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ASSESSMENT OF NATURAL GROUNDWATER RESOURCES AND HYDRODYNAMIC AND HYDROCHEMICAL REGIMES OF THE AKHANGARAN BASIN

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Annotation: This article examines changes in the groundwater regime of the Akhangaron basin, as well as patterns of formation and development of hydrodynamic and hydrochemical aspects under the influence of various factors.

As part of the research, an analysis was conducted on the geological and hydrogeological conditions of the basin, including groundwater recharge sources and discharge areas, as well as the characteristics of groundwater occurrence and distribution. The assessment of natural resources was carried out using methods of hydrogeological zoning, water balance calculations, and analysis of long-term observations of groundwater level regimes. Special attention was given to studying the hydrodynamic parameters of aquifers, including hydraulic conductivity coefficients, specific yield, and groundwater flow directions.

Hydrochemical analysis allowed for the determination of mineralization, ionic composition, and spatial-temporal variability of groundwater quality, as well as the identification of natural and anthropogenic impact factors. The main types of groundwater were classified according to

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their chemical composition, and their suitability for domestic drinking water and agricultural water supply was assessed.

The obtained results can be used in the development of measures for the rational exploitation and protection of groundwater resources in the basin.

Key words: ecology, environment, regime, basin, aquifer, groundwater level, technogenic load, anthropogenic impact, aeration zone, industrial zones, industrial complex, reserves, resources, relief.

Introduction: One of the consequences of the scientific and technological progress occurring in our country is the transformation of the environment. The issue of changes in natural and human-made (technical) systems, alongside environmental pollution, remains one of the most critical ecological challenges globally. Recently, the systematic and economically viable development of natural resources, coupled with their effective utilization, has gained paramount importance. The uneven distribution of consumers across territories contributes to a progressive deficit of groundwater reserves and creates a significant risk of contamination due to anthropogenic (technogenic) processes.

Under the conditions of modern scientific and technological advancement, the primary sources of quality degradation in surface water bodies are industrial activities. In our republic, these notably include the chemical and light industries, ferrous and non-ferrous metallurgy, oil refineries, and oil-and-fat processing plants. When characterizing these impacts, it is essential to determine specific chemical changes, which are highly diverse, alongside general sanitary indicators [1].

The upper part of the Akhangaran River valley is one of the most industrially developed regions of the Republic. Dozens of mining, metallurgical, energy, machine-building, construction materials, and municipal-domestic enterprises are concentrated here, primarily in the city of Angren.

In addition to industrial development, agro-industrial complexes are widespread in all adjacent territories, featuring vegetable and melon farming, orchards, vineyards, grain crops, and other agricultural activities. A significant portion of these agricultural products is processed locally at industrial facilities. Both industrial and domestic water supply systems are well-developed, utilizing groundwater through numerous centralized clusters and individual boreholes.

The future growth of the urban economy and the expansion of the industrial complex will largely depend on the sustainable availability of water resources.

The Akhangaran River basin and the Dalverzin Steppe, which are part of the Tashkent region, are bordered to the north and northeast by the western spurs of the Chatkal-Kurama Range, to the southwest by the Syr Darya River, and to the northwest by the Chirchik River valley. The territory is characterized by its strategic geographical location, where large industrial centers coexist with irrigated agriculture and pastoral livestock farming. Furthermore, the main State transport highway connecting to the Fergana Valley passes through the Akhangaran Valley.

Research Methods: It should be noted that the study area encompasses all lowland and piedmont zones, as well as the groundwater deposit areas of the Akhangaran River basin and the Dalverzin Steppe. The region is characterized by geomorphological diversity, ranging from mountainous and piedmont areas with alluvial fans to river valleys with expansive plains, forests, and steppe massifs. The valley's soil composition, water resources, and abundant solar energy provide favorable conditions for intensive agricultural production.

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Currently, the Akhangaran River basin and the Dalverzin Steppe are home to over one million people, representing 5% of the total population of the Republic of Uzbekistan [2]. This region is the largest industrial hub of the Republic, accounting for nearly the entire national output of ferrous and non-ferrous metallurgy (excluding gold), the bulk of coal mining, construction industry products, and a significant portion of electricity generation.

