 2021).

Different methods have been used to analyze land use changes and estimate the export potential of products in different periods. In recent years, the use of remote sensing, machine learning and deep learning technologies has made it possible to obtain more accurate and automated results. In his article, Johnson (2016) examines the use of NDVI (Normalized Difference Vegetation Index) to predict agricultural productivity in the US Midwest. The paper evaluates how accurately satellite NDVI data can predict the yield of major crops such as corn and soybeans (Hasanova Baba-zada & Baba-zada, 2024).

In their article, Kerimli and Selbesoglu (2023) investigated the use of NDVI (Normalized Difference Vegetation Index) and other vegetation indices in agriculture, especially in productivity assessment. The article used the Mamatkulov method and the MEDALUS model based on Sentinel-2 and SRTM (Shuttle Radar Topography Mission) data. Huang et al. (2024) discuss the use of NDVI data for cropland recognition and crop yield estimation in their research. NDVI reflects the vegetation status and allows for the identification of different crop species and crop yield estimation (Hasanova & Asgarova, 2024). In our study, we examined the role of remote sensing tools, especially NDVI and SAVI indices, in assessing productivity and optimizing management practices in agriculture. These indices are very effective tools for assessing vegetation health and monitoring the health of agricultural land. NDVI measures the intensity of greenness of vegetation, allowing us to monitor changes in cropland productivity. Meanwhile, SAVI more accurately assesses vegetation health by taking into account the influence of soil, especially in areas where the soil is dry or has less green cover (Huseynova *et al*., 2024). These tools help agricultural managers make more informed decisions by helping them predict crop development stages and water and fertilizer needs. The content of nutrients in the soil was influenced by the level of organic matter input into the soil of agrocenoses, the amount of nutrient alienation with the main and by-products and the intensity of the processes of mobilization of nutrients in the soil (Ismayilov *et al*., 2020; Johnson, 2016).

Currently, in conditions of a deficit of the traditional source of replenishment of soil organic matter - manure, caused by a reduction in the number of animals and changes in the technologies of their maintenance, the main sources of organic matter and nutrients in the soil, along with mineral fertilizers, can be the straw of grain crops, the cultivation of green manure plants for green manure in fallows, stubble and post-harvest crops, an increase in the share of perennial grasses in the structure of crops, etc. (Jin *et al*., 2018). Various organic matter reproduction complexes and their influence on the fertility indices of leached chernozem were studied in two agroecosystems: 1) occupied fallow (sainfoin) - winter wheat - sugar beet - barley; 2) green manure fallow (sainfoin) - winter wheat - sugar beet - barley.

2. Materials and methods

Remote sensing data is obtained from satellite images and aerial photographs. These data are collected mainly through Landsat, Sentinel and other satellite platforms. The resulting images are used to calculate vegetation indices such as NDVI and SAVI and are analyzed using GIS programs (ArcGIS, QGIS, etc.). These programs calculate

NDVI and SAVI indices, which are then used to assess cropland productivity and soil health (Jalilova & Baba-zade 2024; Mirzezadeh *et al*., 2025).

Based on the data analysis, detailed assessments of soil fertility and vegetation health are made. These assessments help optimize cropland irrigation, soil salinization and other agricultural management strategies (Rowell, 1999).

Barda district is a large region with an area of 957 km^2, located in the central part of Azerbaijan, in the Aran economic region. This region, as one of the strategically important regions of the country, attracts attention with its geographical location and natural resources. The city of Barda, the center of the region, also functions as a social, economic and cultural center of the region. Barda district plays the role of a center of trade and transport flows due to its location on the border with various regions of the country (Nasirova *et al*., 2022). It borders with Terter district in the north, Aghdam and Aghjabedi districts in the east, Imishli district in the south and Goranboy district in the west. The proximity to this region creates favorable conditions for access to both local and foreign markets.

