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Ecological-geomorphological assessment of the suburban area of Astana

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Abstract. The results of ecological-geomorphological assessment of the suburban zone of Astana is presented in the paper. Climatic and hydrological factors, which are the agents of pollutants' transport and caused the development of exogenous processes in the suburban area of Astana were studied and mapped. On the base of the geoinformation technologies and field studies the geomorphologic structure and morphogenetic processes were studied. The analysis of the data complex led to assess ecological-geomorphological conditions of the suburban area of Astana.

1. Introduction

One of the problems of modern society development is, a significant deterioration of the ecological condition of urban settlements and urbanized territories. The uncontrolled growth of large cities and their suburban areas, high rates of urban ecosystems pollution, the impact of hazardous exogenous processes lead to increased environmental tension, degradation of the natural resource potential of the adjacent territories, affect the safety of local population life [1], and also cause finacial losses [2].

This problem is, also relevant for the suburban area of the capital region of Kazakhstan, which is located approximately in the 50-km zone around the capital. The suburban area, whose total area is 12.118 km^2, includes the part of three administrative districts of the Akmola region: Tselinogradsky, Arshalynsky and Shortandinsky. The growth rates of the population of these regions within the hourly availability from Astana far exceed the projected ones for the last two decades. Within the zone, occupying 8% of the territory of the Akmola region, at the beginning of 2017, 17% of the region population lived. Over the last 15 years, the territory of construction of settlements close to the city has increased almost tenfold, which was accompanied by the expansion and construction of roads and engineering support networks. The riverbeds, floodplains and low terraces within territory of the city and suburban area were significantly amended, that is related as to town-planning organization of territory, as to uncontrolled building materials mining. The dynamic development entailed significant changes in the natural environment, which affected the stability of the basic component of the natural environment – relief and processes shaping it.

2. The problem statement, materials and methods

The aim of the research was an ecological-geomorphological assessment of the impact of modern exogenous processes on the organization of the territory of the actively developing suburban zone of Astana. To achieve the goal, the geomorphological mapping of the suburban zone of Astana was accomplished with the definition of the hazardous geomorphological processes development degree,

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the sources of the natural environment pollution were studied and the main factors of pollutants' transport and accumulation were determined [3,4]. Geomophological mapping is important for geochronology of the newest stage, study of natural resources, assessment of natural hazards [5]. Based on these data, the ecological-geomorphological assessment of suburban zone of Astana was accomplished.

Methods of geoinformation analysis, digital satellite images interpretation, traditional methods of relief studying in cameral and field conditions, digital terrain model creating, ecological-geomorphological mapping and modeling of exogenous processes were used [6,7].

The main natural factors, conductive to the development of exogenous processes were studied. Climatic features of suburban area were studied on the base of data on meteorological stations of Astana and Arshaly village, that located within the study area. In addition to climatic factors analysis the data on 16 meteorological stations of Akmolinsk and Karagandy regions, which have continuous, long-term monitoring raw from 1981 (RSE «Kazhydromet») were used. Through the application of the method of spatial analysis Spatial Analyst ArcGIS 10.2 the climatic inventory and estimated maps were made.

Hydrological factors analysis also was one of the integral parts of ecological-geomorphological assessment. The analysis of hydrological rates was made using data of monitoring on hydrological station of RSE «Kazhydromet». The data on the Esil River were used on the stations Priishimskoe, Turgen, Volgodonovka villages and Astana for the period from 2010 to 2015 years. On the stations Telman, Novoishimka villages and Koktal district for the period of 2015 year, the data on the Nura River were used on the station R. Koshkarbayev village for the period from 2010 to 2015 year. For the spatial analysis of hydrological data, the methods of geoinformation technologies were used. With the use of geoinformation methods of spatial analysis, the complex of inventory and estimated maps of hydrological and soil factors was made.

In addition, the assessment and mapping of the environment pollution sources were accomplished; the assessment of ambient air, soil and water quality was given. On the basis of data on the pollution sources and excess of pollutants limits (MPC), taking into account climatic and hydrological parameters, the pollutants spread halo in «Era» software (1.7 version), that was developed by «Logos-Plus» company (Novosibirsk). The complex of conducted researches, together with the data about exogenous processes activity, let assess ecological-geomorphological situation of suburban zone of Astana.