Diversified agriculture also plays a vital role in the regional economy, focusing on the production of cotton, grain, kenaf, melons, fruits, and vegetables. Water resources, particularly groundwater, are of immense importance. Groundwater is extensively utilized for the drinking water supply of urban and rural populations, industrial and technical needs, and land irrigation. The demand for groundwater for domestic and drinking purposes is increasing annually.

The focus of this research is to identify and assess the changes in the state of groundwater, including freshwater, within the Akhangaran River basin and the Dalverzin Steppe. Under equivalent anthropogenic and hydrogeological conditions (lithological composition of water-bearing sediments, hydrodynamic and hydrochemical parameters), the state of groundwater is determined by the following natural factors:

- Geomorphological structure and relief;
- Thickness of the aeration zone;
- Soil salinity;
- Air temperature and atmospheric precipitation;
- Hydrological regime of rivers;
- Quantitative and qualitative indicators of surface waters.

Based on the surface structure, the study area of the Akhangaran Basin is divided into three distinct zones: mountains, foothills (piedmonts), and plains. The mountains, represented by the Chatkal and Kurama ranges, occupy the eastern and northeastern parts of the region. This terrain is characterized by high ruggedness and limited accessibility.

Along the mountain ranges stretches a piedmont plain with a width ranging from 0.5 km to 5.7 km. It is distinguished by significant fragmentation near the mountains, gradually leveling out towards the lowlands. The absolute elevations of the land surface in this area range from 500 m to 1000 m.

The plains occupy the lower section of the study area and consist of alluvial and alluvial-proluvial terraces, with absolute elevations between 250 m and 500 m. The soil and vegetation cover of the region is highly diverse [3].

In the high-altitude mountain zone (absolute elevations of 2000–2200 m), forest-steppe soils have developed on alluvial and deluvial deposits of bedrock, supporting diverse grass and wheatgrass vegetation.

The lower hypsometric zone, comprising low mountains and foothills, is characterized by the development of dark and typical serozems (gray soils) overlying loess sediments. The well-defined blocky structure of these dark serozems ensures high water permeability and reduced evaporation rates.

Significant areas of the upper terraces of the Akhangaran River, the slopes of Mogoltau, and the low-lying hills (adyrs) are covered by typical serozems. The parent materials for these

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soils are loess-like deposits and, less frequently, fine-earth skeletal deluvium and proluvium of the piedmont plains. These lands are utilized for both rain-fed (bogharic) and irrigated farming. On the middle terraces of the Akhangaran and Syr Darya rivers, floodplain-alluvial soils prevail, while the irrigated lands of the Dalverzin Steppe are characterized by meadow-alluvial and meadow-serozem soils [4].

Climate: The climate of the study area is characterized as sharply continental and belongs to the arid zone, featuring hot summers and moderately cold winters.

Atmospheric Precipitation: Precipitation is unevenly distributed across the region. The minimum annual rainfall of approximately 250–300 mm (rarely reaching 500 mm) occurs in the low-lying southwestern part. In the foothills, this amount increases to 400–600 mm, while in the mountains—exposed to moist western air currents—the quantity of precipitation increases with altitude.

Hydrology: The primary water artery of the study area is the Akhangaran River, one of the largest right-bank tributaries of the Syr Darya River. Its flow is formed in high-altitude conditions through snow-and-rain feeding. In addition to natural watercourses, the region features an extensive artificial network of ancient and modern irrigation systems, as well as a collector-drainage network. The Syr Darya River, serving as the base level for the Chirchik and Akhangaran river runoff, flows through a relatively short transit section from the city of Bekabad to the settlement of Syrdarya.

The Akhangaran River basin, with a catchment area of 6,632 km², provides the most favorable conditions for the formation of surface and groundwater runoff. Its main tributaries include the Irtash, Naugarzan, Dukent, Karabau, Nishbash, Gushsay, Kandyr, Akcha, Shaugaz, Abjaz, Urgaz, Saukbulak, Shavaz, and others.

The mean annual flow rate for the cycle period of 1927–2010 is 37.9 m³/s. According to the Sartamgala gauging station, the coefficient of variation (C_v) for the runoff is 0.45, indicating significant flow variability compared to the Irtash gauging station, where the coefficient is 0.3. The higher variation at the Sartamgala station is attributed to the substantial fluctuation amplitudes in the discharge of the lateral tributaries (sais) of the Akhangaran River below the city of Angren.

