

Geological and Hydrogeological Characteristics of The Isfara Underground Water Deposit

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Abstract

This article presents a systematic analysis of the geological structure and hydrogeological characteristics of the Isfara underground water deposit, which constitutes an integral part of the Fergana hydrogeological basin. The study provides a detailed examination of the Quaternary period sediments of the region, specifically the stratigraphy and lithological composition of the Sokh, Tashkent, Mirzachol, and Syrdarya complexes. The results of long-term scientific investigations concerning the hydrodynamic regime of the Isfara River alluvial fan, the recharge sources of groundwater, and the discharge balance are comprehensively summarized.

Keywords: Isfara deposit, groundwater, Quaternary sediments, hydrogeological zoning, aquifer, alluvial fan, mineralization, exploitable reserves, hydrodynamics, filtration coefficient.

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1. Introduction

The Fergana Valley, one of the largest and most water-rich regions of Central Asia, is distinguished by its complex geological structure and hydrogeological conditions. The rapid growth of the population in the region and the intensive development of agriculture have made the rational use of fresh groundwater and the scientifically grounded reassessment of its reserves an imperative of the time. In this process, the Isfara underground water deposit - considered a key component of the Fergana hydrogeological basin - is regarded as a source of strategic importance.

The history of studying the Isfara underground water deposit spans nearly a century. The first systematic

investigations in this area began in the 1930s, and the classification developed by N.P. Vasilkovskiy (1935) on the age-based subdivision of the Quaternary sediments of the Fergana Valley served as a cornerstone for the advancement of the field. Subsequently, through the research of scholars such as V.A. Geys, A.Kh. Taneyeva, and S.Ye. Kozorez, the principal indicators of the hydrodynamic regime and water balance of the deposit were established.

From the standpoint of geological structure, the Isfara deposit is situated within the alluvial fan of the Isfara River and is composed predominantly of rocks belonging to the Mesozoic-Cenozoic eras. However, the primary water-bearing layers are associated with Quaternary sediments (the Sokh, Tashkent, Mirzachol, and Syrdarya

complexes) with thicknesses ranging from 300 to 500 meters. The lithological composition of these sediments consists of alternating layers of gravel, sand, and clay, a condition that determines the distribution of groundwater in both unconfined (phreatic) and confined (artesian) states.

The relevance of the study lies in the fact that, under current conditions where surface water resources are observed to be scarce, the role of groundwater is invaluable. Regional hydrogeological investigations conducted in recent years have necessitated the recalculation of water reserves in the Isfara deposit on the basis of updated hydrodynamic parameters. This, in turn, serves to ensure the sustainable socio-economic development of the region.

The purpose of this article is to analyze the geological and hydrogeological characteristics of the Isfara underground water deposit on the basis of a comparison of contemporary data and historical research, to reveal the patterns governing the formation of aquifer layers, and to provide a scientific substantiation of the deposit's future operational potential.

2. Literature Review

Geological and hydrogeological investigations

Studies of the geological and hydrogeological conditions began in 1933, when the former organization "Uzpodzemvod" commenced work on monitoring the quantity, water table levels, and quality of groundwater being extracted.

From 1935 onwards, N.P. Vasilkovskiy was the first — based on the results of his research — to establish the age-based subdivision of the Quaternary sediments of the Fergana Valley, thereby laying the foundation for the study of the geological structure of the region.

From 1945, the Fergana Hydrogeological Station (FGGS) compiled its first report. The results of monitoring works conducted under the leadership and direct participation of V.A. Geyns were thoroughly and comprehensively analyzed in annual reports. Materials accumulated over five years were presented in the 1952 report. Subsequently, under his authorship, a consolidated report of the FGGS for the years 1945–1949 was compiled. The data from these monitoring works

were analyzed, and guiding conclusions have been drawn that remain relevant to the present day.

The annual report of the Fergana HGS for 1955 was also compiled by V.A. Geyns and S.V. Strokovich. In the course of this work, experimental field balance investigations were conducted, and the materials from these studies are presented in a dedicated volume.

