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# Assessment of the impact of global climate change on soil degradation in Azerbaijan

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**The article is devoted to the assessment of the impact of climate change on soil degradation in Azerbaijan. The research process was carried out using the modern. The assessment with the new methods is carried out taking into account the influence of complex factors on soil cover changes. The study process showed the existence of a very close relationship between the change in climate quantities and soil degradation, and it was possible to reflect these relationships in concrete numerical terms. Changes in climate factors during the years 2000-2022 played a positive role in the process of soil degradation in most cases. During this period, the area of fertile soils decreased by 18.5%. Studies show that as a result of increasing the temperature in the range of about 0.19-0.22°C; with a decrease in precipitation by 16-18 mm the area of fertile soil cover decreases by about 5.8-6.2%. Especially the intervals of temperature 14.3-14.6°C, precipitation 300-450 mm, maximum soil retention 1000-1100 mm are more critical levels and are accompanied by sharper increases in soil degradation. Compared to 2000, in 2022, the area of highly degraded bare soil has grown by 1234.2 km2 (17.3%). In 2050, this increase is predicted to be 27.4% more than in 2022.**

***Keywords:*** *Climate changes, soil degradation, operative-interactive methods, maximum soil retention, Hydrological soil groups*

## INTRODUCTION

As a result of the reforms carried out in the Republic of Azerbaijan, a powerful socio-economic potential has been created in the country. However, against the background of global climate change, the depletion of natural resources creates additional problems in implementing reforms. The gradual decrease in water, land and biological resources creates a serious imbalance with the development of the economy, especially agriculture, and population growth. Constant and continuous study of vital water, land and biological resources and their adequacy to climate change is necessary for the continuous and sustainable implementation of socio-economic reforms. Therefore, research work to solve existing problems is also of great importance. It is clear that under the influence of climate and other factors, the available natural resources will continue to decline. For this reason, scientific directions and methods should be determined so that research does not lag behind the general pace of reform development. At present, modern conditions require the assessment of natural resources with more modern, sensitive and operational methods that can respond to any changes. Taking into account the current trends in world science and their need for Azerbaijan, we have developed the CWBM (Complex water balance method) and IESA (Interactive electronic soil assessment) methods, which are operational-interactive methods (Mammadov et al., 2018; Mammadov, Teymurov, 2019).



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It is known that changes occurring in natural complexes, especially in the soil and vegetation cover, are primarily associated with changes in the water and heat balance of the area. The most obvious manifestation of climate change is rising temperatures and decreasing rainfall, resulting in lower levels of moisture in most regions, which in turn leads to land cover degradation.

CWBM was developed on the basis of the leading water balance methods currently available in the world, by synthesizing them and taking into account the specific features of the nature of Azerbaijan. With the CWBM and IESA methods, research is evaluated in a completely new context. Currently, in hydrometeorological and soil assessments, preference is given to hybrid and synthesis methods. New synthesis and hybrid methods offer additional benefits by combining important features of several methods at the same time. These aspects were taken into account when conducting a comprehensive assessment of climate and soil elements. Most of the results obtained by the main methods to which they relate are of high accuracy since they are obtained as a result of long-term observations and experimental research. With the help of CWBM and IESA, containing the best features of the basic methods, it is possible to estimate the moisture regime, heat, and water balance of the area with high accuracy. The study takes into account most of the components that make up the natural and anthropogenic landscapes. In this case, the relationship between all the components included in the complex can be evaluated individually or in a complex way. In this case, it is possible to calculate the causes of changes in land resources (climatic, landscape, anthropogenic, etc.) and the impact of each of them on the change.

## MATERIALS AND METHODS

As an example in the research area, the geospace covered by fragment 188-032 of the Landsat satellite image was taken. This geospace with an area of 37.4 thousand km$^2$ is located in an area covering most of the physical and geographical features of the nature of Azerbaijan. Space images of different years, a digital elevation model (DEM), and hydrometeorological observation data were used as the initial inputs for the study. To determine the types of landscape, land cover, and moisture levels, multispectral space images of the terrain from different periods were processed using normalized difference indices (NDI-Normalized Difference Indices). Considering the content of the research work, difference indices of vegetation (NDVI, SAVI), bare soil and badlands (BSI), erosion (NDBal), soil salinization (NDSI), residential and build-up (NDBI), urban (UI), water (NDWI), drought (NDDI) and moisture (NDMI) were preferred in the study. The elevation, slope and aspect values of the study area were determined using DEM, and the morphometric indicators of the rivers using the Hydrology, Surface and Density software of the ArcGIS program. To select similar data and get more reliable correlations between components, multiple linear regression equations (Multiple Linear Regression) were needed. The main source of climate data is the measurement-observation data of the Ministry of Natural Resources and Ecology of the Republic of Azerbaijan.