In summary, the physical and geographical setting of the region, considering the factors mentioned above, is characterized by several key elements influencing the formation of hydrogeological conditions. In the mountainous and piedmont areas, significant atmospheric precipitation feeds a dense hydrographic network and the fissure waters of Paleozoic rocks.

Following the general slope of the terrain, surface and groundwater flows from the mountains enter the piedmont areas. These flows are subsequently depleted through infiltration into the loosely clastic deposits of the piedmont apron (proluvial fans) and large *sais* (lateral streams), as well as through partial evaporation [5].

The geomorphological structure of the described region and its significant slope across most areas (0.07–0.05) facilitate the accumulation of groundwater through the infiltration of atmospheric precipitation and surface waters. This relief also promotes efficient groundwater runoff within the Akhangaran River basin. In contrast, groundwater runoff in the Dalverzin Steppe is significantly hindered due to the minimal surface slope.

At the end of 2010, the observation network underwent optimization. This process involved decommissioning redundant wells, reducing the number of monitoring points at

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centralized groundwater intake sites, and closing clogged wells on private enterprise lands that were beyond restoration. Additionally, hydrochemical monitoring clusters in the Gejigen branch of the Akhangaran Valley were reduced due to the current improvement in groundwater quality. In total, 50 monitoring sites consisting of 59 wells were decommissioned.

The distribution of observation wells by their functional purpose and water balance components is presented in Table 1.

As shown in the table, the monitoring of groundwater balance components for the Pskent and Kokaral loess massifs, as well as the Dalverzin Steppe, is limited to only 1–10 observation points. This is clearly insufficient for ensuring the reliability of the collected data. Conversely, the Akhangaran deposit is equipped with an adequate number of monitoring points. This disparity underscores the necessity for further development of the network to provide a comprehensive assessment of the state changes, particularly within the exploited aquifers of the Dalverzin groundwater deposits.

Distribution of Observation Points of the Akhangaran Hydrogeological Station (HGS) by Depth and Aquifers Across Groundwater Deposits

Таблица№1

№ п/п	Ground water Deposit	Observed Aquifers			К-во наблюдательных скважин	Number of observation wells							К-во скв по основным назначениям.	
		Geological Age	Interval of the Productive Zone Exposure	Productive Thickness (m), м.		Up to 20м	Up to 30м	Up to 50м	Up to 100м	Up to 150м	Up to 200м	<200м	Наблюд. гидродинам. показателей.	Наблюд. гидрохимич. показателей.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1.	Akhangaran Deposit	Q_{IV}	0-15 0-30-35	0,15 30-35	40	34	6	-	-	-	-	-	32	8
		Q_{III-IV}	20÷32-65	~40	12	-	4	8	-	-	-	-	8	4
		Q_{III}	20÷25-45÷60 0-65	15-25 65	29	2	9	13	5	-	-	-	20	9

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		Q_{II}	40÷50-100	50-60	8	-	-	1	3	2	2	-	6	2
Sub-total					89	36	19	22	8	2	2	-	66	23
2.	Pskent Deposit	pQ_{III}	от 3-5м до 15-25,0м	15-25	4	4	-	-	-	-	-	-	4	-
		pQ_{II}	от 5-10 до 60-80	10-15 60-80	4	3	1	-	-	-	-	-	4	-
		aQ_{II}	от 40-60до 160-180	10-20	7	-	-	1	2	3	1	-	4	3
		aQ_{I}	от 170-180 до 300-320м	15-20	8	-	-	-	-	-	2	6	8	-
Sub-total					23	7	1	1	2	3	3	6	20	3
3.	Kokaral Deposit	pQ_{III}	от 3-5 до 40-50м	10-15	2	1	1	-	-	-	-	-	2	-
		pQ_{II}	от 3-5 до 60-70	10-15	4	2	1	1	-	-	-	-	3	1
		apQ_{III}	от 60-80 до 100-150м	25-30	1	-	-	-	1	-	-	-	-	1
		apQ_{II+I}	от 100-150 до 250-280м	55-80	12	-	-	2	2	4	3	1	1	11
Sub-total					19	3	2	3	3	4	3	1	6	13

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4.	Dalverzin Deposit	apQ_{III}	от 0-10 до 50-60	50-60	8	5	-	3	-	-	-	-	6	2
		apQ_{II}	от 50-60 до 140-150	20-30	2	-	-	-	1	-	1	-	2	-
		apQ_{I}	от 140-150 до 250-280м	30-35	1							1	1	-
Sub-total					11	5	-	3	1	-	1	1	9	2
Total					146	51	22	30	17	9	9	8	101	45

Methods: The state of groundwater in the Akhangaran River basin and the Dalverzin Steppe is determined by a combination of natural and anthropogenic (technogenic) factors. For a comprehensive analysis and assessment of how these factors impact groundwater changes, they are examined separately in this study.

