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Research Article

Comparative Analysis of Groundwater Levels in Karauzyak and Takhtakupyr Districts of the Republic of Karakalpakstan

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Abstract

This article investigates the characteristics of groundwater level formation and its spatial distribution in the Karauzyak and Takhtakupyr districts of the Republic of Karakalpakstan, Uzbekistan. The study focuses on identifying the differences in groundwater conditions between the two districts and examining the influence of irrigation infrastructure on groundwater level variations. Particular attention is given to the relationship between the development, expansion, and distribution of irrigation networks and the formation of groundwater levels in the studied territories. The findings indicate that groundwater levels are relatively high in Karauzyak district, which is primarily associated with the development and expansion of irrigation networks and the resulting increase in water infiltration into the soil. Irrigation activities contribute to the replenishment of groundwater resources and influence their spatial distribution. In contrast, irrigation networks are less extensively developed in Takhtakupyr district, resulting in different hydrogeological conditions and groundwater formation patterns. These differences demonstrate the significant role of irrigation infrastructure in shaping the groundwater regime and determining the spatial variability of groundwater levels. The study emphasizes the importance of considering regional differences in irrigation development when evaluating groundwater conditions and managing water resources. The research findings can provide a scientific basis for improving groundwater monitoring systems, promoting the rational use of water resources, and assessing the land reclamation conditions of the studied territories. Furthermore, the results may support the development of scientifically grounded recommendations for regional water resource management, the prevention of unfavorable groundwater-related processes, and the maintenance of favorable land reclamation conditions. The findings are also relevant for improving irrigation management practices and ensuring the long-term sustainability of agricultural land in the region.

Keywords

Groundwater, Groundwater, Karauzyak District, Takhtakupir District, Irrigated Areas, Irrigation System, Comparative Analysis, Mineralization

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1. Introduction

In recent years, as a result of increasing anthropogenic pressure, global climate change, and the depletion of water resources, the study and monitoring of groundwater status has become one of the most important scientific and practical issues. Especially in regions with arid and semi-arid climatic conditions, groundwater plays an important role in providing the population with drinking water, maintaining environmental stability, and irrigating agricultural crops.

The territory of the Republic of Karakalpakstan is considered one of the regions formed under the influence of the Aral Sea ecological crisis, where changes in hydrogeological and natural-geographical conditions significantly influence the formation and regime of groundwater. The depletion of the Amu Darya's water resources, the operation of collector-drainage networks, and changes in irrigation systems are causing territorial and temporal changes in groundwater levels. As a result, groundwater levels are rising or falling in some areas. This leads to the deterioration of the region's reclamation status, soil salinization, and, at the same time, the emergence of agro-ecological problems.

2. Purpose of the Research

The territories of Karauzyak and Takhtakupyr districts of the Republic of Karakalpakstan were selected as the object of the study. The area is characterized by a sharply continental arid climate, high evaporation rates and the impact of intensive antropogenic irrigation.

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The groundwater regime in the Republic of Karakalpakstan is formed under the influence of natural and anthropogenic factors. In irrigated areas, infiltration processes through irrigation canals lead to the rapid saturation of hydrogeological layers capable of retaining and passing shallow groundwater, significantly affecting changes in groundwater levels [1].

The groundwater regime in the Amu Darya delta largely depends on the process of infiltration through irrigation canals, which changes rapidly under the influence of water from channels, especially from shallow groundwater, which accumulates and moves in natural reservoirs; this can be explained by the higher groundwater level in Karauzyak district due to the large number of canal branches. Furthermore, research conducted in recent years indicates that the long-term dynamics of groundwater levels in the territory of Karakalpakstan are linked to climate change and water management activities [2]. Therefore, the comparative analysis of groundwater levels in Karauzyak and Takhtakupyr districts is explained by the regional hydrogeological conditions and the level of development of irrigation systems.

The Amu Darya is the region's primary water source and plays a crucial role in shaping the groundwater regime in the region. The extensive development of irrigation canals and inter-farm irrigation networks in Karauzyak district leads to relatively high groundwater levels and their local saturation as a result of filtration processes. In Takhtakupyr district, there are relatively few irrigation networks, and water supply is more dependent on deep-water strata. At the same time, insufficient development of drainage networks and backflow water generated during the irrigation process may intensify groundwater mineralization and soil salinization processes [3].

Although studies conducted by national and local institutions are available, an integrated, standardized long-term monitoring network for Karauzyak and Takhtakupyr is insufficient. Space satellite technologies (GRACE, Sentinel) and remote sensing data are useful in showing regional trends, but without integration with local well data, they cannot identify deep hydrogeological processes.