## RESULTS AND DISCUSSION

Natural complexes are formed from the close unity of numerous components, and a change in one component necessarily affects others. The essence of the new method lies in the study of intercomponent relationships, taking into account the participation of as many components as possible and achieving this relationship in a specific quantitative expression. Studies show that it is possible to obtain relationships between any components that make up natural complexes in various forms (multiple linear regression, correlation, mathematical, trend forms, etc.). Modern scientific and technical innovations (space information, GIS and other multifunctional technologies) have created conditions for a deeper study of intercomponent relationships. The new method is called the Complex Water Balance Method (CWBM), as the new method comprehensively studies the participation of most of the factors that make up the natural complex and their relationship. Natural and anthropogenic complexes existing in a certain territory are mainly associated with 3 groups of factors:

1) Components that make up the surface

cover of the area. These include LULC (Land use and Land cover), vegetation density, soil cover, granulometric composition of soils and HSG (Hydrological soil groups).

2) Morphometric values. It includes average elevation, slope, aspect of slopes, basin area, river length, horizontal and vertical surface fragmentation, and river network density.

3) Climate and moisture factors. These include air temperature, precipitation, actual and potential evaporation, humidity coefficient, maximum soil water retention, actual soil moisture, hydrological losses, initial abstraction, etc.

The current presentation is dedicated to changes in soil cover as a result of climatic changes. However, the study took into account the influence of other components in addition to climatic influences on soil cover because any area is viewed as a single complex. Figure 1 presents maps of several main components that play an important role in the formation of the soil cover, obtained from satellite images in 2022, climate data, and using GIS technologies.

Using the CWBM and IESA methods, the process of studying the soil-water-air environment is considered as a single mechanism, and the process of assessing soil-climatic factors is analyzed and studied in a completely different context (Teymurov, 2023, pp. 28-32). In traditional scientific approaches, climate factors were estimated based on precipitation and temperature. In modern methods, the concept of "humidity level of the territory" is mainly used. Studies show that assessing the humidity rate of areas only from precipitation and temperature does not give satisfactory results. For example, in areas with a sufficiently high level of precipitation, soil and water can be expressed in small quantities. Or vice versa, in regions with high temperatures, they can be very high. Climate and moisture indicators act as indicators in terms of change and the presence of other components (water, soil, vegetation, etc.). Therefore, the humidity level of territories was estimated using predictors characterizing both air moisture and soil moisture. When assessing the humidity level of the territory among air factors precipitation, temperature, potential evapotranspiration, humidity coefficient; and among soil indicators maximum soil retention, actual soil moisture, HSGs, etc. are accepted as the main indicators. Potential evapotranspiration (M) is the amount of maximum mass of water that can be evaporated into the atmosphere, and maximum water retention (S) - is the highest amount of water that can be stored by the soils under specific natural conditions (Spitalniak et al. 2021).