Natural Factors: Under equivalent anthropogenic and hydrogeological conditions—such as the lithological composition of water-bearing sediments and baseline hydrodynamic and hydrochemical parameters—the state of groundwater is governed by the following natural indicators:

- Geomorphological structure and relief;
- Thickness of the aeration zone;
- Soil and ground salinity;
- Air temperature and humidity;
- Atmospheric precipitation;
- Hydrological regime of rivers;
- Quantitative and qualitative indicators of surface waters [6].

Anthropogenic (Technogenic) Factors: Based on long-term studies regarding the formation patterns of the groundwater regime and balance in the Akhangaran River basin and the Dalverzin Steppe, it has been established that changes in groundwater conditions are primarily driven by hydrodynamic and hydrochemical indicators. Therefore, to ensure a complete evaluation of these changes, technogenic objects have been grouped according to their impact types: those influencing the hydrodynamic state and those influencing the hydrochemical state of groundwater.

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In this article, these technogenic objects and their consequences are analyzed specifically in relation to the hydrodynamic and hydrochemical indicators of groundwater conditions.

Anthropogenic Objects: Technogenic objects influencing the hydrodynamic state of groundwater are highly diverse. To facilitate a targeted analysis, assessment, and identification of their impact on the ecological-hydrogeological conditions of the territory, it is necessary to classify these objects into specific types.

Based on the level, scale, and specific characteristics of their impact and subsequent consequences, technogenic objects are categorized as follows:

- Irrigation systems;
- Systematic land reclamation drainage systems;
- Reservoirs and large hydraulic structures (hydro-networks);
- Major irrigation canals;
- Groundwater intake facilities.

Within the Akhangaran River basin and the Dalverzin Steppe, three primary irrigation systems are operational: the left bank of the Chirchik River, the Akhangaran River system, and the Dalverzin system.

Climatic Zoning: The geomorphological position of the region, situated at the junction of mountainous, piedmont, and lowland territories, has resulted in a significant diversity of climatic conditions. Despite the sharply continental nature of the climate, a distinct vertical climatic zoning is evident due to the substantial range of altitudes [7].

This phenomenon is further enhanced by the varying orientation of mountain ranges relative to the flow of moist air masses. The primary climatic indicators include atmospheric precipitation, air temperature, humidity, and evaporation. Precipitation in the region is distributed extremely unevenly; as observed, the maximum volume of precipitation (in the form of rain and snow) occurs during the winter-spring period.

Details regarding these indicators are provided in Table 2.

Table 2: Average Monthly Discharge (m/s) of the Syr Darya River(Based on data from the "Uzhydromet" gauging station)

№	Period	Year	Months												Annual Average
			I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1.	Bekabad city	2004	1050	748	710	589	232	152	90,5	93,5	278	626	885	877	531,7
		2005	1020	1060	672	406	179	119	86,6	10,4	231	364	524	675	453,4

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		2006	788	1080	563	371	76,6	72,4	65,2	63,6	135	280	514	595	383,6
		2008	773	651	609	752	252	248	61,0	73,5	91,9	208	345	677	395,0
		2010	892	110	647	83,9	45,5	45,3	41,4	41,3	56,4	123	353	263	305,0
		2013	369	698	73,9	244	239	62,7	60,7	718	151	188	128	499	232,0
Average for2004-2008r.															456,2
Average for209-2013r.															310,7

As illustrated in Table 2, the maximum river discharge is observed during the winter-spring period, coinciding with the peak of atmospheric precipitation. The average discharge for the reporting period (310.7 m³/s) shows a significant decrease of 145.5 m³/s compared to the preceding period (456.2 m³/s).

Chemical analysis of water samples collected in the study area indicates a mineralization range from 842 mg/L to 1,394 mg/L (as of 2013). The chemical composition is dominated by sulfate ions, which exceed the Maximum Permissible Concentration (MPC) by 1.13–1.26 times. Among cations, magnesium and sodium ions generally remain within the MPC limits.

