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Ecological-geomorphological analysis of surface processes in the Kura-Araz lowland and adjacent territories on the base of remote sensing data

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Abstract

The relief of the earth's surface is the result of a continuous interaction of endogenous and exogenous forces. This law follows from the general provisions of materialistic dialectics about the unity and conflict of opposites and expresses the basic axiom of geomorphology about the joint action of the main forces of morphogenesis. The purpose of the study is to analyze the distribution and dynamics of exodynamic processes that form ecogeomorphological conditions under the influence of natural and anthropogenic factors. Natural factors include endogenous, such as mud volcanism, modern tectonic movements, buried high, tectonic faults on sediments and the crystalline basement of the territory, exogenous, such as linear and planar erosion, deflation and eolian accumulation, waterlogging, salinization, abrasion, floods, anthropogenic, such as irrigation erosion, intensive grazing, exploitation of oil and gas fields, production of building materials, accelerating unfavorable exodynamic processes.In the study, land use and land cover maps were composed using supervised and unsupervised classification, and different normalized vegetation, humidity, salinity and erosion indices were built using a combination of red, infrared, shortwave infrared spectral channels of the Landsat space image taken in 1976-2017 on the base of aerospace methods and GIS technologies. Based on the interpretation of satellite images and a digital terrain model, the flood process on the Kura and Araz rivers in May 2010, which caused serious damage to the country's economy, was analyzed in detail. The total area of flooding was calculated and the degree of flooding of settlements was assessed. In different years (1976-2017), reductions in the areas of fluvial, arid-denudation and accumulative processes (linear and surface erosion, salinization, deflation and aeolian accumulation, etc.) were revealed based on the analysis of compiled maps of land use and land cover and the construction of normalized vegetation, humidity, salinity and erosion indices. This was due to the expansion of arable land due to anthropogenic activities.

1. Introduction

The unity of endogenous and exodynamic processes on the earth's surface is formed by landscape forms of the earth's crust and geomorphological formations of the environment. Exodynamic processes are activated as a result of a number of natural factors, such as: seismotectonic, tectonic-geomorphological, geological-lithological, hydrogeological and climatic (Fedotov 2019; Jashi et al. 2012). Exodynamic processes of morphogenesis, characterized by high destructive and creative activity, significantly changed the initial appearance of morphostructures formed as a result of endogenous processes, which led to the emergence of new morphogenetic types of relief - morphosculptures (Chalov 1988). Exodynamic processes interacting with static and endodynamic relief factors, as well as other components of the physical and geographical conditions of the area, play an important role in the formation of the ecological and geomorphological conditions of the area (Khalilov, Gasimov 2017). The nature and intensity of exogenous processes depend on tectonic movements, surface slope, rock lithology, climatic conditions, hydrographic network, vegetation, etc. sedimentation (accumulation) took place in negative landforms with a small slope. With the weakening and stabilization of tectonic movements, the destructive and constructive activity of exogenous processes is gradually balanced,

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planation and smoothing of the relief occur (Shirinov 1973). Exodynamic processes that represent geomorphological risk and danger in the study area include floods, coastal erosion, gully erosion, surface runoff, clayey karst, deflation, eolian accumulation, salinization, and waterlogging. There are constructive relief-forming processes of exogenous origin, such as alluvial, alluvial-proluvial, alluvial-deltaic, alluvial-lake-former river beds, deluvial, proluvial-deluvial, alluvial-marine accumulation.

2. Method

The purpose of the study is to analyze the distribution and dynamics of exodynamic processes that form ecological and geomorphological conditions under the influence of natural and anthropogenic factors. To achieve this goal, the following tasks were performed: 1) literary sources were analyzed, the reasons for the formation and distribution patterns of exodynamic processes that create geomorphological risks were studied; 2) an information base was created consisting of Landsat satellite images relating to 1976-2017, a digital elevation model (SRTM); 3) The gradations of surface (exodynamic) processes were determined, reflecting the degree of influence on ecological and geomorphological conditions; 4) On the basis of cartographic generalization, the total area of exodynamic processes in the study area was determined.

