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Assessment of Environmental Quality Indices in the Cities of the Kura-Aras Lowland, Republic of Azerbaijan

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More than 50% of the world's population lives in cities that occupy only 3% of the Earth's surface, while about 10% of the population of the Republic of Azerbaijan resides in cities covering 4% of the Kura-Aras plain. Since 30% of the republic's population is concentrated in the capital, the populations of other cities are relatively small. Nevertheless, the population density in Shirvan, located within our study area, is twice as high as in Baku. Assessing the urban quality index is therefore an important issue for densely populated cities, and this research is devoted to that topic. The geographical conditions of the cities were analyzed using satellite imagery processed with Geographic Information Systems, while the ecological situation was examined through statistical methods. The findings demonstrate that the natural conditions of these cities significantly influence their socio-economic development. Their location at the intersection of major transport routes and along the banks of the country's two largest rivers has played a decisive role in their growth and formation.

Keywords: cities, environment quality indices, Kura-Aras lowland, GIS, satellite images.

Introduction

The Urban Environment Quality Index is a tool that enables cities to assess the quality of the physical urban environment and the conditions of its formation [1]. The results of such assessments can be used to develop recommendations for environmental improvement [2].

In developing the methodology for evaluating urban environmental quality, the compilers of the index drew on international experience and referred to numerous studies in the field of urban area assessment, as well as attempts to unify these systems into a coherent structure [3]. When selecting and finalizing the set of indicators, interna-

tionally recognized documents on the creation of a comfortable urban environment were taken into account, including the UN's 2030 Habitat Agenda and Sustainable Urban Policies [4].

The cities in our study area vary significantly in both population size and climatic conditions [5]. To account for these differences and ensure accurate evaluation, cities were grouped when forming the index rating. At present, two main indicators are considered: the geographical location of the city (a fixed indicator) and its population size [6].

The index is based on the assessment of six types of urban space according to six criteria of urban environmental quality [7]. Each location type is

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Fig. 1. Investigation area

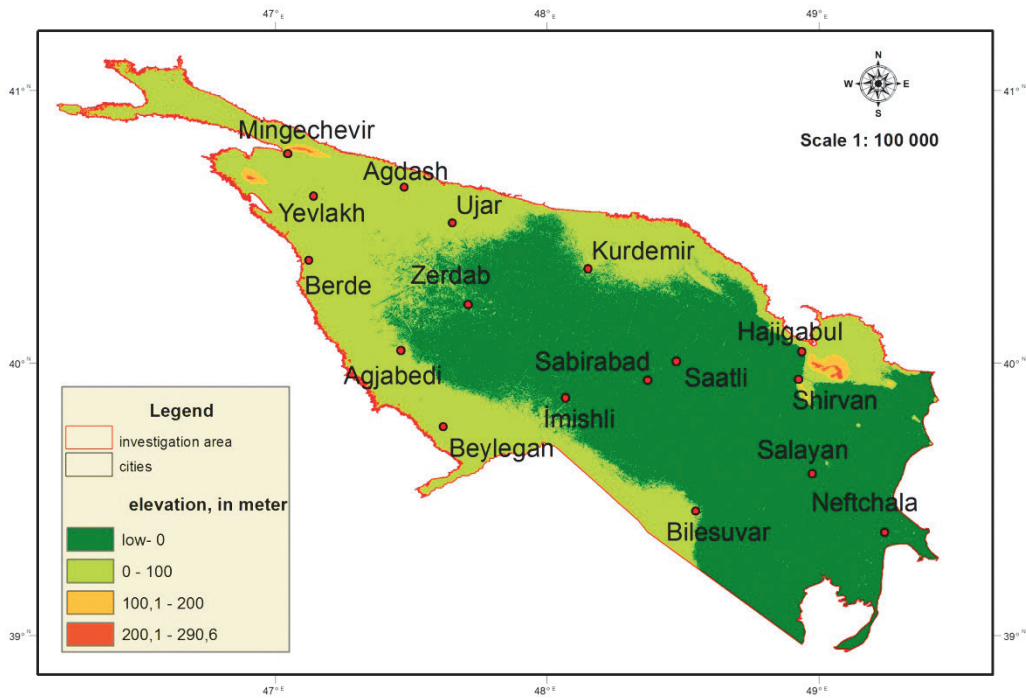


Fig. 2. Hypsometric levels in the Kura-Aras Lowland

evaluated by identifying one key indicator for each criterion. However, given the specific conditions of our study area, it is more appropriate to classify the cities into three groups [8].