3. Results and discussion

The research area is located within the northern part of the Central-Kazakhstan hummocky topography, composed by dislocated rocks of the Dopaleozoic and Paleozoic. The up-to-date relief was formed as a result of a long-term continental regime of development under the influence of a complex of denudational processes, which contributed to the formation of a thick weathering crust. A characteristic type of relief is, the flat and slightly undulating denudation socle plains at absolute elevations of 340-392 m with prevailing surface slopes of up to 3-7°. They are developed along the complexly sedimentary, effusive, sometimes intrusive rocks of the Paleozoic. The accumulative plains within the suburban zone are genetically represented by deluvial-proluvial, proluvial, lacustrine-alluvial and alluvial types.

The results of studies were also the assessment of ecological and geomorphological conditions of the territory. As a result of studies of climatic and hydrological factors, mean annual air temperature, atmospheric precipitation, wind direction and velocity were studied as the main climatic factors contributing to the development of erosion and deflation processes. With the application of Spatial Analyst module of ArcGIS 10, the areas most vulnerable to erosion and deflation during the year were determined. The analysis showed that, soils of the investigated territory are at risk of erosion from May to August considering the average monthly air temperature and the total number of hours with precipitation exceeding 30 mm for a warm period. Due to the fact that, the development of deflation processes is facilitated by wind speeds exceeding 4 meters per second in the warm period of the year, it is revealed that the high risk of deflation is observed from April to May and in October. Despite the decrease of wind speed from June to September, the area of research is still subject to a low risk of removal of finely dispersed material because of the significant increase in air temperature. It is determined that, there is a risk of soil deflation processes almost throughout the whole warm period, as from 42% to 53% of all winds from April to October have a speed higher than 4 meters per second.

Thus, there is two periods of more intensive development of erosion and deflation processes in the study area in the warm season of the year. The risk of deflation increases in April, May and October for the southern and eastern parts of suburban area. In the south, deflation processes are activated within the accumulative alluvial-lacustrine plains, which are extended from the southwest to the northeast and framed by raised wavy and sloping-wavy deluvial-proluvial plains. In the southeastern and eastern parts of the suburban zone, such activation occurs within the widely developed sag-and-swell socle plain with small areas of the rocky hilly and ridge watershed hummocky terrain.

The risk of erosion processes rises from May to August and in September, geographically increasing from south to north. The risk of erosion processes is increased in the northern part of the suburban area within the basin of the river Koluton, which is the right-bank tributary of the Esil river and the upper reaches of the Sileti river basin. The valleys of these rivers were formed within the undulating denuded socle plains with parts of the hummocky terrain.

The integral assessment of climatic factors, which contribute to the development of erosion and deflation processes, has shown that, the eastern part of the investigated zone from the Prirechnoye village to the Nikolaevka village is at high risk of negative processes complex development.

The increased risk zone for the development of erosion and deflation processes is observed to the north and east of Astana. The rest of the territory is subject to a medium risk of erosion and deflation processes that depend on climatic factors.

The modern river network within the suburban area of Astana is underdeveloped due to aridity, the predominance of flat relief with plenty of lake depressions, structural features of the soil and vegetation cover. For the territory, the presence of temporary streams, disappearing in summer, is characterized. River network density does not exceed 0.05-0.10 $km \cdot km^{-2}$, while the density of gully network reaches 0.2-0.3 $km \cdot km^{-2}$ [8].

Area's flat relief causes mild severity watershed, at the same time within the suburban area of Astana. Three of the eight water basins watersheds of Kazakhstan are located: Esil (Esil River and its tributaries), Nura-Sarysu (Nura River) and Ertis (Silety River). Rivers are typical plain, valleys are wide and flat, trapezoidal shape. There are areas of riverbeds bifurcation and runoff intercept on Nura-Esil entre rios.

The nature of the underlying surface of the river valleys determines their vulnerability to eroding and accumulating work of river. The Esil River valley consists mostly of loose deposits (sandy loam and loam, underlanded by sand, gravel and pebbles) and the output of rock is only observed in the upper, which causes the prevailing of the processes of erosion and transfer substances.