In the study, supervised and unsupervised classification was performed. Maps of land use and land cover were composed, vegetation, humidity, salinity and erosion indices were built, the flooding process on the Kura and Araz rivers in May 2010 was analyzed based on the analysis of satellite images, a digital elevation model and using GIS technologies. The total area of flooding was calculated and the degree of flooding of settlements was assessed.

2.1. Flood monitoring

Flood processes that occurred in May 2010 were studied on the basis of unsupervised classification of the Landsat-5 TM satellite image (2010) with a resolution of 30 m in the spectral channels: near-infrared (0.76-0.90 μm), mid-infrared (1.55-1.75 μm) and red (0.63-0.69 μm) and digital terrain model (SRTM) analysis.

2.2. Vegetation, humidity, salinization and erosion indices

The study also calculated the vegetation index (1), which indicates the density of vegetation on the site, and identified areas with sparse vegetation (in the range: -1-0.2) and relatively dense (in the range: 0.2-1) gradations:

$$NDVI = (NIR - RED) / (NIR + RED) \quad (1)$$

During the study, the normalized differential humidity index (2) was calculated for the summer season of 2002 and 2017:

$$NDMI = (NIR - SWIR\text{-}1) / (NIR + SWIR\text{-}1) \quad (2)$$

To analyze the dynamics of salinity in the study area for 1976-2017. the normalized differential salinity index was established (3):

$$NDSI = (RED\text{-}NIR) / (RED+NIR) \quad (3)$$

In order to conduct a comparative analysis of areas where erosion, salinization and clayey karst processes occur in the area, the exposure index (4) was used:

$$NBaI = (NIR - SWIR\text{-}1) / (NIR + SWIR\text{-}1) \quad (4)$$

In formulas (1)-(4): NIR - near infrared, RED - red, SWIR - shortwave channel of the spectrum.

2.3. Land-use land cover map

The study provided a supervised classification of multispectral space images Landsat 2 MSS (1976) and Landsat 8 OLI & TIRS (2017) at wavelengths of near infrared (NIR - 0.7-0.8 μm), red (Red - 0.6-0.7 μm) and green (Green) (0.5-0.6 μm).

3. Results

In different years (1976-2017), reductions in the areas of fluvial, arid-denudation and accumulative processes (linear erosion, surface washout, salinization, deflation and aeolian accumulation, etc.) were revealed based on the analysis of compiled maps of land use and land cover and the construction of normalized indices vegetation, humidity, salinity and erosion. This was due to the expansion of arable land due to anthropogenic activities.

In areas of intense uplift, valley erosion is developed, in areas with a small slope subject to subsidence, lateral erosion is developed (Shirinov, 1973). They are found in the cones of rivers and their tributaries, in the valleys of the Kura and Araz rivers and in the foothills.

Ravine erosion together with clayey karst led to the formation of areas with the so-called badlands, characterized by high ecological and geomorphological tension, devoid of soil and vegetation, completely unsuitable for economic purposes (Shirinov, 1973). We explain this with breccias of mud volcanoes, characterized by a high degree of mineralization, flowing in the foothills along a dense network of ravines developed on the northeastern slope of the depression and causing salinization in these areas.

Gorge erosion is developed in areas with weak tectonic uplift and a relatively humid climate (warm-temperate climate with 400-600 mm of precipitation per year, dry winters). The soil and vegetation in these areas are not completely degraded, but partially preserved (Shirinov, 1973). In our opinion, gully erosion is characterized by moderate ecological and geomorphological intensity compared to gully erosion.

According to observations, planar washout in all flat and adjacent areas is subject to relative uplift and lacks conditions for accumulation (a slight slope, the presence of silt and a small amount of surface runoff) (Shirinov, 1973). We explain this with the flow of water covering the surface with a thin layer and leading to erosion of the fertile soil layer.