The primary water bodies determining the state of groundwater in the Akhangaran basin are the Akhangaran River, and the Akhangaran and Tuyabuguz reservoirs. In this arid zone, the high-water phases of rivers with snow-and-rain feeding are directly dependent on solar activity, which fluctuates cyclically every 11–13 years. The 11-year solar maxima typically occur within solar activation periods lasting 2–3 years. It is naturally assumed that low-water years occur both within and at the boundaries of these cycles.

The key factors in groundwater formation—precipitation, river discharge, and irrigation norms—during the reporting period differ sharply from the previous one. Specifically:

- Precipitation: Total annual rainfall in the district decreased by 13.2–141.6 mm (based on data from the Tuyabuguz and Bekabad meteorological stations).

- River Discharge: Average annual flow rates for the Syr Darya and Akhangaran rivers decreased by 145.5 m³/s and 3.66 m³/s, respectively.

- Irrigation: Water application norms for the irrigation systems of the Chirchik Left Bank and the Dalverzin Steppe were reduced by 3.04 thousand m³/ha and 3.38 thousand m³/ha, respectively.

Based on the analysis of a long-term series of hydrological observations from 1927 to 2010, the annual average discharge rates of 41.65 m³/s, 19.07 m³/s, and 56.5 m³/s correspond to 34.4%, 90%, and 20% exceedance probabilities (reliability) of the Akhangaran River surface runoff, respectively.

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The calculated values of natural groundwater resources, based on their water level regime parameters in the Akhangaran River basin and the Dalverzin Steppe, allowed for the following:

- Determination of groundwater resource volumes and their dynamics: For the entire region, the recharge (recharge) ranges from 29.14 to 33.45 m³/s, while discharge (depletion) ranges from -30.69 to -32.53 m³/s. Consequently, the net change in groundwater storage fluctuates between -48.9 and 29.02 × 10^6 m³/year.
- Identification of correlations: A clear dependence was established between the groundwater resources of the Akhangaran deposit (calculated via water level fluctuation amplitudes) and the discharge volume (water content) of the Akhangaran River during the analyzed periods.

Assessment of the changes in hydrodynamic and hydrochemical indicators reveals that the water level regime in the riparian (near-river) zones and natural stream valleys is closely interconnected with the surface runoff, where level fluctuations depend directly on the hydrological abundance of the year [9].

In contrast, the groundwater level regime within the high terraces, where irrigated agriculture is prevalent, depends primarily on the type of crops cultivated and their irrigation norms. Consequently, the rates of fluctuation in average annual levels and their absolute values vary across different sites and are less dependent on the natural water content of the year.

Conclusion: It has been established that in most cases, the quality of groundwater within the deposits meets the requirements of the national standard O'zDSt 950:2011 "Drinking Water." An assessment of groundwater pollution levels and their sources in areas under anthropogenic impact, conducted using the Pollution Index (PI), revealed that the index values fluctuate from 0.83 (MTF site) to 1.47 (Kust-38) at water intake sites. At observation wells, these values range from 0.89 (well No. 9) to 1.34 (well No. 104-nkh).

The periodic activation of the sun is attributed to its interaction with the gravitational fields of planets orbiting the sun. The magnitude of the total resultant gravitational vector of planetary interaction with the sun depends on their spatial configuration, which varies over time relative to the solar position [8].

Regarding chemical composition, the surface waters of the Akhangaran River are characterized as bicarbonate-sulfate, with calcium-sodium and calcium-magnesium cation profiles.

Observation results of the Akhangaran River's chemical composition indicate a progressive increase in mineralization from upstream to downstream. Specifically, during low-flow (baseflow) periods, while mineralization at the Irtash gauging station ranged from 80 mg/L to 150 mg/L, it increased to 264–376 mg/L at the Sartamgala station. Thus, surface runoff mineralization at Sartamgala is 1.76 to 4.0 times higher than at Irtash, while total hardness increases by 1.67 to 4.0 times.

This increase in mineralization and total hardness primarily occurs up to the Ablyk station (within the boundaries of Angren city); below this point, towards the Sartamgala station, the increase is negligible. The highest values of mineralization and total hardness are consistently recorded during low-flow periods.

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