Particular importance in the analysis of river hydrodynamics has the hydrological regime, especially intra-annual distribution of runoff. The Esil River is a typical river of Kazakh type with exceptionally snow-fed, that defines the sharp intra-uneven flow distribution. The predominant phase of water regime is a spring high tide (90-95% of annual runoff) extending over a short period (April - May) and marked a sharp increase in water consumption. Thus, according to data of hydrological post the Esil River – Volgodonovka village in 2015, the water consumption from the start of the flood (the 10^{th} of April) rose to its peak of up to 4 days in 5 times, from 138 $m^3 \cdot s^{-1}$ up to 682 $m^3 \cdot s^{-1}$ (figure 1a). Also, increased water consumption is observed during floods, caused by heavy rainfall. Thus, during the spring flood active work of river water flow creates favorable conditions for rocks' erosive washout and loose deposits removal. At the low water period eroding capacity decreases and significant changes in the riverbed and the shoreline are not observed, the accumulation processes are activated.

The average altitude of the Esil River basin is about 350 m, at the site to Astana it is higher and reaches 460 m [8]. The Esil river slope along at length is also changing: from the source of the Esil

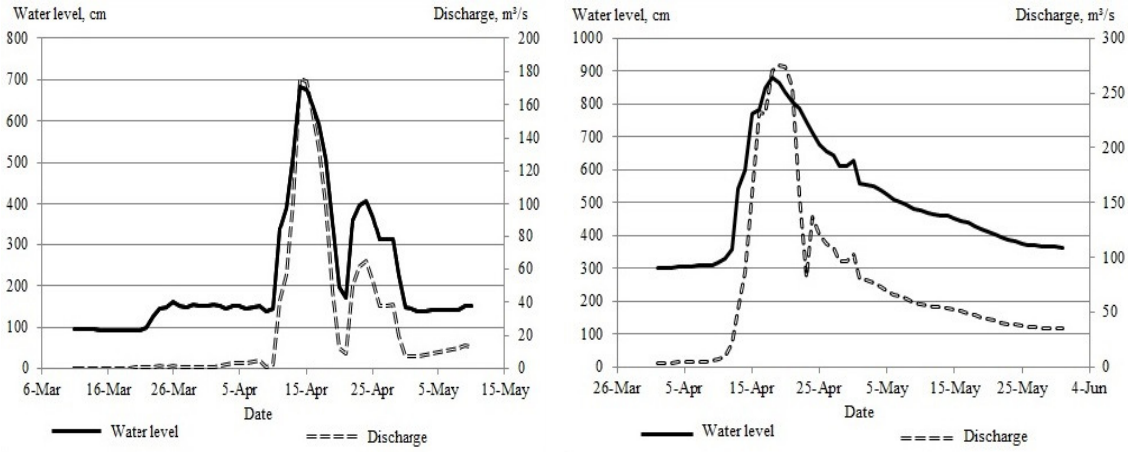
River to confluence of his right inflow Kargala slope is 2.8 ‰ at the absolute altitude of 560-450 m. Further, to Volgodonovka village (450-369 m) slope is reduced to 0.7 ‰. Downstream slope decreases to 0,4 ‰ with an average altitude of 344 m. Flow rate depends on to the channel slope as well as the degree of river flow regulation. The average maximum rate of flow for the period 2011-2015 years during the passage of water flood is 1.08-1.75 $m \cdot s^{-1}$ in the upper reaches of the river Esil before the Astana reservoir. Below Astana reservoir it is reduced to 1.02 $m \cdot s^{-1}$, below in the range of the city suburban area it is already 0.72 $m \cdot s^{-1}$. It is known that even on plain rivers at a flow rate of 1.6 $m \cdot s^{-1}$ ridges of 0.3-1 m height can be formed.

Sinuosity factor of the Esil river bed within the suburban area to hydrological post in Astana (park) is 1.69, at the downstream it is reduced slightly to 1.61. Indicators show the type of meandering riverbed Esil River within the suburban area. The meandering type of the channel sections the are subject to a greater erosive effect of the water flow, since with a greater bending radius of the flow the effect of the centrifugal force increases, which creates conditions for the development of lateral erosion. This type is characterized by meandering within inundated levels, creating multiple flow path, and reaches alternating sills, erosion and the accumulation of deposits.