The Kura-Araz lowland and adjacent areas were a zone of marine and continental accumulation, inherited from the Pliocene and Quaternary period. There are the following genetic types of accumulation prevailing in the study area according to their origin: alluvial, alluvial-proluvial, proluvial, proluvial-deluvial, deluvial, marsh-lake, lake, eolian and saline. In the study area, the area of alluvial accumulation is limited in the deposits of modern river valleys (Kura, Araz and their tributaries), alluvial-proluvial is limited in river fans, and the accumulation of proluvial, proluvial-deluvial and deluvial deposits is limited in the foothills and low-slope areas of the plain (Shirinov, 1973).

Floods in the valleys of the Kura and Araz rivers and their tributaries in March-June are characterized as a destructive natural process. 33.3% of cities and towns, 44.1% of rural settlements, 29.8% of agricultural land, 53% of transport roads, 62.2% of the collector-drainage network, 45.6% of irrigation canals were periodically flooded. In general, during the floods in 2000-2010, the economy of the republic was damaged in the amount of 1.9 billion dollars (66.7% of which was due to floods that occurred only in 2010) (Musayeva, 2013). Flooding in the lower reaches of the Kura River, in 2003 alone, caused about $65 million in damage to the population (Budagov et al. 2008).

Eolian processes in the form of deflation and eolian accumulation are widespread in areas characterized by arid climate, strong winds, poor vegetation cover, salinity of surface sediments (Shirinov, 1973). As a result of the deflation process, over large areas suitable for use as winter pastures, the soil cover loses its fertility and productivity, and in some cases, as a result of complete absorption, loose sediments that are not resistant to denudation have formed. Fine dust particles with a high degree of mineralization, carried by the wind from salt-ridden lands, settle in the adjacent territories, as well as in the sown fields, causing salinization of these territories as a result of eolian accumulation. According to our observations, eolian accumulation creates positive landforms such as sand dunes and dunes.

Approximately 60% of the lands of the Kura-Araz lowland, which make up an area of 2.2 million hectares, consist of medium and highly saline soils (Mammadov, Khalilov, 2005). In our opinion, both natural and anthropogenic factors influence the development of salinization in the deposits of the Kura-Araz lowland and adjacent territories. Natural factors include arid climatic conditions (temperate semi-desert and dry steppe climate), a high degree of mineralization and filtration capacity of sediments, the proximity of water-resistant strata and groundwater to the surface, and anthropogenic factors include irrigation measures without taking into account physical and geographical conditions (irrigation water infiltration into unconcrete canals and subsequent rise in groundwater levels).

Underground erosion (clay karst) in the Kura-Araz lowland and adjacent territories is observed in the areas of occurrence of Pliocene sandy-argillaceous deposits, mud volcanic breccias and deluvial clays.

Floods and inundations in the Kura and Araz rivers in May 2010 were analyzed by us on the basis of uncontrolled and controlled interpretation carried out on the Landsat-5 TM satellite image (Fig. 1). According to the calculations performed on the digital elevation model (SRTM), the absolute height in the flooded areas varies in the range: -27-0 and 0-219 m, the average height is -14.88 m, the slope varies in the range of 0-40°, and the average the slope reaches 0.98°. In total, more than 610 sq.km of the study area was found to be flooded by the waters of the Kura and Araz rivers. More than 26 sq.km of the flooded area, falls on 159 settlements (9 cities, 5 towns, 145 villages) with a population of more than 565 thousand people (2009). The degree of flooding of settlements was calculated (Table 1).