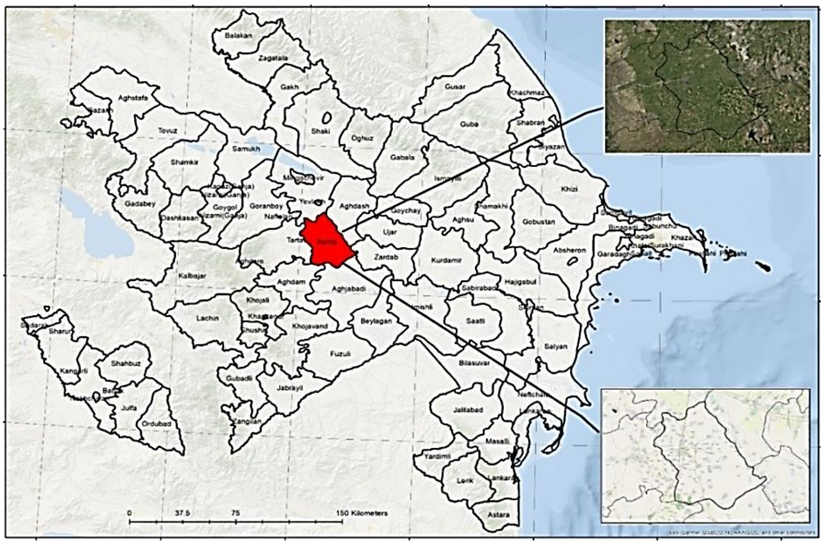

Figure 1. Geographical location of the Barda region

The territory of the Barda district is mostly flat and soil types vary, but soil salinity and irrigation problems can affect productivity in some areas. The Kura River and its tributaries, which are important resources for the region's agriculture, meet irrigation needs. Barda district has a mild arid climate, hot and dry summers and relatively mild winters. These features create favorable conditions for growing grain, cotton and vegetables. In addition, soil salinity and irrigation problems increase the need for modern agricultural technologies to optimize agricultural productivity. Remote sensing methods used in this study help to assess the vegetation status and soil fertility of the district, thereby providing accurate information on the agricultural potential of the district. The agricultural sector of Barda district occupies an important place in the economy of the region and has great potential for both domestic consumption and export. Among the main agricultural crops of the region and their productivity indicators, barley, peas, cotton, sugar beets, sunflower, potatoes and other products can be cited.

3. Results and discussion

In the period from 2015 to 2023, the annual increase in the yield of various agricultural crops and the development of agriculture in the region were studied (Table 1). Vegetables and sugar beets are the main agricultural crops in the region. According to the analysis of 2023, the sown area of vegetable crops was 358.5 hectares, the sown area of sugar beets was 329.5 hectares.

Table 1. Area of planting of agricultural crops in the Barda district by year for 2015-2023, ha

Agricultural plants	Sown area by year, ha								
	2015	2016	2017	2018	2019	2020	2021	2022	2023
Barley	35,1	32,2	32,7	34,9	38,9	39,8	41,0	41,5	41,7
Peas	-	-	30,7	-	-	-	-	-	-
Cotton	28,3	23,2	26,3	26,3	33,7	35,0	27,8	32,6	31,4
Sugar beet	375	549	342	338	301	551,7	455,9	189,9	329,5
Sunflower for a day	19,0	19,6	20,7	20,6	21,5	22,0	22,4	23,0	23,4
Potatoes	106	110	119	120	103	125,0	126,1	126,8	128,0
Vegetables	126	127	184	188	293	304,3	335,2	315,2	358,3
Tomato	110	107	78	156	162	229,8	237,7	238,9	234,6
Melon plants	160	165	201	253	277	300,2	300,7	299,5	305,3
Fruits and berries	75,7	77,1	81,8	88,3	128,8	137,6	156,4	156,1	155,9

Export potential of agricultural products. Since Barda district is a territory that occupies an important place in Azerbaijan's agricultural exports, the export potential of the district allows producing various agricultural products depending on soil and climatic conditions. Agricultural products of the region are in high demand both in the domestic market and in foreign markets.