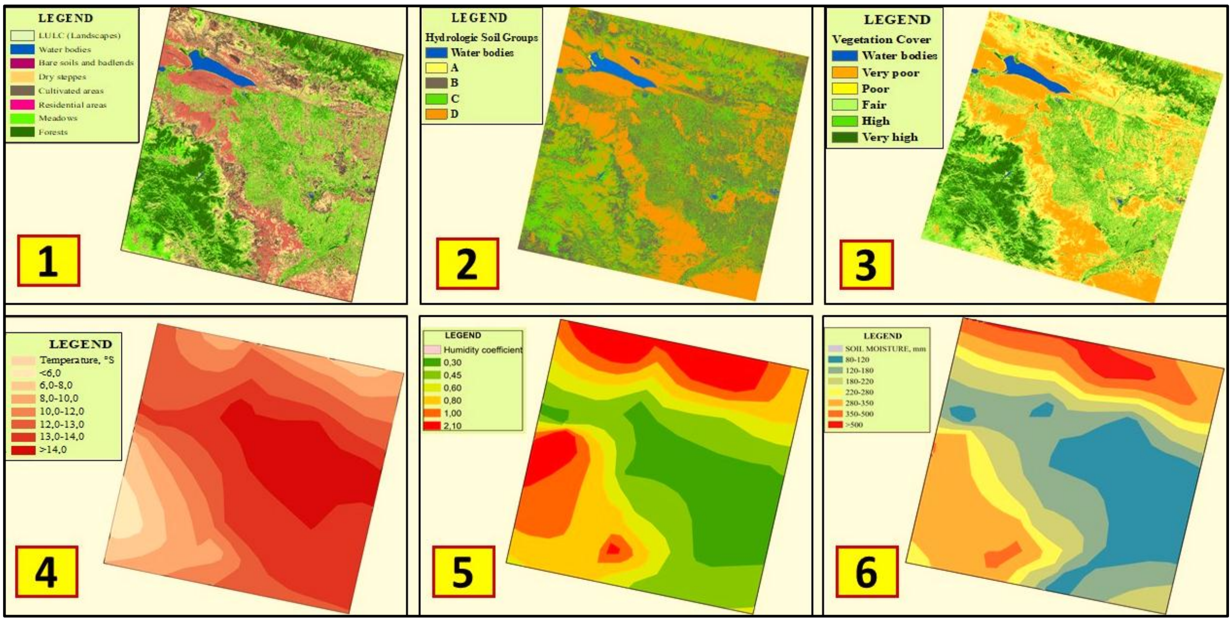


**Fig. 1.** Some important components involved in soil formation: 1-Landscapes; 2-Hydrological soil groups; 3-

Vegetation cover; 4-Air temperature; 5-Humidity coefficient; 6-Soil moisture.

**Table 1.** Changes in soil cover and climatic factors for 2000-2022

| Research object | 2000 | 2022 | Difference, % |
|---|---|---|---|
| Air temperature, °C | 11.5 | 12.7 | +9.45 |
| Precipitation, mm | 580.2 | 521.1 | –10.2 |
| Humidity coefficient | 0.66 | 0.55 | –16.7 |
| Potential evaporation, mm | 873.6 | 955.8 | +8.60 |
| Hydrological soil group (weak infiltration-group D), $km^2$ | 12415 | 14062 | +11.7 |
| Maximum soil water retention, mm | 1012.1 | 1121.0 | +9.71 |
| Actual soil moisture, mm | 236.5 | 200.6 | –15.8 |
| Horizontal surface fragmentation, $km/km^2$ | 1.96 | 2.19 | +10.5 |
| Area of dense vegetation cover, $km^2$ | 5834.4 | 4782.2 | –17.9 |
| Area of fertile soils, $km^2$ | 7843.3 | 6395.4 | –18.5 |

Actual soil moisture (F) is the factual amount of water stored in the soil under existing conditions. The humidity coefficient (R) is expressed as the ratio of precipitation to potential evaporation and is considered the most important parameter in terms of determining the degree of air moisture. The Hydrologic soil group (HSG) is the main indicator in the content of the surface runoff formation and the soil infiltration. In the NRCS classification, 12 soil codes and 4 HSGs (A, B, C, D) are distinguished according to the permeability rate depending on the soil granulometric fraction and porosity. From group A to group D, there is a tendency to weaken infiltration and increase surface runoff.

The collection and processing of the necessary materials in the research work was carried out in the following order:

1) Satellite images of the areas were collected for different periods and their NDI processing was carried out.
2) Maps of soil degradation, vegetation density and climatic factors have been compiled.
3) Climatic and soil-vegetation maps were joined and reclassified, natural conformities were established based on their quantitative changes in different periods.

Table 1 shows the change in soil-vegetation indicators and the most important climatic factors affecting the study area for 2000-2022.

Studies have shown the existence of a very close relationship between the influence of climatic variables and soil cover changes, and these relationships have been reflected in concrete values. Climate change, especially the decrease in air and soil moisture, intensifies the process of soil degradation. It is possible to trace the negative manifestations of the soil cover as a result of climate change, both against the background of an increase in their area and quantitative indicators. As seen in Table 1, the change in climatic indicators that determine the humidity level of the area in 2000-2022 was unfavorable for soil fertility. During this period, there is a negative trend of 8-12% in the change in factors affecting both air moisture and soil moisture. Against the background of a simultaneous decrease in the level of air and soil moisture, the area of dense vegetation decreased by 17.9%, and the area of fertile soil under their combined influence decreased by 18.5%. For 2000-2022, the area of only high-fertility soils decreased by 1447.9 km2, which is 3.87% of the total research area.

