ECOLOGICAL ANALYSIS OF GROUNDWATER CONDITIONS IN THE SYRDARYA REGION UNDER ANTHROPOGENIC IMPACT AND CLIMATE CHANGE.

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Abstract. This article presents a comprehensive study of the dynamics of groundwater level fluctuations and their impact on ecological stability within the Syrdarya region under conditions of global climate change and intensive anthropogenic pressure. The research analyzes how the rising temperatures and increasing evaporation coefficients observed in the region in recent years are affecting the hydrochemical composition of groundwater. Specifically, the study provides data-driven evidence of secondary salinization processes and an increase in water mineralization levels-rising from 1.5–3.0 g/l to as high as 5.0 g/l-resulting from groundwater levels approaching critical thresholds in irrigated agricultural zones and industrialized areas. Furthermore, the paper highlights technogenic issues, such as the increased concentration of heavy metals and nitrates in groundwater caused by the infiltration of industrial and municipal wastewater. The study concludes by proposing strategic recommendations and innovative solutions (such as the Smart Water system and phytomelioration) aimed at maintaining the region's hydrogeological balance, reducing soil degradation, and protecting groundwater resources over the next decade.

Keywords: Syrdarya, groundwater, anthropogenic impact, climate change, mineralization, salinization, hydromodulus, drainage system.

SIRDARYO VILOYATIDA IQLIM O‘ZGARISHI VA ANTROPOGEN TA’SIR NATIJASIDA SIZOT SUVLARINING HOLATINI EKOLOGIK TAHLIL QILISH.

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Annotatsiya. Ushbu maqolada global iqlim o‘zgarishi va jadal antropogen ta’sir sharoitida Sirdaryo viloyatidagi sizot suvlarining sath tebranishlari dinamikasi hamda ularning ekologik barqarorlikka ta’sirini har tomonlama o‘rganish natijalari keltirilgan. Tadqiqotda so‘nggi yillarda mintaqada kuzatilayotgan haroratning ko‘tarilishi va bug‘lanish koeffitsiyentlarining ortishi sizot suvlarining gidrokimyoviy tarkibiga qanday ta’sir ko‘rsatgani tahlil qilingan. Xususan, sug‘oriladigan qishloq xo‘jaligi maydonlari va sanoat zonalarida sizot suvlari sathining kritik (havfli) ko‘rsatkichlarga yaqinlashishi natijasida ikkilamchi sho‘rlanish jarayonlari yuzaga kelayotgani hamda suvning minerallashuv darajasi 1,5–3,0 g/l dan 5,0 g/l gacha ko‘tarilganini tasdiqlovchi ma’lumotlar taqdim etilgan. Shuningdek, maqolada sanoat va maishiy oqova

suvlarning sizib o‘tishi (infiltratsiyasi) oqibatida sizot suvlarida og‘ir metallar va nitratlar konsentratsiyasining ortishi kabi texnogen muammolar yoritilgan. Tadqiqot yakunida mintaqaning gidrogeologik muvozanatini saqlash, tuproq degradatsiyasini kamaytirish va yaqin o‘n yillikda sizot suvlari resurslarini muhofaza qilishga qaratilgan strategik tavsiyalar hamda innovatsion yechimlar (masalan, "aqlli suv ta’minoti" tizimi va fitomelioratsiya) taklif etilgan.

Kalit so‘zlar: Sirdaryo, sizot suvlari, antropogen ta’sir, iqlim o‘zgarishi, minerallashuv, sho‘rlanish, gidromodul, drenaj tizimi.

ЭКОЛОГИЧЕСКИЙ АНАЛИЗ СОСТОЯНИЯ ГРУНТОВЫХ ВОД В СЫРДАРЬИНСКОЙ ОБЛАСТИ ПОД ВОЗДЕЙСТВИЕМ АНТРОПОГЕННОГО ВЛИЯНИЯ И ИЗМЕНЕНИЯ КЛИМАТА.

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Аннотация. В данной статье представлено всестороннее исследование динамики колебаний уровня грунтовых вод и их влияния на экологическую стабильность в Сырдарьинской области в условиях глобального изменения климата и интенсивного антропогенного воздействия. В исследовании анализируется влияние повышения температуры и увеличения коэффициентов испарения, наблюдаемых в регионе в последние годы, на гидрохимический состав грунтовых вод. В частности, исследование предоставляет данные, подтверждающие наличие вторичных процессов засоления и повышения уровня минерализации воды - с 1,5–3,0 г/л до 5,0 г/л - в результате приближения уровня грунтовых вод к критическим порогам в орошаемых сельскохозяйственных зонах и промышленных районах. Кроме того, в статье освещаются техногенные проблемы, такие как повышенная концентрация тяжелых металлов и нитратов в грунтовых водах, вызванная инфильтрацией промышленных и бытовых сточных вод. В заключение исследования предлагаются стратегические рекомендации и инновационные решения (такие как система «умного водоснабжения» и фитомелиорация), направленные на поддержание гидрогеологического баланса региона, снижение деградации почв и защиту ресурсов грунтовых вод в течение следующего десятилетия.