Table 1. Flooding of settlements in 2010

Degree	City	Settlement	Village	Common	Population	S, km²
Weak	8	2	121	131	456788	7,25
Moderate	1	2	11	14	91271	8,61
Medium	-	1	4	5	7950	2,37
High	-	-	9	9	9330	8,34
Sum	9	5	145	159	565339	26,6

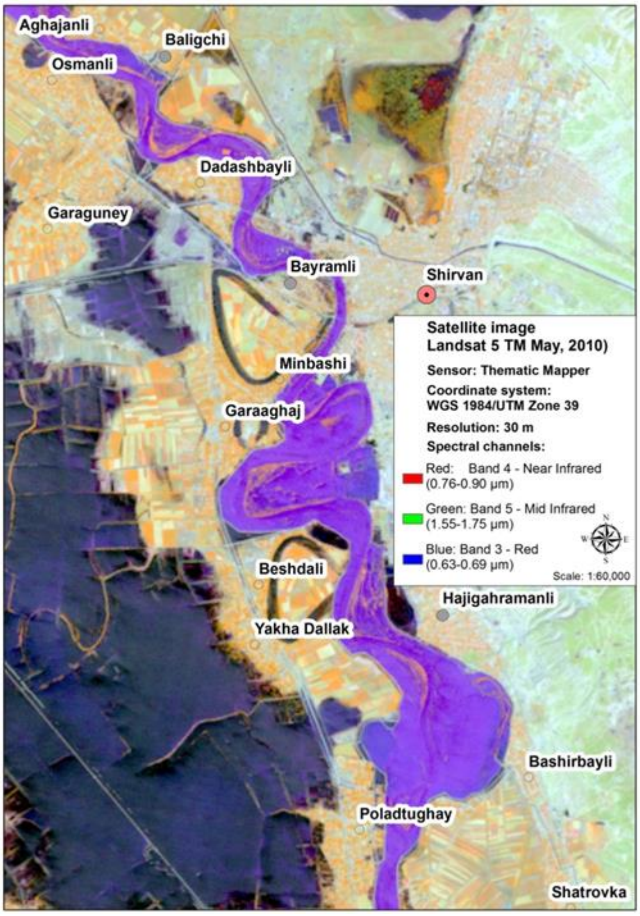

Figure 1. Flooding process in Kura-Araz lowland in May, 2010

4. Conclusion

Due to anthropogenic influence, the area of fluvial, arid-denudation and accumulative processes in the territory is decreasing. Based on the interpretation of the satellite image, it was revealed that as a result of the flood that occurred in May 2010, more than 610 sq.km of the territory adjacent to the floodplains of the Kura and Araz rivers were flooded and caused enormous damage to the population. The degree of flooding was assessed by the area of flooding of 159 settlements and four degrees were divided: weak, moderate, medium and high. 9 settlements with a population of about 10 thousand people were classified as high, as more than 30% of the area of these settlements were flooded. According to the interpretation and comparative analysis of space images, the area of erosion, salinization and eolian processes for 1976-2017 decreased by 2596.0 sq.km, and the average annual decrease for 41 years reached 63.32 sq.km. The average annual decrease of exodynamic processes in the study area was 25.26 sq.km according to the estimated vegetation index (NDVI) for 1976-2017, 30.01 sq.km according to the salinity index (NDSI), 80.77 sq.km according to the moisture index (NDMI), 192.43 sq.km according to the erosion index (NBaI).

In conclusion, let us note that anthropogenic influence plays an important role in the development of such processes as salinization, waterlogging, etc. The failure of main, inter-farm and intra-farm canals, as well as improper irrigation and drainage, led to the infiltration of irrigation water into irrigated areas, an increase in the level of groundwater, swamping and salinization processes. In conclusion, we note that all harmful exodynamic processes create geomorphological risk and danger. But the potential damage can be quite different. The whole complex of these exodynamic processes leads to desertification. This study can serve as a theoretical and practical basis for monitoring and taking measures to protect the environment in various areas with similar environmental problems.

In order to regulate the level of groundwater and prevent the development of the processes of re-salinization and waterlogging caused by them in the study area, abandoned, main and inter-farm canals and collectors should be concreted, drip irrigation should also be introduced, and in areas with intensive development of wetlands and saline lands to expand a closed horizontal collector-drainage system and vertical drainage to flush soils.

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