In addition to being an important agricultural export product of Azerbaijan, cotton is also of strategic importance for the country's economy. Increasing cotton production and improving its quality will have a positive impact on Azerbaijan's foreign trade balance. Optimizing crop areas in the region and modernizing irrigation systems are important steps to increase cotton production.

Barda district also has significant production potential in the field of vegetable and fruit growing. To increase export potential, it is necessary to improve production processes and enhance product quality. The introduction of an improved logistics and certification system in this area will play an important role, especially in the export of high-quality vegetables and fruits to foreign markets. At the same time, growing crops in accordance with current market requirements will contribute to an increase in export volumes. With the development of technology, especially digital platforms and the application of precision farming technologies, agricultural productivity can be improved and resources can be used efficiently. The use of smart agricultural technologies will help to carry out irrigation, fertilization and other agricultural operations more efficiently and correctly, increasing productivity and enhancing competitiveness in global markets. These technologies will also promote sustainable farming practices, reducing the impact on the environment.

In the future, to further increase the export of agricultural products of the Barda region, it will be important to use modern technologies, develop logistics and certification systems and strengthen international trade relations. These measures will not only optimize domestic production, but also make the Barda region more competitive in world markets (Ramazanova, 2017).

Productivity Assessment Using Vegetation Indices: In areas with high agricultural intensity such as Barda district, remote sensing techniques and vegetation indices, especially NDVI (Normalized Difference Vegetation Index) and SAVI (Soil-Adjusted Vegetation Index), are very useful for productivity assessment. These indices help optimize the productivity of arable land by assessing the vegetation condition and soil condition. In this part, by assessing the NDVI and SAVI indices obtained in Barda district, the soil and vegetation condition will be analyzed and the results regarding the productivity of cultivated fields will be presented.

NDVI is the most widely used vegetation index used to assess vegetation health. It measures the photosynthetic activity of plants by their ability to reflect red and near infrared (NIR) light. NDVI values range from -1 to 1. SAVI is an index that allows assessing vegetation taking into account the influence of soil reflectivity and is especially used in areas with open soil surface. The main purpose of this index is to prevent the influence of soil color and reflectivity on NDVI. The maps were prepared based on NDVI and SAVI assessments carried out on various agricultural lands in the Barda district. These maps clearly show the soil conditions and vegetation condition of the cultivated fields and facilitate data analysis.