Ключевые слова: Сырдарья, грунтовые воды, антропогенное воздействие, изменение климата, минерализация, засоление, гидромодуль, дренажная система.

Introduction. The Syrdarya region is a primarily agrarian province of Uzbekistan, where ecological stability is fundamentally dependent on the state of water resources. In recent decades, the dual pressure of global warming and the diminishing flow of the Syrdarya River has adversely affected the regional groundwater balance. Groundwater is not merely a resource for economic consumption; it is the primary determinant of the soil's fertile layer. Fluctuations in the water table-whether sharp rises or significant declines-trigger ecological crises, most notably the secondary salinization of arable land. The formation and discharge volumes of water resources within the Syrdarya basin have undergone a profound transformation. Research indicates that

long-term hydrological shifts in the basin are driven by both natural climatic variability and intensive economic activities, such as dam construction and expansive irrigation [1]. These anthropogenic and natural drivers exert varying degrees of pressure on the water balance, hindering the sustainable development of the entire basin [5,10]. In the Aral Sea basin specifically, the interplay between climatic factors and human interference is identified as the core driver disrupting the hydrological cycle [8]. The spatiotemporal relationship between groundwater levels and mineralization degrees in the irrigated lands of the Syrdarya region is of critical importance. Studies monitoring the province's agrolandscapes under climate change scenarios have noted a rising water table coupled with deteriorating water quality [2]. Long-term data analysis confirms that the groundwater regime and soil salinity levels are intrinsically linked, accelerating land degradation-a phenomenon characteristic of arid zones [4]. Furthermore, global climate change has emerged as the most critical variable in the groundwater hydrological cycle. Evidence suggests that climatic fluctuations impact not only the quantity of water but also its hydrochemical composition [11]. Specifically, rising temperatures and erratic precipitation patterns lead to the degradation of groundwater quality through increased mineralization [12]. On a regional scale, changes in meteorological indicators cause sharp oscillations in the water table, posing a severe threat to ecosystem resilience [19]. In the Aral Sea region and its adjacent territories, climate change has catalyzed a broad environmental decline, where altered hydrological regimes serve as the primary catalyst for ecosystem degradation [6]. Consequently, efficient water resource management remains the most urgent ecological priority for Central Asia and neighboring regions amidst global climatic shifts [7]. The degradation of water resource quality is driven not only by climatic shifts but also significantly by industrial pollution. For instance, in Kazakhstan and its adjacent territories, the formative conditions of groundwater are undergoing continuous transformation due to anthropogenic stressors [9]. Specifically, the petroleum industry and other technogenic factors elevate the risk of chemical contamination in both groundwater and soil layers, thereby jeopardizing regional ecological security [3].

Human economic activities are fundamentally altering the natural regimes of groundwater. The transformation of hydrogeological conditions under technogenic influence is manifested through groundwater pollution and the depletion of viable reserves [15]. Furthermore, shifts in land-use patterns-driven by urbanization and intensified agriculture - affect infiltration processes and disrupt the overall groundwater balance [14]. Such alterations in the hydrogeodynamic regime serve as primary factors negatively impacting the general ecological state of the environment [18]. Fluctuations in the water table pose serious risks not only to natural ecosystems but also to engineering infrastructure. The construction of reservoirs often triggers a rise in surrounding groundwater levels, leading to soil waterlogging and environmental deterioration [17]. Neglecting groundwater levels during the construction or reconstruction of buildings can result in foundation erosion and premature structural aging [16]. As an integral component of the ecosystem, groundwater interacts with the environment based on fundamental ecological principles [13]. Within the context of Uzbekistan, the general principles of ecology and nature conservation define the rational use and protection of groundwater from contamination as a strategic priority [20-22].

Methods. In the course of the research, data from the Syrdarya Regional Hydrogeological-Melioration Expedition, statistical analysis, and comparative monitoring methods were utilized. As a source of information, an analysis was conducted on observation well data from the period between 2015 and 2025. During the analysis, the groundwater levels and quality indicators in the Mirzobod, Sayhunobod, and Boyovut districts of the region were studied. Furthermore, the results of experiences from reputable international publications and scholars of the Republic were analyzed.