Geophysical Investigations

In 1950, the enterprise "Glavneftegeofizika," represented by G.P. Yefimov and L.N. Andreyeva, conducted electrical prospecting works in the central part of the Fergana depression using the Vertical Electrical Sounding (VES) method with AB/2 spacings of 30 km. Based on the results of this work, an isoohm map was compiled.

In 1952, N.K. Islentiyeu and V.I. Pereshin carried out electrical prospecting works (using VES and electrical profiling methods) in the southern Fergana fields. A geoelectric cross-section was constructed, and isoohm maps with AB/2 spacings of 1000, 500, and 150 m were compiled.

In 1953, in addition to the above, field electrical prospecting works were conducted using the deep VES method, and VES curves from previous years were reinterpreted. These data characterize only the deep geological structure of the area; hydrogeological conditions, however, were not taken into account.

In 1955, the Fergana Hydrogeological Station conducted electrical prospecting works using the VES method along the Sariqo'rg'on–Syrdarya profile and a circular profile in the upper portion of the Sokh River alluvial fan, with the aim of determining the direction of groundwater movement.

In 1979–1985, electrical prospecting works were carried out at the Isfara deposit by the Isfara HGP and Rapkon HGP teams using VES and CVES (Combined Vertical Electrical Sounding) methods. Based on the results of these works, the structure and thickness of the Quaternary sediments were determined. Water-bearing layers were identified both in cross-section and across the area.

In 1979–1983, the Isfara HGP conducted surface geophysical works in the western part of the study area using the VES method, with $AB/2 = 4000$ m and point spacings of 1000 m. As a result of the works carried out, the lithological composition of rocks to a depth of 400 m and the groundwater table were determined. Zones of tectonic disturbance within the Quaternary and Neogene sediments were identified.

In 1984–1985, the Rapkon HGP completed surface geophysical works in the eastern part of the area using VES and CVES methods, with $AB/2 = 4000$ m and point spacings of 500 m.

3. Methodology

The study of the geological and hydrogeological characteristics of the Isfara underground water deposit employed a comprehensive approach and systematic analysis methods. The research process includes the following methodological stages:

1. Retrospective and Comparative Geological Analysis
As the foundation of the study, data from geological reports, maps, and scientific publications spanning the period from 1935 to 2024 were analyzed. In this process, the stratigraphic subdivision and lithological cross-section of the area were reviewed on the basis of modern classifications.

2. Geophysical Research Methods Vertical Electrical Sounding (VES) and CVES methods were applied to determine the vertical and horizontal structure of the deposit. Objective: To determine the thickness of Quaternary sediments and the boundaries of alternation between water-bearing gravel layers and clay layers. Based on geophysical data, geoelectric cross-sections were generated to depths of 400–500 meters.

3. Hydrodynamic and Experimental-Test Works** To determine the filtration characteristics of aquifer layers, well drilling and experimental-test pumping (aquifer testing) methods were employed. *Calculation method:* The filtration coefficient (K) and the degree of transmissivity were calculated using the Dupuit and Theis formulas:

$$K = \frac{Q \cdot \ln(R/r)}{2\pi \cdot m \cdot S}$$

$$K = \frac{Q}{S \cdot m} \quad K = S \cdot mQ$$

where Q is the well discharge rate, S is the drawdown, and m is the aquifer thickness.

4. Hydrochemical and Balance Method Laboratory analyses were conducted to determine the mineralization level and chemical composition of groundwater. The hydrogeological balance method was applied to assess the total reserves of the deposit.