Since the quality of the urban environment is not simply the sum of housing, streets, landscaping, and infrastructure, but rather a collective mea-

sure for the entire city, comprehensive evaluation is required.

Our study area—the Kura-Aras lowland and surrounding regions—extends between the Talysh Mountains, the Lesser Caucasus, and the Greater Caucasus. This depression is the largest in Transcaucasia and covers nearly the central part of the

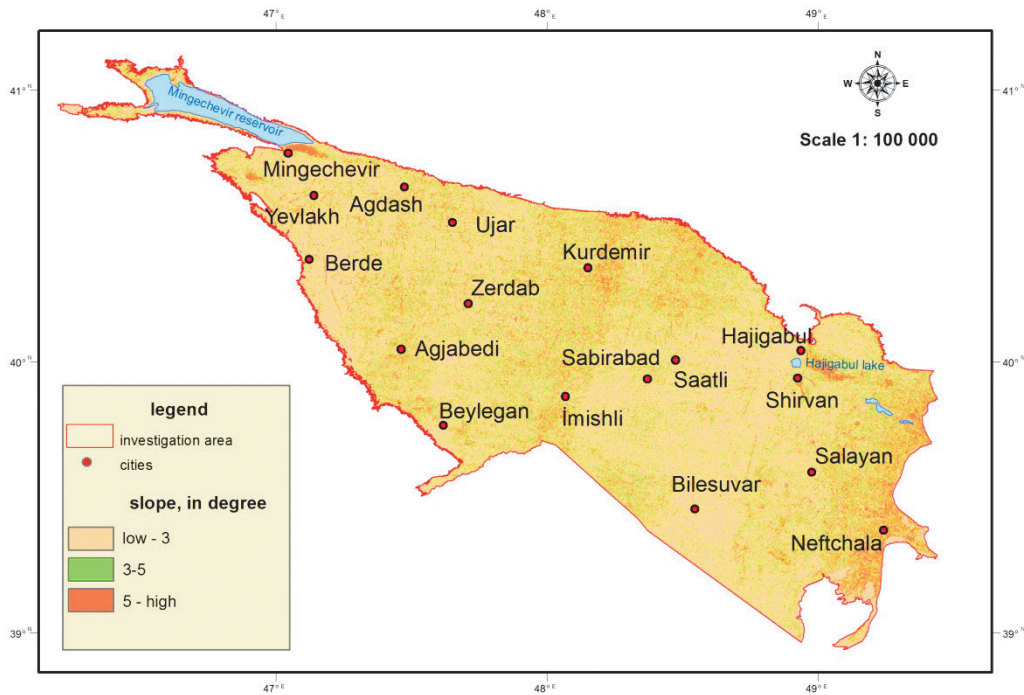


Fig. 3. Slope inclination in the Kura-Aras Plain



Fig. 4. Environmental Quality Indices of cities in the Kura-Aras Lowland

country [9]. The plains of Salyan, Mil, Karabakh, and Shirvan, divided by the Araz and Kura rivers, have influenced the development of cities [10].

The Kura-Aras plain is bordered by the Caspian Sea to the east, the Lankaran plain and Talysh Mountains to the southeast, the eastern foothills of the Lesser Caucasus to the west, and Bozdag to the

north [11]. The plain stretches 25 km from west to east, and at its widest point reaches 150 km. Its total area is 22,500 km².

Material and Methods

In this study, the natural and socio-economic conditions of 18 cities located in the Kura-Aras plain

were analyzed. To examine the natural conditions, satellite imagery was processed to produce elevation and slope maps of the area. Geological development and climatic characteristics of the cities were assessed using published literature sources. The ecological situation was evaluated through the analysis of statistical indicators. Finally, these indicators were synthesized to determine the urban quality index of the cities, with particular consideration given to their ecological status.

Results and Discussion

The research area encompasses urban landscapes located within the Kura-Aras plain, including the cities of Mingachevir, Yevlakh, Agdash, Ujar, Zardab, Barda, Agjabadi, Beylagan, Sabirabad, Saatli, Salyan, Hajigabul, Kurdamir, Shirvan, Neftchala, Bilasuvar, and Imishli. The natural conditions of these cities are largely similar (*Fig. 1*).

In evaluating urban development, it is essential to consider the role of natural environmental factors alongside economic drivers. Among the most significant natural factors are terrain and climate. Accordingly, the relief of the study area and its morphological elements were analyzed using ArcGIS software. For this purpose, the Digital Terrain Model of the region was employed to assess absolute elevation, slope orientation, and their influence on the expansion of urban construction.