Our studies showed that with an increase in temperature by about 0.19-0.22°C; and a decrease in precipitation by 16-18 mm, a moisture coefficient of 0.20-0.23 and soil moisture of 4.3-4.5 mm, the area of fertile soil cover simultaneously decreased by about 5.8-6.2%. Especially in the temperature range of 14.3-14.6°C, precipitation of 300-450 mm, humidity coefficient of 0.35-0.38, soil moisture of 80-120 mm, soil fertility is accompanied by a higher decrease. Before these intervals, the relationship between climatic and soil indicators is mainly in the form of a linear regression dependence, and after the indicated critical limits, it manifests itself in the form of mathematical dependences, accompanied by a logarithmic or other sharp increase. When classifying the most important climatic factors affecting soil cover, low-medium-high intervals were determined: for air temperature <8°, 8°-12°, >12°C; precipitation <450, 450-850, >850 mm; humidity coefficient <0.6, 0.6-1.0 >1.0; actual soil moisture <120, 120-400, >400 mm; maximum soil retention <800, 800-1100, >1100; potential evaporation <500, 500-1000, >1000 mm. As a result of a decrease in the humidity level, the area of high-quality soils in all cases decreased and the area of low-quality soils increased (Table 2).

Figure 2 shows the changes in maximum soil retention, precipitation and soil fertility, which are the main indicators of humidity level of areas, for the period 2000-2022.

From 2000 to 2022, there were significant changes in the hydrological soil groups (HSGs). An increase by 11.7% in the area of group "D", characterized by poor water permeability, led to a decrease in the infiltration capacity of the territory. This process played an active role in the degradation process significantly reducing soil moisture.

During this period, a serious increase in soil erosion was observed in the area, and horizontal fragmentation of the surface over the entire area increased from 1.96 km/km$^2$ to 2.19 km/km$^2$ (10.5%). The erosion process was most active in cultivated areas, and most weakly in areas with dense forest cover.

**Table 2.** Changes in the humidity level and the area of soil-vegetation cover in 2000-2022 (%)

| Research object | 2000 | | | 2022 | | |
|---|---|---|---|---|---|---|
| | low | average | high | low | average | high |
| | Air moisture indicators | | | | | |
| Atmospheric precipitation, mm | 43.7 | 35.9 | 20.4 | 50.3 | 35.2 | 14.5 |
| Air temperature, °C | 7.8 | 27.3 | 64.9 | 5.9 | 23.8 | 70.3 |
| Potential evaporation, mm | 19.4 | 40.7 | 39.9 | 17.5 | 37.8 | 44.7 |
| Humidity coefficient | 45.0 | 35.3 | 19.7 | 52.8 | 30.0 | 17.2 |
| | Soil moisture indicators | | | | | |
| Maximum soil water retention, mm | 31.6 | 34.0 | 34.4 | 18.0 | 39.2 | 42.8 |
| Actual soil moisture, mm | 38.0 | 41.5 | 20.5 | 45.5 | 40.9 | 13.6 |
| Infiltration capacity (HSG) | 21.8 | 55.1 | 23.1 | 24.7 | 55.7 | 19.6 |
| | Change of soil-vegetation cover | | | | | |
| Soil cover fertility | 35.7 | 43.3 | 21.0 | 42.1 | 41.8 | 16.1 |
| Vegetation density | 50.6 | 33.8 | 15.6 | 62.1 | 27.1 | 10.8 |