4. Results

The water deposit and its boundaries

The underground water deposit under description encompasses the Isfara alluvial fan. The boundaries of the deposit are delineated as follows: to the north and west by the Syrdarya River and the Kairakkum Reservoir; to the south by the border of the Republic of Tajikistan and the Sokh-Isfara foothills; and to the east by the Sokh underground deposit (separated by the Achchiqsub and Sokh-Isfara collector). The Sokh-Isfara foothills along the southern boundary of the deposit reach absolute elevations of 800–1000 meters. The Isfara River cuts through the foothills from south to north in a narrow, deeply incised valley. At the northern foot of the foothills, piedmont plains have formed where the Isfara River alluvial fan develops. To the north, the plain is bounded by the Novqot ridge extending along the left bank of the Syrdarya River. Nearly the entire area of the deposit (excluding the Novqot ridge) is composed of Quaternary sediments of considerable depth (300–500 m and more). The external boundaries of the deposit are formed as follows:

- ✓ The upper (southern) boundary consists of the Sokh-Isfara foothills, composed of middle and lower Quaternary boulders and waterless conglomerate rocks.
- ✓ The northern boundary consists of Neogene clay aquitard deposits of the Novqot ridge.
- ✓ The western boundary is defined by the Syrdarya River and the Kairakkum Reservoir.
- ✓ The eastern boundary is delimited by flows along the flow line (along the inter-fan depressions between the Sokh and Isfara fans).

Groundwater recharge and discharge conditions

Groundwater in the Quaternary sediments of the Isfara River alluvial fan is formed primarily in the upper portion of the fan, and its sources are the infiltration of river water, canals, and their irrigation networks into the subsurface. In the lower portion of the alluvial fan, additional sources of groundwater recharge include the infiltration of surface water from irrigated lands and, to a lesser extent, the filtration of atmospheric precipitation.

Groundwater discharge conditions consist primarily of abstraction from existing operational wells, seepage into collector-drainage networks, outflow beyond the deposit boundary, and evaporation to a minor degree.

The Isfara underground water deposit contains 2 balance zones — recharge and discharge areas. The recharge areas are located in the upper portion of the deposit's alluvial fan and are composed of coarse-grained rocks of modern and ancient Quaternary sediments. The discharge areas are observed in the lower portion of the alluvial fan, in zones where confined waters are developed. In this zone, gravels are replaced predominantly by fine-grained rocks, aquifer thickness decreases, the water acceptance coefficient of the rocks diminishes, and groundwater reserves become limited.

Brief Description of the Geological and Hydrogeological Conditions of the Isfara Underground Water Deposit

Geological structure

The Isfara underground water deposit encompasses the Isfara River alluvial fan and the Syrdarya River valley deposits and possesses a complex geological structure. Nearly the entire area (excluding the Novqot ridge) is composed of Quaternary sediments reaching depths of 300–500 m and beyond.

These consist of alluvial-proluvial deposits of ancient and modern Quaternary age, as well as fluvial alluvial and aeolian sediments. The stratigraphic subdivision of the Quaternary sediments into distinct complexes remains highly challenging at present, owing to the similarity of the lithological composition of the rocks across complexes and the absence of faunal data.

Neogene deposits (N_2) are developed within the Novqot ridge and consist of sandstones, clays, and marls with a steep southward dip. Neogene rocks underlie the

Quaternary rocks in the northern portions. Their thickness reaches 1000–1500 m and more.

Sokh-age deposits (QI sh) are exposed at the surface in the foothills. Based on exploratory drilling data in the plain areas, they are encountered at considerable depths. In the upper portion of the Isfara alluvial fan, boulders and gravel rocks are distributed. In the lower portion, the deposits consist of gravel, pebbles, sand, loam, sandy loam, and clay. The thickness of the Sokh-age deposits ranges from 85 to 120 m.

Tashkent-age deposits (QII ts) are exposed at the surface in the foothill zone and occur overlying the Sokh-age deposits with a cover of varying thickness (20–40 m). In the foothills and on foothill slopes, they are composed of boulders and gravels. Within these rocks, the transition from one lithological composition to another follows the general pattern of the alluvial fan: coarse-grained rocks (boulders and gravels) in the upper portion give way to fine-grained rocks (gravel-sand, loam, sandy loam, and clay) in the lower portion. The thickness of the Tashkent-age rocks ranges from 130 to 165 m; on the surface of the Novqot ridge they appear as a thin layer (2–5 m) composed of gravels and pebbles.