Within the Kura-Aras plain, the absolute elevation of the relief lies below sea level across most areas, which account for approximately two-thirds of the plain.

1. Relief

Hypsometric maps of the Kura-Aras lowland and its individual cities were compiled to study the natural landscape of urban areas (*Fig. 2*). Based on these maps, it can be noted that approximately eight of the research cities are located below sea level.

The slope inclination in most parts of the study area does not exceed 3° (*Fig. 3*). Such low gradients create various challenges for urban management and planning.

2. Geological and Geomorphological Structure

The study area is characterized by a gently sloping surface, with ridges distributed along flat beds, interspersed trough systems, and contact depressions associated with older river valleys. At the outer margins of the lowland, the foothills consist of

wide, gently sloping plains, while riverside areas are marked by alluvial cones and depressions between them.

In the southeastern Shirvan plain, located in the eastern part of the study area, geomorphological features include low brachyanticlines, small ridges, mud volcano hills, ancient coastal levees, synclinal depressions, and the young Kurun delta within the Neftchala region.

The lithological composition of sediments plays a significant role in shaping diverse landscape units. Deluvial and alluvial-proluvial deposits dominate the margins of the lowland, while alluvial-lacustrine and alluvial sediments are widespread in its central part. Marine-origin sediments are found along the coastal strip in the east.

Due to the more intense uplift associated with neotectonic movements near the Lesser and Greater Caucasus, the relief in these marginal zones takes the form of relatively sloping plains. Consequently, absolute elevations vary between 350–400 m in the Karabakh plains and 150–200 m in the Shirvan plains, located west of the study area. In such areas, where river cones create complex relief, groundwater depth may reach 10–15 m or more, reducing its role in biomass accumulation. In contrast, inter-cone depressions exhibit shallow groundwater levels, which enhance hydromorphism in moist landscapes and lead to more intensive biomass accumulation.

Buried tectonic uplifts within the plain create a fragmented surface that differs from the surrounding areas, leading to the formation of more complex landscape groups.

As a result of relatively weak differential tectonic movements occurring against the background of general subsidence in the study area, buried anticlines have developed. However, the intensity of these folds is lower than both the overall rate of sediment bending and the pace of accumulation processes. Consequently, the expression of these buried anticlinal structures in the relief is weak or, in some cases, absent altogether.

Although these buried structures are not morphologically visible on the surface, they can manifest in various geomorphological forms. Many of them alter the morphology of river valleys, influence river courses, and affect local accumulation conditions. Others contribute to the creation of anomalous landscapes or to the differentiation of existing landscape units.

The complexity of the landscape structure in the study area is particularly evident in the buried uplifts of Sorsor, Padar, Bicaghchi, and several others.

The predominance of the general bending process in the study area over other forms of neotectonic movement has resulted in the absence of small-scale buried structures, as well as the lack of surface expression of the underlying crystalline basement, tectonic faults, and major structural units. This is due to the high degree of structural differentiation at depth not being reflected morphologically on the surface.

One of the defining characteristics of the morphostructure of the Kura-Aras plain is the presence of morphological and tectonic asymmetry. In the northern part of the plain, an intensive bending zone corresponds to the Khaldan–Kyzilagac line. Within this zone, the steep slopes of the Acinohur foothills descend sharply onto the Kura-Aras plain. The transition between these morphostructural units is marked by its abruptness, which is clearly visible in both the morphological structure and hypsometric elevation of the area.

In the northeastern and northern parts of the Kura-Aras lowland, the absolute elevation of the relief does not exceed 100 m. The flow cones of the major rivers—Girdimanchay, Goychay, Turyanchay, and others—do not produce sharp morphological differentiation in the relief, as they are relatively flat. Instead, extensive deluvial plains are clearly observed in these areas.

The study area is characterized by a variety of landscape complexes: alluvial complexes (approximately 35%), alluvial-proluvial complexes (around 25%), sea-lagoon and marine plains (with smaller proportions), and partially hydromorphic complexes (about 6–8%).

3. Climate

The prevailing climate of the Kura-Aras plain is classified as semi-desert and dry desert, characterized by mild winters and hot, dry summers. Warm and relatively clear tropical air masses, often carrying dust from the south, form the core of the atmospheric circulation in the study area. However, due to the influence of the local surface cover, these air masses are rapidly transformed, reflecting the specific geophysical features of the region.