Intra-annual distribution of the Nura river is caused to the Kazakh type of water regime and snow-fed character of river. According to the hydropost Nura River - R. Koshkarbayev village in 2015 water discharge was increased by 3 times, from 317 to 882 $m^3 \cdot s^{-1}$ for 8 days (figure 1b). The Nura river is also characterized by increased runoff during the water floods. The slope of the Nura river bed within the suburban area is 0.1-0.2 ‰ at average altitude of 345-365 m. The average long-term maximum flow velocity of the Nura river is 1.06 $m \cdot s^{-1}$. Loose deposits, in which the Nura River valley within the study area is developed, contribute to their erosion, transport, and redeposition. Sinuosity of the Nura river bed within suburban areas of Astana is 1.48, the channel has a moderate-winding type.

A characteristic feature of the Esil and Nura rivers, whose main phase is an strongly pronounced spring water tide, contributes to the high risk of flooding caused by extreme water level rises during a high and significant rain flood. It should be noted that, nowadays the risk of flooding in rivers is reduced due to the flow regulation. At the same time, a high risk of flooding and inundation of low river valleys surfaces in high-water years and flooding of low areas surrounding plains during the spring snowmelt remain. It should also be noted that, over the past decades Esil and Nura rivers bed within Astana and suburban area have undergone significant anthropogenic transformation, modification of morphometric characteristics, and consequently, ecological-geomorphological conditions.

Moreover, the active anthropogenic conversion of bed, plains and low terraces, especially within the city and urban management zone, overlap on changes of the natural processes of hydrological and hydrodynamic conditions. Anthropogenic transformation of the riverbed within the suburban area and Astana was held with different purposes, from the formation of water-regulating and spillway (the creation of the Astana reservoir, Nura - Esil channel) to the strengthening and improvement of the coastal zone. Within the city at artificialisation rectification and expansion of the riverbed Esil is conducted, and in some areas covering with ground. The analysis carried out on the basis of satellite images for the period 1975-2015 years the Esil river bed bias on 3 areas from 403 to 907 m. Regulation of Esil river bed, concreting coast within the city causes too low flow velocity – 0.02 $m \cdot s^{-1}$, which even in the period of maximum flood reach only 0.19 $m \cdot s^{-1}$. Such low rates contribute to the formation of an oxygen-free environment, overgrown by aquatic vegetation. Currently, arrangements for the reconstruction of Esil river bed within the city and suburban areas continues at multiple sites. They are aimed at ensuring the sustainability of existing hydraulic structures and protection of Astana from the floodwaters.



a) b)

Figure 1. The water level and water discharge course for spring time, 2015 on the hydrological stations: a) the Esil River - Volgodonovka village, b) the Nura river - R. Koshkarbayev village.

Assessment and mapping of the environmental pollution sources within the suburban area and the city of Astana are based on published official data. Sources of pollution are mainly represented by the enterprises producing construction materials (asphalt, concrete, cement, bricks), housing and communal services (Cogeneration plant-1 and Cogeneration plant-2) and landfills for municipal solid waste (MSW). Other 15% of industrial enterprises are related to the mining sector, the main activity of which is the mining of construction materials, that became a reason of geomorphological hazards development [9].

The dynamics of air pollution within the territory of Astana for 2010-2016 is studied on the basis of atmospheric pollution index [10]. In 2010 higher degree of air pollution was indicated, which increased the risk to the health of the city's population. During the period of 2011 – 2015 the index decreased and corresponded to a safe level. Then, in 2016, the index increased to 7 what corresponds to a high degree of air pollution. In general, air pollution was traced in the eastern and south-eastern parts of the suburban area. Average value of the excess of MPC was 6.7, while maximum excess of MPC was 8.4 and was observed in the eastern part of the city.

To assess the ecological state of soils, concentration coefficients for 14 polluting components of I, II and III classes toxicological hazard were calculated using data provided by the analysis of the soil samples taken along the roads, railways and river valleys.

The elements of I hazard class are presented by lead, zinc, cadmium, fluorine, arsenic and mercury. In 28% of the samples there is observed excess of MPC from 1.2 to 4.3 times on lead and in 14.8% of the samples there is excess 1.008 - 1.945 times on zinc.