High evaporation levels cause intensive vertical water movement in areas where the groundwater level is at a depth of 0–2 meters, leading to active soil salinization.

The degree of mineralization of groundwater composition increases as the water level deepens. According to studies, the filtration coefficient of water-bearing sandstone layers is 0.5–1.0 meters per day. The high degree of evaporation in the area, especially in areas where the groundwater level is located at a depth of 0-2 meters, intensifies active soil salinization processes [3].

In irrigated areas, the groundwater regime is primarily linked to irrigation processes. As a result of increasing irrigation volumes during the growing season, the groundwater level rises, while in the autumn and winter months, the water level decreases. Changes in groundwater levels in non-irrigated areas are also observed depending on the irrigation regime of adjacent irrigated areas.

On the territory of the district as a whole, as in Amu Darya delta, groundwater is divided into two groups based on the conditions of its formation and location: the first group consists of groundwater from pre-quaternary deposits, which are concentrated in chalk, polyogenic, and neogene sands, sandstones (sandstones), and clays. The thickness of their aquifers ranges from 10 to 120 meters.

Based on the groundwater regime of the district, it has the following characteristics:

1) The formation of canals is directly related to the formation of main and inter-farm canals, the level of which

is directly related to the water level in the canals.
2) In irrigated areas, their regime develops depending on leaching and irrigation.
3) The highest groundwater level occurs during the growing season, and the lowest during the autumn and winter months.
4) The groundwater level of non-irrigated lands gradually rises and falls depending on the irrigation regime of adjacent irrigated areas.
5) A continuous rise in the groundwater level is observed in areas where groundwater has not been artificially drained.
6) The average mineralization level of groundwater ranges from 1–10 grams per liter (in irrigated areas) to 7 grams per liter (in non-irrigated areas).

Especially in the zone of their influence along the irrigation networks, the mineralization level is significantly lower. This is due to their active filtration due to their significant height (1-5 m) above the surrounding environment [5].

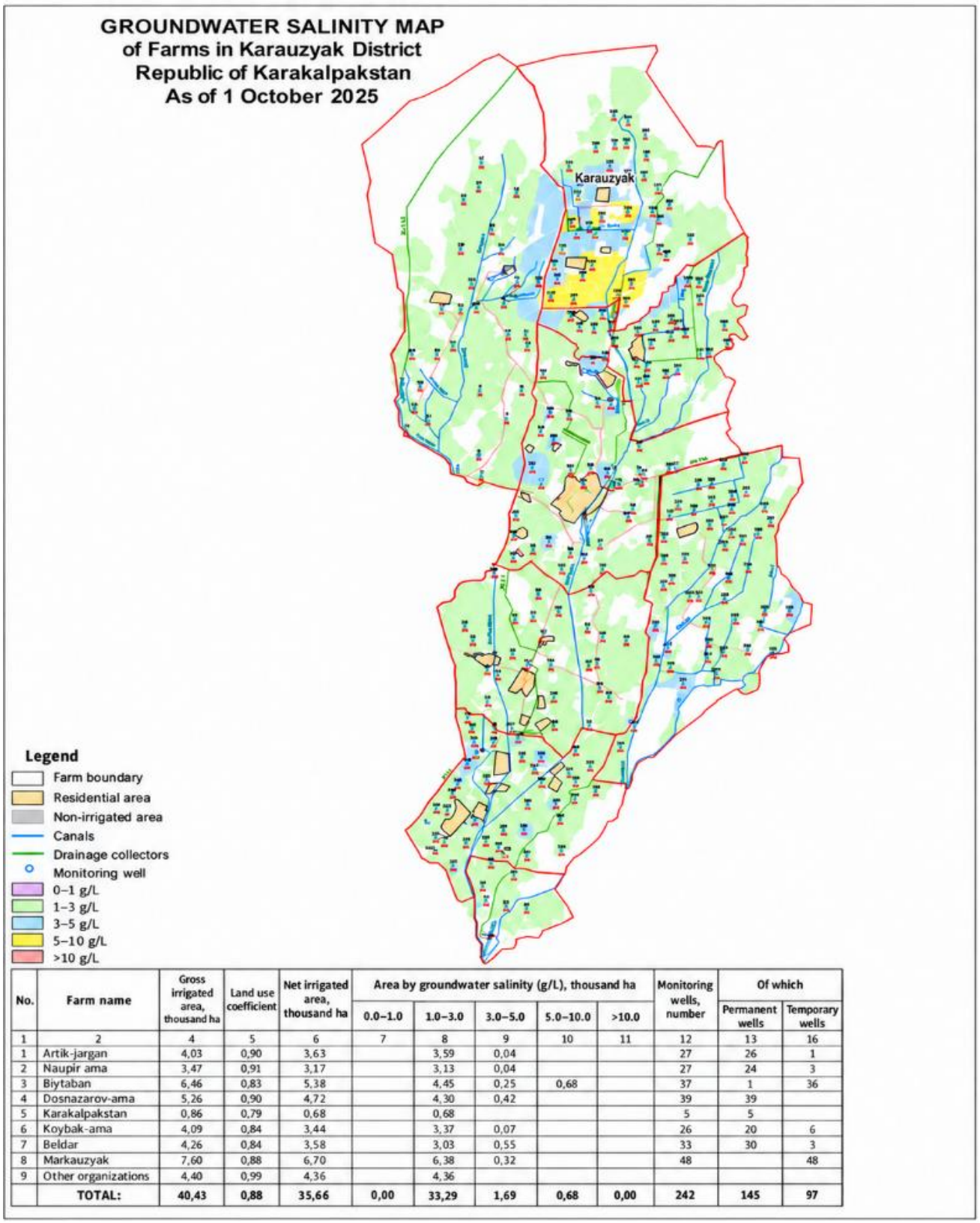
The average salinity of collector drainage system waters is 2.3 g/l. The amount of salt exported with them amounted to 485,000 tons per year. The total mineralization of river water averages more than 1 g/liter per year in recent years. According to data from the land reclamation expedition for December 2024, the average mineralization of Karauzyak district canals was 1.218 g/l, and the average mineralization of collector waters was 4.268 g/l. In Takhtakupyr district, the average mineralization of canal waters is 1.276 g/l, and the average mineralization of collector waters is 2.828 g/l. If the total salinity of the water is 1 g/l, then about 660,000 tons of salt were received from the district's sown areas, and the salt accumulation balance was about +175,000 tons; that is, the amount of salt removed from the district's areas was 175,000 tons less than the amount of salt received with the water. This leads to a further increase in salt content in the soil [4].