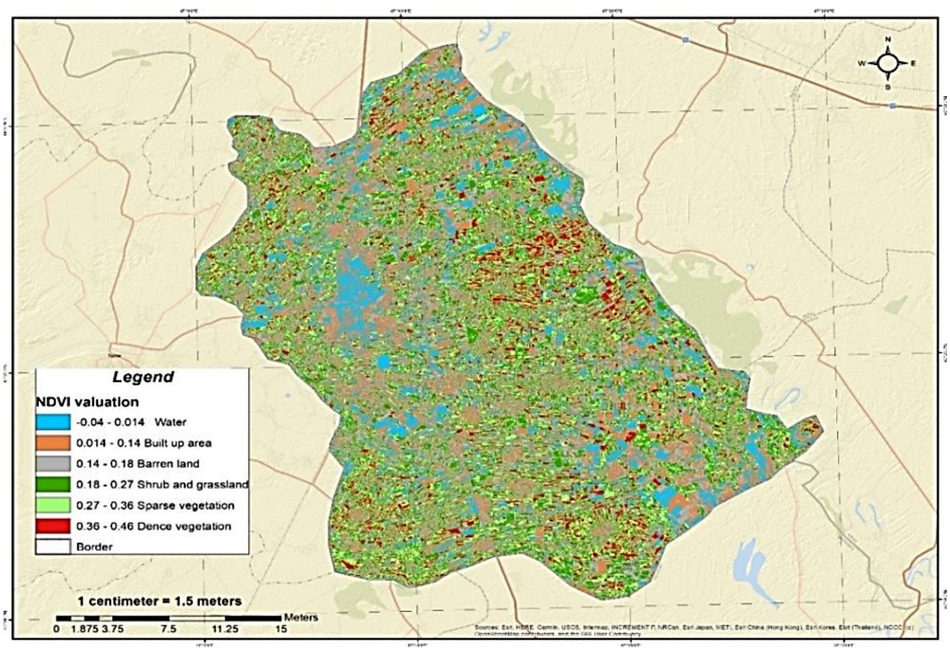

Figure 2. NDVI analysis map for the Barda region

The NDVI analysis map shows the vegetation status of cultivated areas. Blue areas represent water bodies, meaning that these areas have no vegetation. Orange areas represent construction sites and unused land. Yellow and green areas represent agricultural land and vegetation density. Dense green areas are areas with high vegetation density, where productivity is high. Red areas are mostly construction sites and unused land, indicating that these areas have little or no vegetation cover. Areas with high NDVI values indicate regions of high productivity. Conversely, low NDVI values indicate areas with poor plant health.

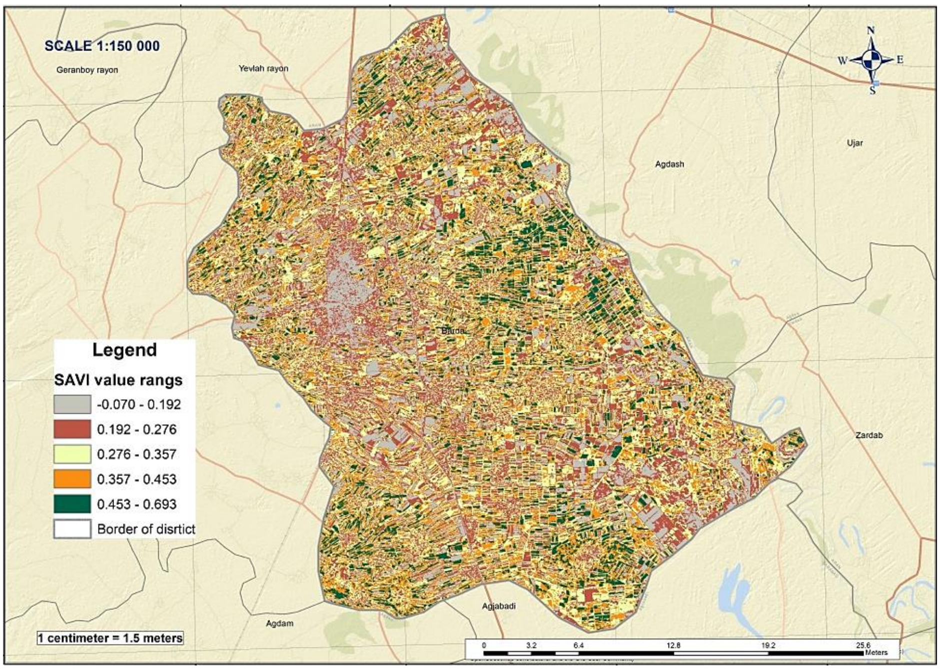

Figure 3. SAVI analysis map for the Barda district

The SAVI map shows soil salinity and vegetation density. Light colors indicate areas with sparse vegetation cover or bare soil. Yellow and green indicate soils with well-developed vegetation (Zhang *et al*., 2015). Dark green areas are areas with high productivity. Areas with high SAVI values show healthy and dense vegetation, while low SAVI values indicate soil problems and require management measures. NDVI and SAVI analyses are important tools for assessing the potential of agricultural production and optimizing productivity in the Barda district. These analyses help to accurately assess the condition of the soil and vegetation, which allows for more accurate decisions on irrigation and soil management. In the future, using these indices, it will be possible to increase the productivity of farmland and use land resources more efficiently.