Mirzachel-age deposits (QIII gl) have the largest areal distribution within the study area. In the upper portion of the alluvial fan, the deposits consist of boulders and gravels up to 45 m thick, with rare thin conglomerate layers. In the lower portion, the deposits are composed of sand-clay and sand-gravel rocks. The deposit thickness varies from 2–15 m to more. The thickness of the Mirzachel-age deposits increases from the upper portion of the alluvial fan by 10–15 m or more. Deposit thickness ranges from 30–50 m in the southwest to 100 m in the northeast.

Hydrogeological conditions

The Isfara underground water deposit is hydrogeologically situated within the Isfara River alluvial fan and the Syrdarya River valley. It is distinguished by the diversity of the geological-geomorphological structure of the area and the lithological and lateral variability of the Quaternary sediments, which leaves its imprint on the hydrogeological characteristics.

The principal source replenishing groundwater in the study area is the Isfara River. In the upper portion of the alluvial fan, groundwater is formed mainly through infiltration of surface water and atmospheric precipitation, and the flow moves northward and northwestward toward the lower portion.

In the lower portion, the water-bearing gravels lie beneath soil rocks, between soil and clay layers, and take on the character of a confined aquifer. Groundwater from the Isfara deposit discharges into the Syrdarya River valley and the Kairakkum Reservoir. Groundwater discharge is mainly associated with seepage into collector-drainage networks and abstraction from operational wells.

As a result of investigations conducted in the Fergana Valley, including the Isfara underground water deposit, 5 aquifer layers were identified: the Syrdarya, Mirzachol, Tashkent, Sokh, and Neogene-age deposits.

Syrdarya-age aquifer deposits (QIV). Waters of this aquifer occur in the alluvial deposits of the Syrdarya and Isfara river valleys. These waters subsequently disappear into the thick alluvial-proluvial deposits of the Isfara alluvial fan. The total thickness of the Syrdarya-age aquifer layers reaches 1–3 m, and rarely up to 10 m. The aquifer is closely linked to the surface waters of rivers and streams. Groundwater mineralization in this aquifer ranges from 0.6 to 1.8 g/L.

Mirzachol-age aquifer deposits have a total thickness ranging from 30–50 m in the southwest to 100 m in the northeast. Phreatic waters are located primarily at depths of 1–2 m, and in some places at 2–3 m. They are recharged not only from below, but also significantly from above, since the entire area is under irrigation. The filtration properties of the water-bearing boulder-gravel deposits increase from the upper to the peripheral portion of the alluvial fan, reaching their maximum at the periphery. In the upper portion of the alluvial fan, well discharge rates are 12–28 L/s, drawdown up to 30 m, and specific discharge 0.5–1.13 L/s. In the regional zones, discharge rates reach up to 119 L/s, drawdown 5–6 m, and specific discharge up to 19.4 L/s. Filtration coefficients range from 30–100 m/day or higher.

In the lower portion of the alluvial fan, the filtration properties of gravel-sand and gravel deposits decrease from the beginning to the end. At the beginning of the

lower portion, well discharge rates are 55–80 L/s, drawdown 17.9–21.12 m, and specific discharge 2.63–4.65 L/s; at the terminal portion, discharge rates decrease to 20–50 L/s, drawdown 10–25 m, and specific discharge 0.8–3 L/s. Filtration coefficients range from 5–10 m/day to 50 m/day. Groundwater mineralization in the recharge zone generally corresponds to that of river water, with a dry residue of 0.9–2.1 g/L. Confined waters are predominantly fresh, with a dry residue of 0.3–0.5 g/L. Outside the eastern portion of the alluvial fan, in the inter-fan plains, mineralization rises to 0.8–0.9 g/L, and rarely reaches 1–1.2 g/L. Total hardness varies from 2.8 mg-eq/L (in the lower portion) to 18.6 mg-eq/L (in the recharge zone). In irrigated areas, phreatic waters are predominantly low-mineralization, with a dry residue of 1–3 g/L. Water type is sulfate and sulfate-hydrocarbonate, magnesium-calcium.