The decrease in the level of water resources causes a number of problems in water supply. Water salinization and pollution are reducing the quality of water resources essential for agriculture. It will be necessary to update and modernize wells, canals, drainage systems, and irrigation equipment. GIS technologies and automated systems should be used to manage and monitor water resources.

Comparative analysis of groundwater levels is the process of studying various factors and their influence by identifying changes in groundwater levels in regions and comparing them with each other. Such an analysis may consist of the following stages:

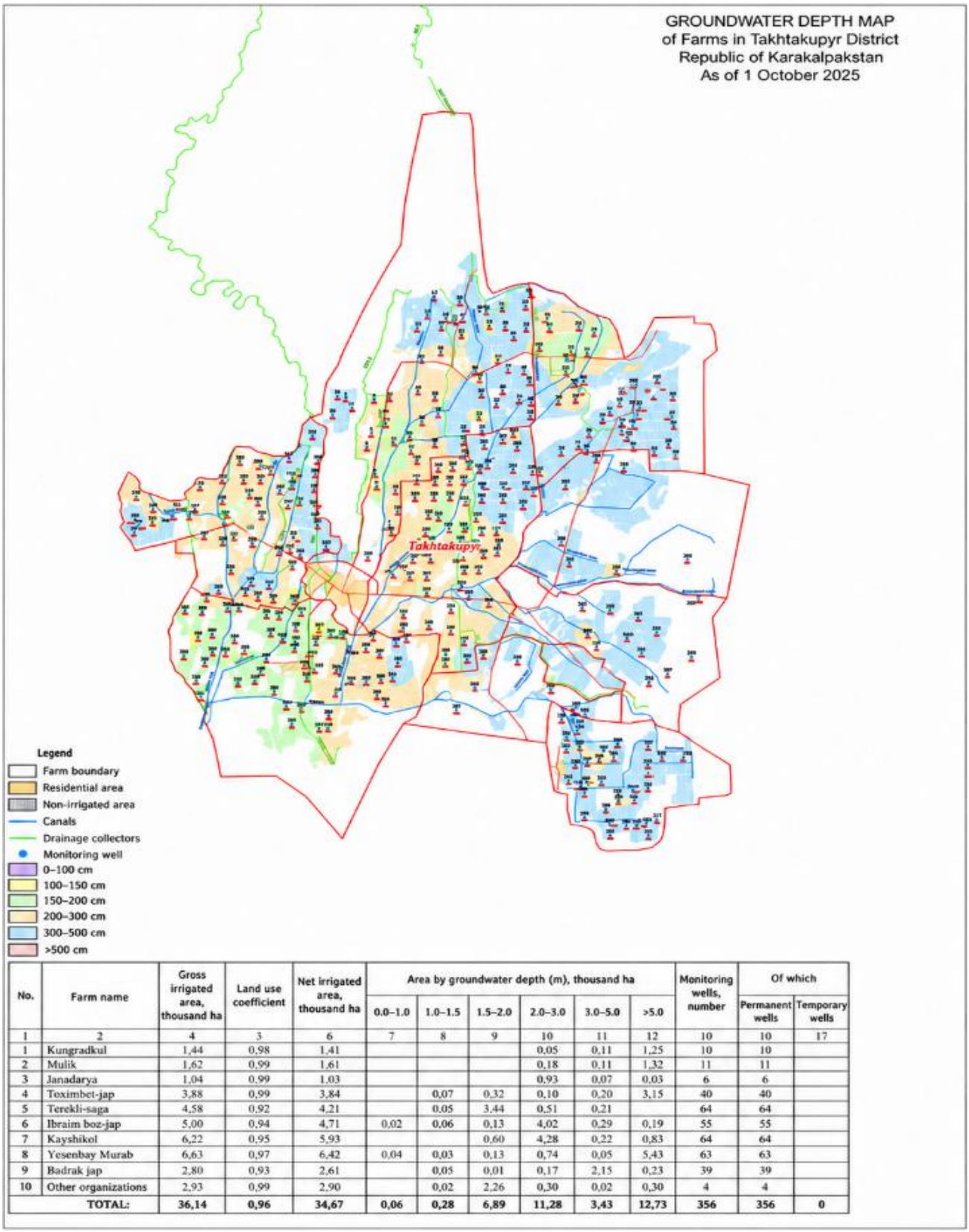
It is necessary to collect preliminary data, specifically to select the study areas; for example, we have selected Karauzyak and Takhtakupyr districts. The geographical coordinates for each of these two districts are determined. It will be necessary to select wells for monitoring groundwater in each region and collect measurement results, as well as to collect data on groundwater levels for recent years (for example, the last 10 years).

We need to process the data, i.e. identify and correct the incorrect or incorrect data, verify the completeness of the data set, calculate the average values of the groundwater level for each region, calculate the variance of the water level change and the standard flow, as well as determine the general trends of the water level change. Comparative analysis, i.e., the comparison of changes in groundwater levels over time in each region (for example, seasonal