Studies have shown that the balance of phosphorus in the soil was determined by the processes of its entry with fertilizers and its removal with the harvest and weed component of agrocenoses. Our research has shown that in the variants without fertilizers, the highest number of weeds on average over the years of research was in barley crops (269 pcs/m^2), which is associated both with its weak competitiveness and the peculiarities of its cultivation technology; the lowest - in sugar beet crops (32 pcs/m^2), which is primarily associated with the implementation of inter-row cultivation during the growing season of the crop. The mass of weeds in crops did not correlate with their number, its greatest value was in sugar beet crops (207 g/m^2), which is explained by the long period of crop vegetation and the practical absence of weed control measures in the second half of the vegetation period in the stationary experiment; the smallest - in winter wheat crops, then sainfoin, which is associated with the high competitive ability of these crops to suppress weeds due to the early resumption of plant vegetation in the spring and earlier harvesting times, interrupting the growth and development of weeds. The number of weeds was higher in the variants with the application of fertilizers compared to the unfertilized variants. At the same time, the ranking of cultivated crops by their impact on the weediness of agrocenoses was maintained as with the use of fertilizers. In all variants with the application of fertilizers, the largest mass of weeds was in barley crops (225-281 g/m^2), the smallest - in winter wheat crops, which is explained by its early regrowth and better ability to use nutrients and compete with weeds. The number of weeds in barley crops, using the aftereffect of fertilizers applied to sugar beet, increased depending on the level of organic matter in manure, stubble green manure, mineral fertilizers and their combined application by 26.4-66.2%, sainfoin - 12.2-26.4, winter wheat - 7.3-21.1 and sugar beet - 3.2-13.7%. Moreover, the higher the level of fertilization by the sum of NPK, the higher the number of weed components of the agrocenoses. The mass of weeds in the crops of various crops also changed depending on the level of fertilization. Thus, in the crops of winter wheat and barley it changed by 25.6-45.7% and in the crops of sugar beet - by 11.5-13.6%, while the greatest increase in the mass of weeds from different types of fertilizers was noted in the variants where more organic forms of fertilizers were applied. The increase in weed infestation of agrocenoses occurred mainly due to the use of manure and green manure biomass, with which weed seeds entered the soil, whereas in agrocenoses with occupied fallow, the sainfoin biomass and mustard post-harvest crops were alienated from the field. Another reason for the increase in weed infestation of crops in this variant is the improvement of the soil nutritional regime when plowing in green manure biomass.

With the combined use of straw and manure against the background of BSH (use of sainfoin biomass harvest) + Pp (Post-harvest sowing of oilseed radish) + Bs (Barley straw left in the field) + (NPK)200 (option 4), the number and mass of weeds in crops increased on average over the crop rotation compared to the option of plowing only straw (option 2) by 13.0 and 16.0%, respectively and compared to the option of applying only manure (option 3), the weed infestation remained virtually unchanged. Plowing straw against the background of manure in agrocenoses had virtually no effect on the weed infestation of crop rotation crops. Compared to a similar crop rotation option with occupied fallow, the mass of weeds was 5.1% greater (although the number of weeds decreased by 4.0%), which we associate with better conditions for mineral nutrition of plants in this option. With an increase in the dose of mineral fertilizers by 1.75 times and winter wheat straw by two times (option 5), the number and mass of weeds increased compared to the variant of their single doses (option 2) by 2. 2 and 6.0%, respectively. Compared with a similar variant with occupied fallow, the number and mass of weeds in this variant were higher by 9.3-9.0%, which is explained by better conditions for plant nutrition in this variant. In agrocenoses with green manure fallow in variants with the use of organic and mineral fertilizers, the number of weeds was, on average, 22.0-39.0% higher compared to the unfertilized variant and their mass was 13.0-33.0% higher, which depended on the level of use of organic and mineral fertilizers.