Results and Discussion. The research results indicated that two opposing processes related to groundwater are occurring in the Syrdarya region. According to the analysis of water level rise and salinity levels, it was revealed that the groundwater level in the Syrdarya region is extremely dynamic and changes drastically on a seasonal basis. During the irrigation season, due to the malfunction of collector-drainage networks, the groundwater level approaches the surface within 1.5–2.0 meters. This leads to salt accumulation in the upper layer of the soil (secondary salinization) as a result of evaporation. Under the conditions of the region, the "critical depth" of groundwater is 2.0–2.5 meters. If the water level rises above this indicator, salt begins to emerge on the soil surface due to capillary rise. During the vegetation (irrigation) period, especially in June-August, the water level rises to a depth of 1.2–1.8 meters across 60-70% of the region's area. According to "Hydromodul" zoning, this is considered an extremely severe condition.

Secondary Salinization. As a result of groundwater evaporation, the salt content in the topsoil layer (0–30 cm) increases in a geometric progression. If the groundwater mineralization is 3–5 g/l and the water table rises to within 1.5 meters of the surface, evaporation can lead to the accumulation of up to 10–15 tons of new salt per hectare annually. This process is termed "secondary salinization." The primary cause of this phenomenon is not merely natural factors, but the inefficiency of drainage systems. Approximately 35–40% of the existing collector-drainage networks (CDN) in Syrdarya are in need of reconstruction or are clogged with silt.

Efficiency Coefficient (EC): The efficiency coefficient of irrigation networks stands at approximately 0.60–0.65. This means that 35–40% of the water diverted from the river seeps into the ground (filtration) before reaching the fields, directly contributing to the rise of the groundwater table. This numerical chain reaction poses a severe threat to the regional economy. In highly saline lands, cotton yields drop by up to 50–60%, while in moderately saline areas, productivity decreases by 25–30%. To leach these salts (salinity control), an additional 3000–5000 m^3 of freshwater is required per hectare annually, further exacerbating the general water scarcity. To maintain the groundwater level at a depth of 2.5–3.0 meters in the Syrdarya region, it is a strategic necessity to increase the discharge capacity of collectors by 1.5 times and restore the operational efficiency of vertical drainage wells. Currently, nearly 45–50% of the irrigated land in the province is salinized to varying degrees, a condition directly linked to the groundwater regime.

Climate warming is acting as an "accelerant" on the hydrogeological regime of the Syrdarya region. The annual evaporation rate in the region (1200–1400 mm) is several times higher than the annual precipitation (200–300 mm). Rising temperatures increase the evaporation coefficient, releasing moisture from the groundwater into the atmosphere while leaving behind dissolved salts (primarily Na_2SO_4, $MgSO_4$, and NaCl), thereby increasing their concentration.

Observations indicate that over the last decade, the quality of groundwater in the central districts of the Syrdarya region has shifted as follows:

- 2015: Average mineralization was 1.8–2.2 g/l (Slightly saline).
- 2025: Average mineralization has risen to 3.5–5.0 g/l (Moderately to highly saline).

In extreme cases, within closed depressions and areas with poor drainage (e.g., the remote parts of the Mirzobod district), this figure reaches 7.0–10.0 g/l, effectively turning the water into "toxic" brine. Constraints on agriculture were also studied; accordingly, water with a mineralization level exceeding 3.0 g/l is considered "hazardous" for agricultural use. When irrigated with such water, plant roots cannot absorb moisture due to osmotic pressure (a state of "thirst amidst water"). Magnesium and sodium ions in the water break down soil colloids,

reducing water permeability and leading to the "sealing" or hardening of the land. The rise in mineralization from 1.5 g/l to 5.0 g/l necessitates a 2.5-fold increase in the freshwater volume required for salt leaching in irrigated areas. This, in turn, deliberately intensifies the water deficit. In the industrialized regions of the Sirdaryo region, the chemical composition of groundwater is undergoing transformation due to anthropogenic factors. This process is most evident around the industrial hubs of Gulistan, Shirin, and Yangiyer.In the city of Shirin, heavy metals (such as copper, zinc, and chromium) contained in technological wastewater discharged from energy and industrial enterprises are filtering through soil layers and mixing into the first-level groundwater. In Gulistan, the deterioration of the sewage system and the discharge of untreated water into open collectors have led to a sharp increase in the concentration of nitrates (NO_3) and ammonium ions in the groundwater. Research indicates that the maximum allowable concentration (MAC) levels in these areas are being violated as follows.