and annual changes), requires a comparison of groundwater levels in each region. We will need to identify and conduct a comparative analysis of how the geological characteristics of each area, such as soil type and rock formations, influence on groundwater levels, and how climatic factors, such as precipitation, evaporation levels, and temperature, affect groundwater levels; at the same time, we will need to study the impact of anthropogenic factors, agriculture, industry, and other human activities on groundwater levels [6-15]. As of November 1, 2025, the groundwater level in Karauzyak district is 2.79 cm, and in Takhtakupyr district, it is 3.57 cm. As can be seen, the groundwater level in Takhtakupir district is low.



No.	Farm name	Gross irrigated area, thousand ha	Land use coefficient	Net irrigated area, thousand ha	Area by groundwater salinity (g/L), thousand ha					Monitoring wells, number	Of which	
					0.0–1.0	1.0–3.0	3.0–5.0	5.0–10.0	>10.0		Permanent wells	Temporary wells
1	2	4	5	6	7	8	9	10	11	12	13	16
1	Artik-jargan	4,03	0,90	3,63		3,59	0,04			27	26	1
2	Naupir ama	3,47	0,91	3,17		3,13	0,04			27	24	3
3	Biytaban	6,46	0,83	5,38		4,45	0,25	0,68		37	1	36
4	Dosnazarov-ama	5,26	0,90	4,72		4,30	0,42			39	39	
5	Karakalpakstan	0,86	0,79	0,68		0,68				5	5	
6	Koybak-ama	4,09	0,84	3,44		3,37	0,07			26	20	6
7	Beldar	4,26	0,84	3,58		3,03	0,55			33	30	3
8	Markauzyak	7,60	0,88	6,70		6,38	0,32			48		48
9	Other organizations	4,40	0,99	4,36		4,36						
	TOTAL:	**40,43**	**0,88**	**35,66**	**0,00**	**33,29**	**1,69**	**0,68**	**0,00**	**242**	**145**	**97**