The content of organic matter and mobile forms of phosphorus, exchangeable potassium and nitrogen in the soil was directly dependent on the mass of applied manure, straw, green manure crops, cultivated in fallows, after stubble and after mowing, both separately and together with mineral fertilizers. The numerical and species diversity of the weed component of agrocenoses depended both on the biological characteristics and technologies of cultivated crops and on the level of organic and mineral fertilizers entering the soil, which, along with indicators of the bioproductivity of agroecosystems, provides grounds for using these indicators to indicate the environmental sustainability of agroecosystems and the environment as a whole. The introduction of 40 t/ha of manure under sugar beet instead of winter wheat straw increased the number and mass of weeds in agrocenoses with green manure fallow by 13.0 and 17.0%, respectively, while against the background of occupied fallow, the introduction of manure and straw in these indicators turned out to be practically equivalent agricultural practices (Figure 4). The highest weed infestation of crops in both agrocenoses with occupied and green manure fallows was observed with the combined use of manure, winter wheat straw and mineral fertilizers. Our research has shown that in agrocenoses with occupied fallow, the smallest number and weight of weeds were found in the control variant - 124 pcs/m^2 and 182 g/m^2, respectively (Table 2).

Table 2. Weed infestation of agrocenoses before harvesting crops, pcs/m^2

	Crop rotation with occupied fallow					Crop rotation with green manure fallow				
Sainfoin	1	2	3	4	5	1	2	3	4	5
Winter wheat	69	78	81	87	80	82	88	83	85	89
Sugar beet	87	94	96	108	93	110	122	126	130	123
Barley	39	40	44	46	40	39	44	56	39	43
Average by crop rotation %	299	402	403	502	377	129	158	179	178	162

Note: Numerator - number of weeds, pcs/m^2; denominator - wet weight of weeds, g/m^2

NDVI and SAVI-based analyses will not only help increase agricultural production, but also strengthen the export potential of this crop. These methods will help optimize the quality and quantity of products and increase competitiveness in international markets.

a.  b. 

c. 

Figure 4. a - Winter wheat; b - sugar beat; c - Barley (40°22'58.4544" N 47°7'29.9856" E)

4. Conclusion

As a result of the conducted research, the agricultural potential, the level of productivity and export opportunities of the Barda region were assessed. As a result of the application of the NDVI and SAVI indices, the state of productivity of agricultural fields in the region was analyzed and the indicators of soil and vegetation health were determined. Analysis of NDVI and SAVI indices showed that agricultural areas of the Barda district have different levels of productivity. Although soil salinity and irrigation problems negatively affect productivity in some areas, the region's main agricultural products (cotton, grain, vegetables and fruits) have high potential. The region's agricultural sector has the potential to meet domestic demand and produce for foreign markets. Cotton, vegetable and fruit products have high export value. Improving logistics and certification systems can help realize this potential. The use of GIS-based mapping technologies and remote sensing technologies enables more effective decision-making in the field of irrigation and land use. The use of digital agricultural tools helps to increase productivity by ensuring efficient resource management.

Mineral fertilizers, when applied to the soil together with different types of organic fertilizers and separately, increased the number and mass of weeds in all variants of the studies. In this case, in the variants with green manure fallow and manure, these indicators exceeded those in the variants of occupied fallow by 4.3-12.7%. The use of green manure crop biomass in fallow and stubble sowing, as well as barley straw in variants with green manure fallow, led to an increase in the number of weeds by 13.0-15.0% compared to crop rotation with occupied fallow and their mass - by 15.0–16.0%, respectively.

Acknowledgements

The authors express gratitude for the support of the scientific and technological research project to the Institute of Soil science and Agrochemistry of the Ministry of Science and Education of Azerbaijan Republic, Department of Soil GIS and Baku State University, also State Cadastre and Registry of Real Estate Public Legal Entity under the State Service for Property Issues of the Ministry of Economy of the Azerbaijan Republic.

Data availability

All data generated or analyzed during this study are included in this published article and could be received by reaching authors.

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