УДК: [556.314(02)](575.16)

SPATIAL VARIATION PATTERNS OF GROUNDWATER CHEMICAL COMPOSITION IN THE UPPER HYDRODYNAMIC ZONE OF THE FERGANA REGION

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Abstract: This article describes the distribution of water content in wells in the Fergana region according to geochemical features. The most important issue of regional hydrogeochemistry is hydrogeochemical zoning, which manifests itself in a natural change in the composition and mineralization of groundwater in area and depth.

During the research, the hydrogeological conditions of the territory, the lithological and stratigraphic features of aquifers, and their feeding and depletion conditions were analyzed. Based on the results of hydrochemical analyses, the spatial differentiation of groundwater by mineralization level, water types (hydrocarbonate, sulfate, chloride, and mixed), and prevailing cations and anions was studied. Zones with varying intensities of leaching processes, ion exchange, water mixing, and evaporation processes have been identified.

It has been established that spatial changes in the chemical composition of groundwater are caused by a combination of natural factors (geological structure, lithology of rocks, hydrodynamic conditions, climate) and anthropogenic impact (irrigation, drainage, economic activity). Special attention is paid to the role of irrigation water use in the transformation of the hydrochemical regime of the upper hydrodynamic zone.

The obtained results have practical significance for quality assessment.

Keywords: Groundwater, chemical composition, hydrogeochemistry, mineralization, hydrodynamics.

eISSN: 2229-3213 pISSN: 2229-3205
The Journal of Applied Science and Social Science
Volume 16,Issue 02 February, 2026

Introduction: In recent decades, the condition of natural waters has become a subject of increasing global concern. Natural waters are not only a vital source of water supply for the population and industry but also fundamentally determine the lifestyle and health of society. The pollution and depletion of water bodies have become primary causes of water management crises and ecological emergencies in many regions worldwide. This situation has posed several fundamental challenges for modern geoecology, hydrology, hydrogeology, hydrochemistry, and hydrobiology. Among these, the assessment of the current eco-geochemical state of groundwater and the identification of patterns in its spatial variations are of paramount importance.

Groundwater is considered one of the most valuable natural resources. It is utilized for drinking water, diverse economic and domestic purposes, and as a therapeutic and preventive tool in medicine. Furthermore, several industrially useful chemical elements are extracted directly from groundwater.

The rapid industrial development observed globally in recent decades, coupled with urbanization and the intensification and chemicalization of agriculture, has led to significant environmental pollution. As previously noted, groundwater is a critical environmental component and an object that responds most sensitively to anthropogenic impacts. Therefore, hydrogeochemical research is of great significance for environmental protection and pollution prevention [1]. **Theoretical Framework: Water-Rock Interaction and Hydrogeochemical Zoning.** In recent years, ideas regarding systemic interactions within the underground hydrosphere and the equilibrium-disequilibrium state of the "water-rock" system have significantly advanced. However, the structural organization of the subsurface hydrosphere, the operational specifics of systems at different hierarchical levels, their mutual influence, and their responses to anthropogenic impacts remain partially unresolved.

Anthropogenic Metamorphism: Over the past 35 years, the chemical composition of groundwater within Quaternary deposits has been predominantly shaped by technogenic factors. Across much of the urban territory, the hydrogeochemical regime has been disrupted; groundwater undergoes partial or complete technogenic metamorphism, typically following a direct trend: HCO_3^- \rightarrow SO_4^2. In the vertical section, Quaternary rocks act as a natural-technogenic geochemical barrier, which helps preserve the inherent hydrogeochemical zoning.

The Samoylov Hypothesis: O.Y. Samoylov suggests that in basins where groundwater moves slowly from recharge areas to discharge zones, an additional flux of dissolved matter (ions) and solvent (water molecules) occurs. In this process:

- Water molecules (not part of the immediate ion hydration shells) exhibit upward self-diffusion.
- Hydrated ions migrate downward.

This mechanism is a primary driver for the formation of a "normal" hydrogeochemical profile, characterized by an increase in mineralization with depth. The distribution of specific ions is linked to varying rates of "translational" (leap-like) movement relative to water molecules.

Geological Context: It can be stated with certainty that hydrogeochemical zoning is a product of the region's geological history. Lithological composition, tectonic structure, the depth of erosional incisions, and numerous other factors collectively influence this formation. This applies to direct zoning (mineralization increasing with depth), as well as reverse and variable zoning patterns [2].

Geomorphological Settings and Groundwater Characteristics of the Fergana Region. Geomorphological Zoning: Based on geomorphological conditions, the Fergana region is divided into the following zones:

The Modern Syr Darya River Valley.

1. Undulating and Flat Plains of Central Fergana, composed of alluvial fan deposits from mountain rivers.

2. Trans-adyr Depressions (Intermountain Basins), formed by alluvial fans where mountain rivers exit the low-mountain zones.

3. Hilly Ridges (Adyrs), which separate the Central Fergana plains from the trans-adyr depressions and are dissected by mountain river valleys.

Geological Structure of the Syr Darya Valley: The modern valley consists of sand-gravel-pebble formations from all stages of the Quaternary system: Holocene (QIV), Upper Quaternary (QIII), Middle Quaternary (QII), and Lower Quaternary (QI). These alluvial deposits overlie Pliocene clays, siltstones, and sandstones.

Central Plains: The undulating and flat plains on the left bank of the Syr Darya are formed by merged or isolated alluvial fans. They are composed of alluvial-proluvial pebbles, gravels, sands, and loamy-clayey deposits of Lower to Upper Quaternary age.