Figure 1. *Map of groundwater levels by farm in Karauzyak district.*



No.	Farm name	Gross irrigated area, thousand ha	Land use coefficient	Net irrigated area, thousand ha	Area by groundwater depth (m), thousand ha						Monitoring wells, number	Of which	
					0.0–1.0	1.0–1.5	1.5–2.0	2.0–3.0	3.0–5.0	>5.0		Permanent wells	Temporary wells
1	2	4	3	6	7	8	9	10	11	12	10	10	17
1	Kungradkul	1,44	0,98	1,41				0,05	0,11	1,25	10	10	
2	Mulik	1,62	0,99	1,61				0,18	0,11	1,32	11	11	
3	Janadarya	1,04	0,99	1,03				0,93	0,07	0,03	6	6	
4	Toximbet-jap	3,88	0,99	3,84		0,07	0,32	0,10	0,20	3,15	40	40	
5	Terekli-saga	4,58	0,92	4,21		0,05	3,44	0,51	0,21		64	64	
6	Ibraim boz-jap	5,00	0,94	4,71	0,02	0,06	0,13	4,02	0,29	0,19	55	55	
7	Kayshikol	6,22	0,95	5,93			0,60	4,28	0,22	0,83	64	64	
8	Yesenbay Murab	6,63	0,97	6,42	0,04	0,03	0,13	0,74	0,05	5,43	63	63	
9	Badrak jap	2,80	0,93	2,61		0,05	0,01	0,17	2,15	0,23	39	39	
10	Other organizations	2,93	0,99	2,90		0,02	2,26	0,30	0,02	0,30	4	4	
	TOTAL:	**36,14**	**0,96**	**34,67**	**0,06**	**0,28**	**6,89**	**11,28**	**3,43**	**12,73**	**356**	**356**	**0**

Figure 2. *Map of groundwater salinity by farm in Takhtakupyr district.*

On these maps, the groundwater level is plotted based on data obtained from 242 observation wells in 9 households in Karauzyak district and 356 observation wells in 10 households in Takhtakupyr district. That is, these maps also reflect the location of economic boundaries, settlements, non-irrigated areas, canals, and collectors. In the interpolation method,

groundwater is plotted according to the colors of each gravity at 0-100 cm, 150-200 cm, 200-300 cm, 300-500 cm, and 500< cm; that is, when viewing a groundwater map, we can see how many cm the groundwater level is based on the colors of the symbols.

3. Conclusion

In conclusion, the study of groundwater levels and mapping based on modern technologies are the primary tools for the effective management of water resources. The example of Karakalpakstan shows that integrated monitoring and the harmonious use of modern technologies create opportunities for the protection and rational distribution of water resources.

In conclusion, studying the patterns of groundwater level changes and mapping them based on modern technologies is one of the important scientific and practical tools for the effective management of water resources. The systematic collection of data on groundwater levels, their analysis using geographic information systems (GIS), and the determination of territorial distribution through cartographic modeling allow for the assessment of the state of water resources and their rational management.

4. Results

The results of the study show that the formation of the groundwater regime in the territory of the Republic of Karakalpakstan, particularly in Karauzyak and Takhtakupyr districts, is largely linked to regional natural-geographical conditions, the level of development of irrigation systems, and hydrogeological factors. At the same time, an important role in the formation of the groundwater regime in the region is played by the water resources of the Amudarya basin, collector drainage systems, the activity of climatic factors, and anthropogenic impact. Changes in groundwater levels, the deterioration of reclamation conditions, soil salinity, and the fertility of agricultural lands can have a direct impact.

Author Contributions

Yakhshimurad Khudaybergenov: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Methodology, Resources, Software, Validation, Writing – original draft, Writing – review & editing

Mexriban Allanazarova: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Resources, Software, Validation, Writing – original draft, Writing – review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

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Biography



Yakhshimurad Khudaybergenov is a researcher at Karakalpak State University, Nukus, Uzbekistan. His research focuses on Geographic Information Systems (GIS), remote sensing technologies, land reclamation, soil salinity assessment, agricultural geography, and environmental monitoring. His scientific work is particularly related to the assessment of land resources, mapping of natural landscapes, and the application of modern geospatial technologies to environmental and agricultural studies in the Aral Sea region.



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Research Field

Yakhshimurad Khudaybergenov: Geographic Information Systems (GIS), Remote Sensing, Land Reclamation, Soil Salinity, Agricultural Geography, Environmental Monitoring, Aral Sea Basin Studies

Mexriban Allanazarova: Geographic Information Systems (GIS), Remote Sensing, Soil Salinity Assessment, Groundwater Monitoring, Land Reclamation, Irrigation Management, Soil Mapping, Environmental Monitoring