The formation of semi-desert and dry desert landscapes in the study area is primarily driven by high cumulative active temperatures (above 100

units), a prolonged hot season, potential evaporation rates of 1100–1400 mm, and average annual precipitation ranging between 300–350 mm. The disparity between evaporation and precipitation—three to four times or more—creates arid conditions. Since these climatic elements vary little across the broad surface of the Kura-Aras plain, their role in intra-landscape differentiation is significant. As a result, distinguishing between semi-desert and dry desert boundaries is challenging, and the transitions between them are often indistinct.

The average annual radiation balance in the central part of the study area is 7–8 kcal·cm⁻² higher than in comparable Central Asian deserts. For example, in the Kurdamir region the radiation balance reaches 47.1 kcal·cm⁻², whereas in Ashgabat, Central Asia, it is 40.4 kcal·cm⁻². Overall, the annual radiation balance across the study area ranges between 40–50 kcal·cm⁻².

Urban development has a significant impact on the microclimate, as reflected in our long-term analyses of climate dynamics. A gradual decrease in precipitation over the years has influenced the agricultural, residential, and industrial sectors of cities and their surrounding areas.

In Salyan, one of the study cities, the total annual radiation reaches 131.8 kcal·cm⁻², with a radiation balance of 45.4 kcal·cm⁻². The average annual air temperature is 14°C, with mild winters. The coldest month averages 1.6°C, while the hottest month averages 26.1°C. In summer, absolute maximum temperatures occasionally rise to 40°C. The average annual absolute minimum is –11°C, ranging between –9°C and 16°C throughout the year, though extreme lows of –24°C have been recorded. The average annual surface temperature is 18°C, with monthly values varying between 2°C and 34°C.

Relative humidity averages 73%, with annual fluctuations between 59% and 84%. Annual precipitation is 302 mm, while potential evaporation reaches approximately 1000 mm, highlighting the arid nature of the region.

Wind conditions are generally mild, with an average annual speed not exceeding 2.2 m/s. Prevailing winds blow from the east and southeast. Strong winds exceeding 15 m/s occur on no more than seven days per year. The area experiences approximately 24 days of frost annually, fewer than 12 snowy days, and only about 0.5 days of rainfall per year.

Climatic conditions also influence patterns of settlement. High summer temperatures require adaptation in construction, industrial activity, and daily life. Elevated heat levels cause streets and building walls to overheat, creating discomfort. A practical solution is the expansion of green spaces, particularly along the banks of the Araz River, where vegetation would help mitigate these effects.

Climate factors affect the maintenance of housing stock, the operation of enterprises, and the costs of production processes. Therefore, urban planning must be closely aligned with climatic conditions.

The city of Saatli, located in the northern part of the Mugan Plain, is characterized by a mild-hot semi-desert and dry steppe climate with arid summers. The total annual radiation reaches $133 \text{ kcal}\cdot\text{cm}^{-2}$, while the radiation balance is $45 \text{ kcal}\cdot\text{cm}^{-2}$. The average annual air temperature is 14°C . The coldest month averages 1.4°C , and the hottest month averages 26.2°C . In summer, absolute maximum temperatures occasionally rise to 40°C . The average annual minimum temperature is -12°C , while absolute minimums in the coldest months can drop to -26°C .

Thermal resources are limited: the cumulative sum of active temperatures above 5°C amounts to $4900\text{--}5000^\circ\text{C}\cdot\text{days}$, and above 10°C totals $4400\text{--}4500^\circ\text{C}\cdot\text{days}$. Relative humidity averages 74%, with annual fluctuations between 60% and 85%. Annual precipitation is insufficient compared to potential evaporation, which reaches $900\text{--}1000 \text{ mm}$ per year.

Wind conditions are generally mild, with an average annual speed of 2.2 m/s .

Such climatic conditions are among the key factors influencing the development and expansion of the Saatli urban landscape in the Aran region. Cumulative temperatures above 5°C and 10°C , the limited number of snowy and hail days, and the low average annual wind speed create favorable conditions for agriculture. At the same time, the abundance of sunny days across the plain terrain provides opportunities for the construction of solar power plants within the framework of the green economy. Considering the hydropower potential of the Araz River, there are also favorable prospects for the development of small hydropower plants. However, due to recent droughts, it would be advisable to postpone such projects to some extent.