Hydrogeological Characteristics:

- Holocene Complex (QIV): Groundwater is distributed within the modern Syr Darya valley. In the upper part of the section, mineralization generally exceeds 2 g/L, while in the southwestern part, it reaches 5–10 g/L. The groundwater forms a single flow system, primarily recharged by surface waters.

- Upper Quaternary Complex (QIII): This complex is nearly ubiquitous across the region, except for adyr ridges.

Mineralization Patterns:

The mineralization of groundwater in the QIII complex is highly heterogeneous:

- Apex of Alluvial Fans: Waters are fresh, with mineralization < 1 g/L.

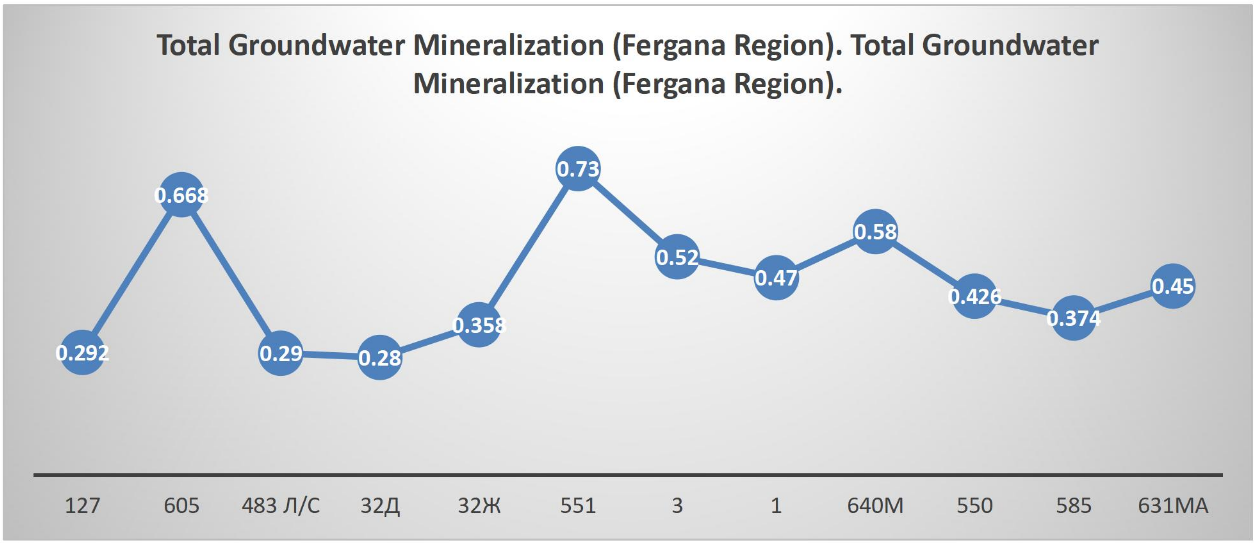
- Periphery of Fans: Mineralization increases with distance from the apex, reaching 5–25 g/L or more.

- Vertical Profile: High mineralization (5–10 g/L) typically extends to a depth of 10–15 m.

- Irrigated Areas: Some freshening occurs due to irrigation, with mineralization levels around 3–5 g/L.

- Inter-adyr Basins: Groundwater remains fresh or slightly brackish. Sub-pressure (sub-artesian) waters are fresh, with mineralization ranging from 0.29 to 0.45 g/L.

Рис-1



The formation of groundwater within the described complex occurs due to the subsurface inflow from the foothills and trans-adyr depressions (in Central Fergana), as well as the absorption of surface runoff, which, according to V.A. Geints, reaches up to 30%. The Syr Darya River serves as the primary draining artery. These waters are widely utilized for drinking and domestic water supply, as well as for irrigation.

One of the most critical issues in regional hydrogeochemistry is hydrogeochemical zoning, which manifests as a systematic change in the composition and mineralization of groundwater across both area and depth. Understanding these patterns and analyzing the available data allows for concluding where and what types of water can be found, justifying the exploration for groundwater of various compositions, and forecasting changes in groundwater mineralization within geological structures [3]. Three manifestations of hydrogeochemical zoning are recognized: horizontal (or latitudinal, geographical), vertical (or geological, deep-seated), and altitudinal (mountainous).

Conclusion: The near-surface part of the Earth's crust, characterized by low-temperature geological processes and defined by Academician A.E. Fersman as the "supergene zone" (zone of hypergenesis), is increasingly attracting the attention of researchers across a wide range of disciplines [4]. Virtually all processes within this zone occur with the participation of groundwater. As an active component of the geological environment, groundwater facilitates the transformation, migration, and concentration of matter. In doing so, it undergoes transformation itself, serving as a vital carrier of information necessary for scientific and engineering decision-making. Groundwater is instrumental in both the degradation of existing mineral deposits and the formation of new ones.

It is within this zone that fresh and slightly mineralized waters are formed. These waters are essential for water supply and represent a strategic resource—a fundamental food product ensuring human existence. At the same time, the supergene zone is an actively exploited, highly vulnerable part of the geological subsurface that is most susceptible to anthropogenic impact. The ecological safety of a territory depends significantly on the state of this zone.

Given the unique significance of groundwater in the supergene zone, studying its chemical composition and the processes occurring with its involvement is extremely relevant and important. These issues fall within the scope of the hydrogeochemistry of the supergene zone—an actively developing scientific field. Modern approaches in this discipline are based on the concepts of the equilibrium-disequilibrium nature, self-organization, and the staged evolution of transformations within the "water-rock" system [6].

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