Table 1. Indicators of Chemical Pollution of Groundwater in the Industrialized Areas of Sirdaryo Region (Relative to MAC)

Chemical Element	Exceedance of MAC (times)	Area (Location)	Ecological Risk Level
Nitrates (NO_3)	1.2 – 1.4 times	Around Gulistan	High (toxic)
Heavy Metals (Cu, Zn)	1.3 – 1.5 times	Shirin industrial zone	Chronic accumulation
Petroleum Products	1.1 – 1.2 times	Near transport routes	Moderate

This pollution triggers a “chain reaction.” Contaminated groundwater seeps into riverbeds, deteriorating the overall hydrochemical state of the Syr Darya River. When this water is used for irrigation, heavy metals pass into agricultural products and harm human health through the food chain. The high concentration of nitrates leads to the excessive growth of algae in collectors and canals, reducing the self-purification capacity of water bodies.

The deterioration of groundwater conditions is causing irreversible processes in the ecosystem of the Syr Darya region. Research has identified the following primary consequences: Soil degradation and decreased productivity, according to which the rising of the groundwater level above the critical depth (2.0 m) is causing aggressive soil salinization. In saline areas, the yield of cotton and grain is observed to decrease by an average of 20-30%, and in severely saline zones, by up to 50-60%. The agrophysical properties of the soil are worsening, and its humus layer is eroding, which leads to the withdrawal of land from agricultural rotation. Loss of biodiversity and landscape transformation, according to which changes in the hydrogeological regime are dealing a direct blow to the flora and fauna of the region. Native plant species that are not salt-tolerant are disappearing, replaced by halophytes and ephemerals adapted to salty soils. The increase in groundwater mineralization is leading to the drying up of riparian tugai forests and the migration or extinction of the unique wildlife there. Socio-economic damage and public health: the pollution and mineralization of groundwater directly affect the population's quality of life. In the groundwater wells used by a portion of the provincial population, the salt content exceeds standard limits. This can cause an increase in kidney stones and gastrointestinal diseases. The energy and financial costs required for water desalination and filtration have increased 1.5–2 times. Additionally, saline water seeping into building foundations leads to the corrosion of infrastructure and a reduction in its service life.

Conclusion. The research results indicate that the ecological crisis related to groundwater in the Syr Darya region can only be resolved through a comprehensive approach. In the coming decade (2026–2036), focus must be placed on the following priority areas. Equipping all observation wells in the province with automated sensors. This will allow for the monitoring of water levels and mineralization in real-time. It is also necessary to create digital maps that predict the direction of groundwater movement. To fundamentally modernize land reclamation infrastructure, open collectors should be gradually replaced with closed (horizontal) drainage pipes to reduce evaporation and increase efficiency. It is advisable to increase the capacity of wastewater treatment plants in the cities of Gulistan and Shirin, thereby preventing nitrates and heavy metals from seeping into the groundwater. The artificial rise of groundwater levels must be halted by lining irrigation canals with concrete (increasing the Efficiency Coefficient to 0.90). Drip irrigation technology should be optimally applied as the most effective method for maintaining groundwater levels at a normal range. Establishing "biological pumps"-plantations of poplar, willow, and acacia trees (windbreak forests) in areas with high groundwater levels. Measures such as establishing strict protection zones around groundwater extraction wells and mandating "zero discharge" technologies for industrial enterprises will serve to improve the province's ecological state. The ecological stability of the Syr Darya region relies on a culture of groundwater management. If the above measures are not taken within the next 10 years, there is a risk that soil degradation could reduce the province's agricultural potential by up to 40%. Therefore, protecting this "hidden resource"-groundwater-is an urgent task that cannot be delayed.

REFERENCES

1. Bissenbayeva, S., Abuduwaili, J., Saparova, A., & Ahmed, T. (2021). Long-term variations in runoff of the Syr Darya River Basin under climate change and human activities. Journal of Arid Land, 13(1), 56-70.
2. Kulmatov, R. A., Adilov, S. A., & Khasanov, S. (2020, December). Evaluation of the spatial and temporal changes in groundwater level and mineralization in agricultural lands under climate change in the Syrdarya province, Uzbekistan. In IOP Conference Series: Earth and Environmental Science (Vol. 614, No. 1, p. 012149). IOP Publishing.
3. Adenova, D., Sapargaliyev, D., Sagin, J., Absametov, M., Murtazin, Y., & Smolyar, V. (2025). Assessing groundwater and soil quality in West Kazakhstan amid climate impacts and oil industry contamination risks. Scientific Reports, 15(1), 6663.
4. Khasanov, S., Li, F., Kulmatov, R., Zhang, Q., Qiao, Y., Odilov, S., ... & Akhmatov, D. (2022). Evaluation of the perennial spatio-temporal changes in the groundwater level and mineralization, and soil salinity in irrigated lands of arid zone: as an example of Syrdarya Province, Uzbekistan. Agricultural Water Management, 263, 107444.
5. Zou, S., Jilili, A., Duan, W., Maeyer, P. D., & de Voorde, T. V. (2019). Human and natural impacts on the water resources in the Syr Darya River Basin, Central Asia. Sustainability, 11(11), 3084.
6. Stulina, G., & Eshchanov, O. (2013). Climate change impacts on hydrology and environment in the Pre-Aral region. Quaternary International, 311, 87-96.
7. Khalilov, I., & Eminov, F. (2024). Against the background of global climate changes, the current ecological situation of Azerbaijan's water resources and the directions of efficient