Turning to another city in our study area, Imishli, the total annual radiation amounts

to $131.8 \text{ kcal}\cdot\text{cm}^{-2}$, with a radiation balance of $45.4 \text{ kcal}\cdot\text{cm}^{-2}$. The average annual air temperature is 14°C , with mild winters. The coldest month averages 1.6°C , while the hottest month averages 26.1°C . In summer, absolute maximum temperatures occasionally rise to 40°C . The average annual absolute minimum temperature is -11°C , ranging between -9°C and 16°C throughout the year, although extreme lows of -24°C have been recorded. The average annual soil surface temperature is 18°C , with monthly values fluctuating between 2°C and 34°C .

Relative humidity averages 73%, with annual variations between 59% and 84%. Annual precipitation is 302 mm , while potential evaporation reaches approximately 1000 mm , underscoring the arid nature of the region.

The average annual wind speed in the study area does not exceed 2.2 m/s , with prevailing winds blowing from the east and southeast. Strong winds exceeding 15 m/s occur on no more than seven days per year. Snowfall is rare, with fewer than 12 snowy days annually. Rainfall is extremely limited, averaging only 0.5 days per year.

4. Hydrological and Hydrogeological Conditions

Over the past 25–30 years, numerous studies conducted in the Kura-Aras lowland have identified the presence of different types of groundwater occurring at various depths. These investigations examined the water content of stratigraphic horizons widely distributed across the study area, as well as the bedding conditions of the rocks, water permeability, chemical composition, groundwater regime, and other hydrogeological characteristics.

Because Mesozoic sediments occur at greater depths in the study area, their hydrogeological conditions have not been studied in detail. In comparison, the hydrogeological properties of Tertiary sediments have been investigated only to a limited extent. Relative to the deposits of the third geological period, the deep waters of the fourth period have been studied with varying degrees of accuracy. Groundwater in the study area is found within several stratigraphic horizons, including continental deposits, as well as the Ancient Caspian, Agcagil, and Absheron formations, the Fertile layer, and the Sarmatian rocks of the fourth period.

Among these, the hydrogeological conditions of groundwater in the first aquifer horizon have been studied more thoroughly than those of deep-

Table 1. Waste composition (%) [12]

No.	Waste	Cities									
		Shirvan	Hajigabul	Aghdash	Ujar	Zardab	Kurdamir	Sabirabad	Mingachevir	Bilasuvar	Saathli
	Amount of waste delivered (m ³ /day)	144	144	80	130	50	153	50	300	65	40
	Area (ha)	30.36	9.68	13.62	1	1.07	8.08	7.59	16.95	4.09	2.01
1	food waste	47	52	52	51	48	40	50	50	53.5	50
2	other organic waste (greenery, livestock, etc.)	10.5	11.5	14	16	16	16	10	10	15	10
3	metal	2.5	2	1.1	1.2	1.6	1.3	1	1	1.5	1
4	plastic — predominantly polyethylene (PE)	3.5	0.5	1.5	1.8	2.6	1.5	1	1.6	2	1
5	paper/cardboard	12	10	17	15	15	19	11	20	10	11
6	inert construction and demolition waste	13	11	4	3	3	15	12	3.4	9	12
7	glass	1	2	0.9	0.8	0.7	1	1.5	0.5	2.5	1.5
8	rubber, leather, textiles, etc.	2	1.5	2.3	2.1	2.1	3.6	2	2	3	2
9	electrical/electronic waste	2	1	1.4	1.2	1.4	0.7	1	1	1.5	1
10	other	6.5	8.5	5.8	7.9	9.6	1.9	10.5	10.5	9	10.5

er horizons. Based on their origin, chemical composition, bedding conditions, and other properties, the groundwater of the study area can be classified into several distinct types.

First, it is important to note the groundwater that is most widespread in the Quaternary deluvial-proluvial, proluvial, marine, and alluvial deposits of the study area. This groundwater moves freely under the influence of gravity and forms the first aquifer layer. Its primary sources of recharge are atmospheric precipitation and seepage from surface waters. Consequently, the regime of this groundwater is strongly dependent on hydrometeorological conditions. As a result, its chemical composition and discharge may vary on daily, seasonal, annual, and even multi-year scales. This type of groundwater is commonly found in alluvial sediments within river valleys, alluvial cones, and other depositional environments of the study area.

The depth of groundwater in the region ranges between 1–5 m. These waters are highly mineralized and have been determined to be largely unsuitable for use. The widespread occurrence of swamps and salt marshes in the area is closely linked to groundwater conditions. Irrigation canals constructed without concrete lining, along with leakage from reservoirs, contribute to rising groundwater levels.

To address this issue, a collector-drainage network has been established, though its capacity should be expanded in the future. Through the Bash Mil-Mugan, Bash Mil-Karabakh, and Bash Shirvan collectors, highly mineralized groundwater is discharged into the Caspian Sea.