Tashkent-age aquifer deposits (QII ts). The aquifer layers of this complex are widely distributed throughout the entire area and are overlain from above by the Mirzachol aquifer complex. Based on data from drilled hydrogeological wells, they are represented by boulder-gravels in the upper portion of the alluvial fan and by loam layers in the lower portion. Thickness is 130–165 m. Within this complex, no aquitard exists between the aquifer layers of the complexes above and below it. Clay and loam layers play the role of local relative aquitards. The upper portion of the alluvial fan consists of boulder-gravels, which constitute unconfined waters. Well discharge rates are 28.5–62.5 L/s, drawdown 4.54–22.33 m, and specific discharge 1.3–13.77 L/s (in the central gravel zone); along the boundary of the confined zone, discharge rates reach 104–105 L/s, drawdown 3.54–9.17 m, and specific discharge 12.18–37.12 L/s.

Groundwater mineralization in the Tashkent complex aquifer layers varies from 0.8–1.0 g/L in the recharge zone to 0.3–0.6 g/L in the lower (peripheral) zones. The water type is sulfate-hydrocarbonate and hydrocarbonate-sulfate, calcium-magnesium or magnesium-calcium. Discharge of the aquifer complex occurs mainly into the upper layer complex and partially through subsurface outflow beyond the boundary of the Isfara underground water deposit.

Sokh-age aquifer layers (QI sh). Both confined and unconfined waters are present in this aquifer complex. Unconfined waters are located in boulder-gravel rocks in the upper portion of the Isfara River alluvial fan. Here

they form a single aquifer together with younger deposits, with a penetrated thickness of 246 m. Well discharge rates are 22.1–52.5 L/s, drawdown 11.17–26.75 m, and specific discharge 1.74–3.59 L/s. Confined waters are located in sand-gravel deposits in the lower portion of the alluvial fan. The piezometric water level ranges from +1.06 m to 8.2 m, and rarely reaches +10.1 m. Well discharge rates are 2.6–12.6 L/s, rarely 24 L/s; drawdown 0.6–30.8 m; specific discharge 0.4–1.0 L/s, rarely up to 2 L/s. The dry residue of these waters is 1.1–2.1 g/L in the recharge zone and 0.3–0.5 g/L in the lower portions; water type is hydrocarbonate-sulfate, sulfate-hydrocarbonate, calcium-magnesium. The recharge and discharge conditions of the Sokh-age aquifer layers are similar to those of the Tashkent-age aquifer layers.

5. Conclusion

A systematic analysis of the geological and hydrogeological characteristics of the Isfara underground water deposit has confirmed that this area represents a major freshwater source of strategic importance for the southwestern part of the Fergana Valley. Research demonstrates that the principal water-bearing complexes of the deposit are associated with Quaternary sediments, whose hydrodynamic regime is continuously replenished through the infiltration of river and irrigation network waters. In the upper portion of the alluvial fan, the high filtration properties of the rocks facilitate the intensive formation of groundwater, while in the lower portions, the presence of clay layers ensures the development of high-pressure artesian waters. In particular, the low degree of mineralization (0.3–0.60.3–0.6 0.3–0.6 g/L) and the stability of the chemical composition of the aquifer layers in the Tashkent and Sokh complexes make it possible to utilize them as the primary source for centralized domestic and drinking water supply to the population. In the future, the scientifically grounded utilization of the operational reserves of this deposit to mitigate potential water scarcity arising from demographic growth and climate change in the region, the rational placement of water abstraction wells, and the continuous ecological-hydrogeological monitoring of the deposit's condition constitute an urgent socio-economic imperative.

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