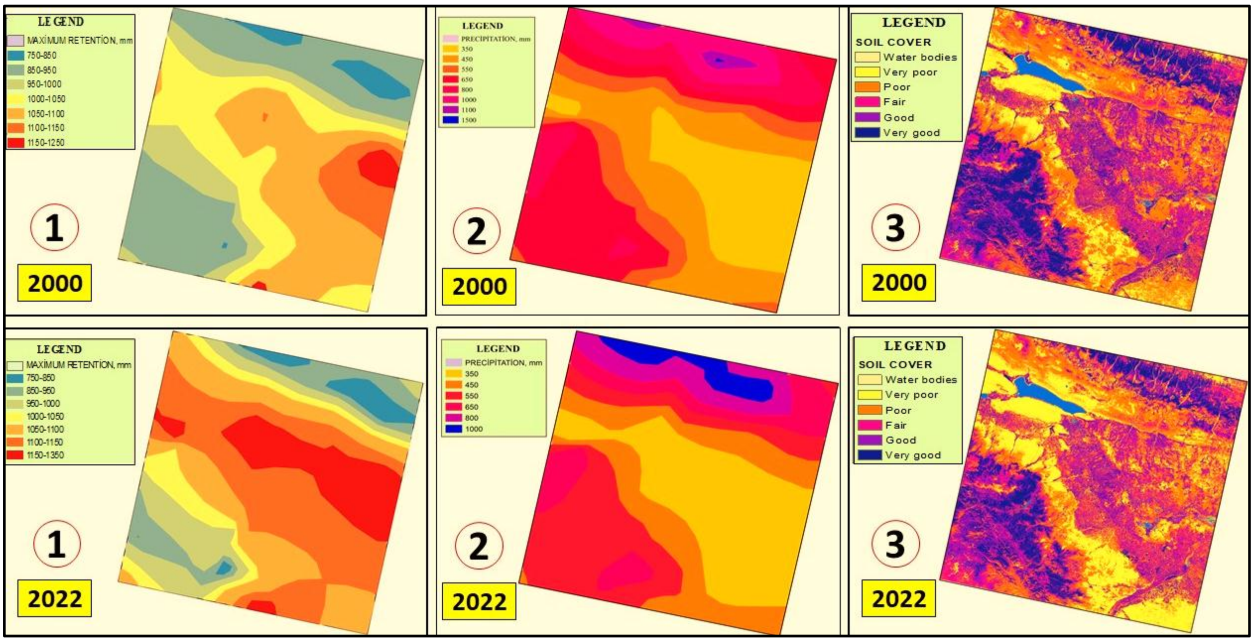


**Fig. 2.** Changes for 2000-2022: 1- Maximum soil retention; 2–Precipitation; 3–Soil cover.

Determining the role of anthropogenic and climatic factors in soil degradation is one of the most difficult scientific problems to solve. In addition, the advantages of the combined use of Analogue terrains, Counter-approach and NDI methods allow you to track the results of natural and anthropogenic impact on changes separately. By combining change maps of various components and reclassifying, it is possible to track the extent of these effects using various software in ArcGIS. Since there are very few natural landscapes left on the plains and foothills, this process is more accurately observed in mid-mountain and high-mountain regions. The analysis of anthropogenic impacts was determined by the way processing and decipher of vegetation (NDVI), moisture (NDMI), erosion (NBaI), salinity (NDSI), drought (NDDI), Karaburun, 2010). During the study years, the effects of climate change manifested themselves faster than the effects of anthropogenic changes. The boundary between climatic and anthropogenic impacts was discovered by comparing land plots with similar physical-geographical conditions, but different land use. The impact of human activities is mainly tested by the change in the area of rural and urbanized settlements, cultivated areas, badlands located in the plains and foothills. The rate of soil degradation is different in areas subject to anthropogenic impact. As can be seen from Figure 1, although negative climatic impacts increased to a greater extent on agricultural lands (yards, crops, pastures) in the study period, the expansion of the area of infertile soils was relatively slow. Various therapeutic measures carried out in these areas could at least partially slow down the growth rate of the degradation process.

The CWBM assessment is based on 3 stages of the study: Previous, Current, and Forthcoming. The study of the physical-geographical conditions of the area from the past period, being carried out in parallel with the modern evaluation, allows the following of the quantitative and qualitative changes that occurred in the past period. At the same time, the reasons for these changes, the assessment of the role of various factors, and the analysis of the mistakes made are the basis. These, in turn, provide additional advantages in terms of predicting and modeling possible changes. The forthcoming studies of the territory are carried out on the basis of a possible change in the direction of landscape, climatic and anthropogenic impacts in a long-term period; changes in the settlement and employment of the population; the content of the upcoming socio-economic and agrarian reforms, etc. At present, in contrast to the traditional three-way forecasts, preference is given to the modern multi-way forecasting model. Modern scientific technologies make it possible to predict millions of options taking into account the influence of complex factors and interactively manage them according to the content of natural and anthropogenic changes and transformations. Table 3 and Figure 3 show the areas of degraded soils based on Previous (2000), Current modern (2022) and Forthcoming (2050) studies of the area. The forecast for 2050 is given with only one of the climate models (CCCM), based on possible landscape changes, the rate of population settlement and the content of expected reforms (Mammadov, 2002; Makhmudov, 2022).

Compared to 2000, in 2022, the area of highly degraded unsuitable lands increased by 17.3% (1234.2 $km^2$). It is predicted that in 2050, this increase will be 27.4% more (2692.8 $km^2$) than in 2022.