use. Visnyk of VN Karazin Kharkiv National University. Series Geology. Geography. Ecology, (61), 392-398.
8. Berdimbetov, T. T., Ma, Z. G., Liang, C., & Ilyas, S. (2020). Impact of climate factors and human activities on water resources in the Aral Sea Basin. Hydrology, 7(2), 30.
9. Gafurov, Z. (2019). Change of Formation Conditions of Groundwater of Kazakhstan Under the Influence of Anthropogenic Changes of the Environment. NEWS of National Academy of Sciences of the Republic of Kazakhstan.
10. Van de Voorde, T. Human and Natural Impacts on the Water Resources in the Syr Darya River Basin, Central Asia.
11. Kumar, C. P. (2012). Climate change and its impact on groundwater resources.
12. Barbieri, M., Barberio, M. D., Banzato, F., Billi, A., Boschetti, T., Franchini, S., ... & Petitta, M. (2023). Climate change and its effect on groundwater quality. Environmental Geochemistry and Health, 45(4), 1133-1144.
13. Younger, P. L. (2009). Groundwater in the environment: an introduction. John Wiley & Sons.
14. Mishra, N., Khare, D., Gupta, K. K., & Shukla, R. (2014). Impact of land use change on groundwater—a review. Advances in Water Resource and Protection, 2(28), 28-41.
15. Iegupov, V., & Strizhelchik, G. (2021, March). Sustainability resource of the hydrogeosphere to anthropogenic impacts with urbanization. In Advances in Geoethics and Groundwater Management: Theory and Practice for a Sustainable Development: Proceedings of the 1st Congress on Geoethics and Groundwater Management (GEOETH&GWM'20), Porto, Portugal 2020 (pp. 267-270). Cham: Springer International Publishing.
16. Semko, O., Vynnykov, Y., Filonenko, O., Yurin, O., Ilchenko, T., Hranko, O., ... & Mahas, N. (2025). To the Issue of Assessment of the Technical Condition of Underground Structures of Buildings. Sustainability, 17(5), 2264.
17. Sun, Y., Xu, S. G., Kang, P. P., Fu, Y. Z., & Wang, T. X. (2019). Impacts of artificial underground reservoir on groundwater environment in the reservoir and downstream area. International journal of environmental research and public health, 16(11), 1921.
18. Kløve, B., Ala-Aho, P., Bertrand, G., Boukalova, Z., Ertürk, A., Goldscheider, N., ... & Widerlund, A. (2011). Groundwater dependent ecosystems. Part I: Hydroecological status and trends. Environmental science & policy, 14(7), 770-781.
19. Falkenmark, M., Wang-Erlandsson, L., & Rockström, J. (2019). Understanding of water resilience in the Anthropocene. Journal of Hydrology X, 2, 100009.
20. Liu, Y., Wang, P., Ruan, H., Wang, T., Yu, J., Cheng, Y., & Kulmatov, R. (2020). Sustainable use of groundwater resources in the transboundary aquifers of the five Central Asian countries: challenges and perspectives. Water, 12(8), 2101.
21. Nasibov, B. R., Abdullaev, B. D., Razzakov, R. I., & Ruzimurodov, A. B. (2025). The relationship between the characteristics of groundwater and surface water in the kashkadarya region. Экономика и социум, (5-1 (132)), 544-550.
22. Abdullaev, B., Razzakov, R., Nasibov, B., Mukhamedov, G., Aytmuratov, T., & Dadajonov, B. (2025). Estimating the Amount of Water Required for Crop Irrigation Based on the Application of FAO's CROPWAT Program in the Case of Kashkadarya Region. In BIO Web of Conferences (Vol. 151, p. 04003). EDP Sciences.