The highest number of excess of MPC is observed for polluting elements of II hazard class. In 98% of the samples there is recorded excess of MPC from 1.1 to 8.2 times on copper, in 78.7% of the samples – from 1.02 to 4.1 times on nickel and in 54.8% of the samples – from 1.2 to 5.5 times on boron. Concerning pollutants of III hazard class, there is an excess of vanadium from 1.01 to 1.33 times. Meanwhile, an excess of MPC from 1.33 to 2.18 times on manganese were recorded in two samples. According to the soil pollution indices for assessing contamination, the territory of the suburban zone of Astana city primarily refers to the permissible degree of soil contamination. Only within two sections of the industrial zone close to the villages of Saryadyr and R. Koshkarbayev and one area inside of the city of Astana moderately hazardous category of soil contamination is recorded. Maximum values of MPC excess vary from 17.2 to 22.7.

Based on the data provided by the Akimats of the city of Astana, an analysis of the ecological state of water bodies was carried out for 11 monitoring points of surface water and groundwater. Samples of water of Esil river close to Koktal district (complex water pollution index – 7.86) and groundwater near the storage lake Taldykol (8.42) are classified as very dirty. Sample of water taken from Esil river close to the village of Karaotkel (5.31) is recorded as dirty, while water samples of Shenet lake (3.29; 3.16) as well as Silety river close to the village of Prirechnoe are classified as contaminated. Water samples of the Astana reservoir (0.42), groundwater sources near the village of Shenet (0.94), siding 41 (0.63), the village of Arnasay (0.53) and siding 42 (0.20).

Analysis of data on the quality of water of Nura river has shown environmental state change over several years – from contaminated in 2011 to a high level of pollution in 2015 (3.14) and a moderate level of pollution in 2016 (2.3). Thus, within the suburban zone, the cleanest waters are observed along the Esil river to the city of Astana, the most polluted waters are characterized by river sections below the city of Astana due to the city's influence, the large volume of produced pollutants and sewage. There is also some correlation between the changes in the complex index of water pollution and the water content of the years.

The analysis results of climate, water and geomorphology factors, and data of sources and quantitative parameters of pollution allowed managing the ecological and geomorphological zoning. The territories were identified by the prevailing degree of development of erosive and deflationary processes, from mild to severe. The areas of flat and slightly-undulating watersheds and slighty-dissected flat areas of river terraces refer to the low-hazard zone in terms of the erosion on the basis of typing of relief and analysis of morphometric parameters. The medium-dissected watershed surfaces (denudation plains), valley territories refer to relatively erosion-dangerous areas [11]. Erosion-prone areas are the most dissected areas with a dense network of gullies and ravines. Erosive and deflationary processes are observed as a whole at 3.5% of farmland. The total area of eroded soils of Arshalynskii, Shortandinskii and Tselinogradskii districts is 9.4%. Total deflated soil area of these districts is less than 1%.

Within the framework of ecological and geomorphological evaluation of suburban areas of Astana the relief resistance to the external influences was also studied. It was given a particular focus on human impact on the transformation of relief. Changing the morphometric characteristics, morphological relief appearance and the lithogenic base lead to reduced stability of the relief, a change in direction and activization of dangerous exogenous processes [12]. It is determined that most of the area refers to the relatively stable areas with erosive potential of 0.3 to 0.5 ton·km^{-2}. The areas with an unstable terrain, characterized by sufficiently high rate of erosion and the potential reaching 7.1m·km^{-2} are limited.

Conclusions

It is determined that, the sheet and linear erosion and deflation processes are the largest development processes in the territory of suburban area of Astana in accordance with the ecological and geomorphological features of the terrain. The modern geomorphological processes of natural and man-made and only man-made genesis were identified in addition to the processes of the natural genesis. Analysis of the spatial development of these processes in relation to the zones of environmental pollution, residential and industrial facilities, engineering and transport networks, and agriculture allowed determining the degree of danger to the life of the population. The research results will form the basis of recommendations development aimed at reducing the impact of dangerous exogenous processes on the territory suburban area of Astana.

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