**Table 3.** Changes in soil fertility in the study area in different periods

| Soil cover condition | 2000 | | 2022 | | 2050 | |
|---|---|---|---|---|---|---|
| | $km^2$ | % | $km^2$ | % | $km^2$ | % |
| Water bodies | 673.2 | 1.80 | 602.1 | 1.61 | 456.3 | 1.22 |
| Very poor (bare soils) | 5909.2 | 15.8 | 7142.4 | 19.1 | 9834.2 | 26.3 |
| Poor | 7180.8 | 19.2 | 9124.6 | 24.4 | 10767.2 | 28.8 |
| Fair | 8265.4 | 22.1 | 7592.2 | 20.3 | 6244.3 | 16.7 |
| Good | 7517.4 | 20.1 | 6917.3 | 18.5 | 5647.4 | 15.1 |
| Very good | 7854.0 | 21.0 | 6021.4 | 16.1 | 4450.6 | 11.9 |

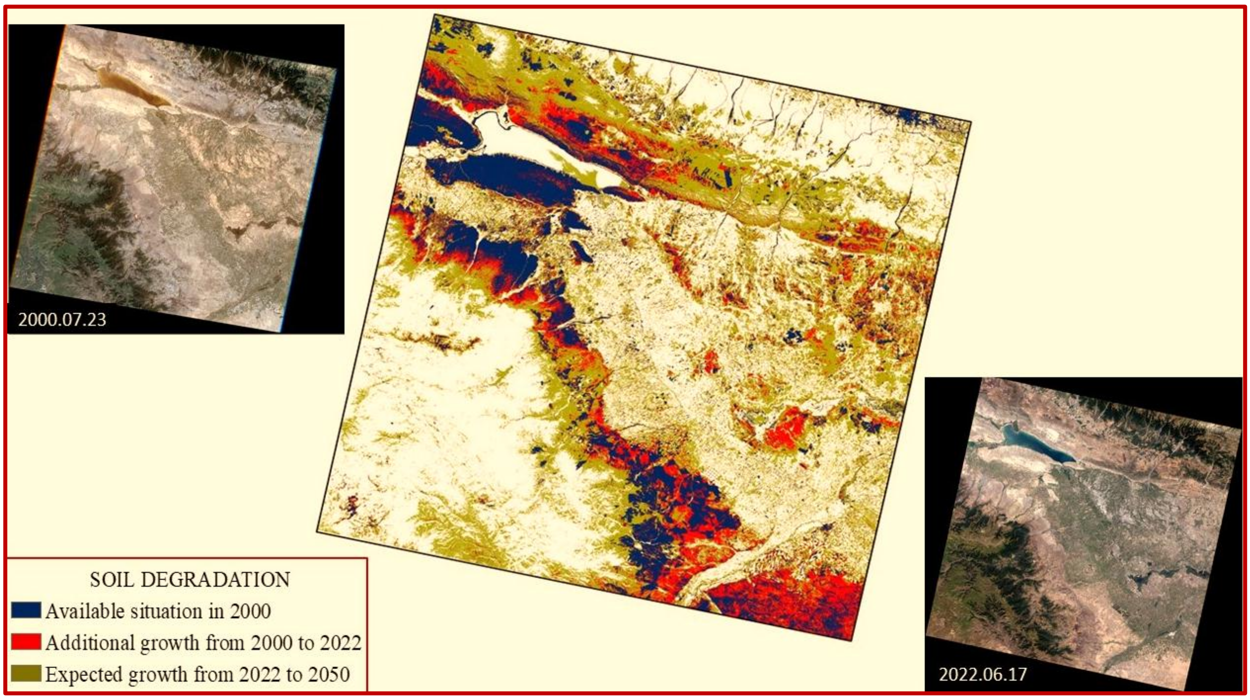


**Fig. 3.** Areas of degraded soils in the study area in 2000, 2022 and 2050

## CONCLUSION

The new method (CWBM) is very important from the point of view of solving many problems, such as the heat-moisture balance of the area, the assessment and forecast of natural resources, the protection of the existing ecosystem, territorial planning, and more efficient management of the use of water, soil and other natural resources. In the CWBM, the entire research process is carried out without spatial and temporal restrictions on the basis of satellite images of the area and GIS technologies. CWBM is an innovative and operational-interactive method. The results obtained with its help are distinguished by their sensitivity and adequacy to any changes, high accuracy. The advantages of the new method make it relevant to popularize and expand the use of the possibilities of its application.

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