5. Environmental Conditions of the Evaluated Cities

The landfill in Ujar covers an area of 1.0 ha, with a daily waste intake of 130 m³. It is located 5.1 km from the city center and 1.8 km from the village of Gulabend, adjacent to the Garabork forest. The landfill borders both the forest and a drainage canal, into which generated wastewater is discharged.

In Zardab, the landfill occupies 1.07 ha, receiving approximately 50 m³ of waste per day. The site is situated 220 m from the Ujar–Zardab highway, adjacent to the Main Shirvan Collector. The landfill lacks fencing, gates, and warning signs; entry and exit are uncontrolled. Waste is collected without a systematic approach, partially sorted, and residual waste is buried.

The landfill in Kurdamir is significantly larger, covering 8.08 ha, with a daily waste volume of 153 m³. It is located along the central street of the

city, directly bordering residential areas. The primary composition of waste includes construction and demolition debris, inert materials, and solid household waste.

Analysis of waste composition across all cities indicates that food waste constitutes the largest share. In Hajigabul, Agdash, and Ujar, food waste accounts for more than half of the total waste generated (*Table 1*).

The transport sector is also a significant source of pollution in the study area, as several major highways and railways traverse it. Within the Kurdamir district, 43 km of the Aghsu–Kurdamir–Bahramtepe highway (Grade III), 42 km of the Alat–Gazimammad–Kurdamir–Yevlakh road (Grade II), and 44 km of the Baku–Tbilisi main railway pass through the territory.

A number of factors—including the technical condition of vehicles, the quality of fuel used, and the structural characteristics of highways—affect emission levels. For example, improved road surface quality and smoothness alone can reduce emissions by 13% for trucks and by 9% for passenger cars.

According to 2021 data, passenger cars account for 86.2% of vehicles in the study area, trucks for 10.7%, and buses for 1.8%. Overall, the number of vehicles increased by 32.8% compared to 2015. This growth was most pronounced in passenger

cars, which rose by 34.7%, while trucks increased by 19.8% and buses by 20.6%.

Based on the analyses conducted, a map of the Environmental Quality Index of the cities was prepared. The cities were categorized into three groups: high, medium, and low index urban landscapes (*Fig. 4, p. 44*).

Conclusion

Favorable natural conditions, strategic location at the crossroads of major transport routes, and proximity to the Kura and Aras rivers are among the most significant factors influencing the environmental quality index of the cities in the study area.

Taking these factors into account, the cities were grouped according to their quality indicators. The classification revealed three categories:

- Group 1 (High Index): Shirvan, Mingachevir;
- Group 2 (Medium Index): Yevlakh, Hajigabul, Kurdamir, Salyan, Bilasuvar, Neftchala, Imishli;
- Group 3 (Low Index): Saatli, Beylagan, Barda, Zardab, Sabirabad, Agjabedi, Ujar, Agdash.

This grouping highlights the role of natural and geographical conditions, as well as infrastructural and socio-economic factors, in shaping the quality of the urban environment across the Kura-Aras lowland.



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Оцінювання індексів якості довкілля міст Кура-Араксинської низовини Азербайджанської республіки

УДК 628.45:628.477(479.24):911.375.4(045)

Як відомо, понад 50 % населення світу проживає в містах, на які припадає лише 3 % площі суходолу. Нині близько 10 % населення Азербайджану проживає в містах, на які припадає 4 % Кура-Араксинської низовини. Оскільки 30 % населення Азербайджану зосереджено в столиці, населення в інших містах відносно невелике. Однак щільність населення в м. Ширван, яке розташоване досліджуваній зоні, вдвічі вища, ніж у м. Баку. Аналіз індексу якості міського середовища є важливим питанням у густонаселених містах. Із цієї причини наше дослідження присвячене актуальній темі. Під час дослідження географічні умови міст Кура-Араксинської низовини було проаналізовано на основі оброблення супутникових знімків за допомогою геоінформаційних систем. Екологічну ситуацію в містах було проаналізовано на основі статистичного методу. Проведені дослідження довели, що природні умови міст Кура-Араксинської низовини мають важливий вплив на соціально-економічну ситуацію. Розташування на перетині транспортних шляхів і водночас на берегах двох найбільших річок країни істотно вплинуло на їхнє формування та розвиток.

Ключові слова: міста, показники якості навколишнього середовища, Кура-Араксинська низовина, ГІС, супутникові знімки.

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