FORMATION OF THE HYDROCHEMICAL REGIME AND INTER-IONIC CORRELATION DEPENDENCIES IN ARTIFICIAL WATER BODIES FED BY GROUNDWATER

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Abstract: This study examines the variations in mineralization states within several artificial lakes fed by a common drainage canal. Regardless of the chemical and hydrochemical composition of the wastewater supplied by the drainage channels – the primary water source for these artificial bodies – the research focuses on the impact of groundwater seepage. Specifically, it analyzes how groundwater percolates through the soil into the artificial lakes and subsequently interacts and mixes with the existing surface water, thereby altering the overall hydrochemical regime.

Keywords: Artificial lakes, drainage canal (collector), groundwater, buffer, sulfates, chlorine ions.

Introduction

Globally, agricultural water consumption accounts for 72–83% of total usage, emerging as a critical environmental stressor that drives agroecosystems into a state of severe ecological strain. This, in turn, disrupts the biospheric equilibrium between ensuring food security and maintaining environmental sustainability, fostering a high degree of dependence on freshwater resources, as well as risks associated with water stress and pollution. Consequently, the global scientific community is conducting in-depth, large-scale research on improving water quality, mitigating water scarcity, and facilitating the reuse of treated wastewater.

Following the independence of the Republic, and against the backdrop of global climate change, population growth, the intensive development of economic sectors, and the sharp increase in water demand, a series of measures have been implemented to further improve water management and protection to effectively address emerging threats. Consistent efforts are also underway to promote the rational use of water resources, wastewater treatment, and water conservation.

As noted in several studies, the presence of various inorganic and organic chemicals, toxic metals, aromatic compounds, and other hazardous elements in wastewater poses a significant threat to both human health and the environment as a whole [1]. Research indicates that aquatic plants such as Eichhornia, Pistia, Lemna, Azolla, and Phragmites can be widely and successfully employed for the remediation of waters contaminated with these chemical components [2].

Specifically, according to researchers, such aquatic macrophytes as Pistia stratiotes and Lemna minor are capable of absorbing up to 99.76% of nitrates, 52.11% of ammonium, and 46.29% of sodium [3]. Scientific literature emphasizes that phytoremediation is one of the most effective methods for the biological treatment of wastewater [4, 5]. It is a technologically simple, cost-effective, and promising approach suitable for the restoration of contaminated soils, as well as groundwater and wastewater [6]. Furthermore, scientists highlight its significance in maintaining critical ecological functions: it contributes to improving water quality and energy efficiency, has a positive impact on climate change mitigation (by reducing CO_2 emissions) [7], and helps stabilize hydrological processes [8, 9].

Uzbekistan has also accumulated significant experience in this field: domestic specialists have conducted research on the application of bioremediation methods for the treatment of domestic and industrial wastewater [10, 11, 12]. These studies have investigated the algoflora of wastewater at treatment facilities and evaluated the role of aquatic macrophytes grown in such environments, both in biological water treatment processes and as a forage base for aquaculture.

Research Methodology

The buffer capacity of the water in the artificial lakes was evaluated with respect to HCO_3^- and CO_3^{2-}, water hardness was determined based on Ca^{2+} and Mg^{2+} content, and dissolved substances were analyzed using Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^-, SO_4^{2-}, CO_3^{2-}, and HCO_3^- ions as examples. Furthermore, the research utilized generally accepted hydrochemical, photometric, titrimetric, potentiometric, and colorimetric methods; the assessment of water color and quality was conducted in accordance with current standards [13, 14, 15].

Analysis and Results

It is established in scientific literature that when establishing fish farms in the form of artificial lakes, primary attention is paid to assessing the stability of hydrochemical ions within the system of "groundwater – soil (the land plot allocated for the artificial lake) – artificial lake water," particularly regarding their impact on fish and the primary food base of the aquatic environment (adaptability and survival of hydrobionts). According to the data presented in Table 1 (mean values for the soil of plots divided into two groups, and groundwater), the influence of groundwater mineralization on the total mineralization of artificial lakes is increasing.

However, in ichthyology, the interrelation and balance of ions are considered critical indicators compared to the general salinity level of the water. Specifically, the analysis of the results shows that the Ca^{2+} to Na^+ ratio in the first group was 3.73, which plays a significant role in determining the biological productivity and viability of the food base in artificial lakes. This is due to the fact that an excessive concentration of sodium in the aquatic environment disrupts the osmotic pressure of fish cells and tends to facilitate its penetration into them.

Table 1

Hydrochemical parameters of artificial lakes and correlation dependencies of ionic composition with groundwater composition

Parameters	Unit	Group 1 (Mean±SD)	Group 2 (Mean±SD)	SE	Correlation (r)	Groundwater
Total dissolved salts	g/L	2,98±0,28	2,05±0,42	±0,15	0,91*	4,90
Sum of anions	mg-eq/L	20,60±1,55	13,30±3,25	±1,02	0,94*	70,69
Sum of cations	mg-eq/L	18,00±1,30	11,41±2,65	±0,85	0,92*	68,20
Electrical conductivity (Ec)	mS/cm	2,85±0.30	1,95±0,45	±0,17	0,92*	4,17
Sulfates (SO_4^{2-})	mg-eq/L	18,45±1,20	12,10±2,80	±0,69	0,96	54,25
Calcium (Ca^{2+})	mg-eq/L	14,20±0,90	9,50±2,10	±0,52	0,91	42,50
Magnesium (Mg^{2+})	mg-eq/L	2,83±0,15	1,51±0,60	±0,18	0,76	15,33
Chlorides (Cl^-)	mg-eq/L	2,15±0,35	1,20±0,45	±0,20	0,78	6,99
Sodium + Potassium (Na^++K^+)	mg-eq/L	3,80±0,60	1,90±0,55	±0,34	0,72	12,86

Note: SD — standard deviation; SE — standard error of the mean, indicating the representativeness of the sample relative to the population; r — Pearson correlation coefficient, representing the relationship between ions in lake water and groundwater (Ec = 2.85 for Group 1, 1.95 for Group 2, 4.17 for groundwater); * — correlation value, $p < 0.05$, $n = 25$.

This, in turn, can reduce the viability of fish and lead to their mortality. However, the critical role of calcium in ensuring the vitality of fish and other hydrobionts in the studied artificial lakes is clearly demonstrated. The optimal calcium content hinders the penetration of high sodium ion concentrations into the cells of hydrobionts, thereby strengthening intercellular balance and reducing the permeability of cell membranes to sodium. Notably, scientific literature emphasizes that when establishing fisheries in highly saline conditions, the calcium-to-sodium ratio should be maintained within the 0.5–1.0 range to support stable fish metabolism.

Furthermore, the difference between the sum of cations and anions in the water of the studied artificial lakes can be explained by the presence of a carbonate system. In particular, the low but stable alkaline environment identified in Group 2 (0.638 mg-eq/L) prevents sharp fluctuations in pH levels within the artificial water bodies. The dominance of calcium ions (9.50–14.20 mg-eq/L) compared to other measured cations ensures high efficiency of ionic antagonism in the water body and plays a significant role in mitigating the negative effects of sodium on hydrobionts, including fish (i.e., by preventing the disruption of cellular osmotic pressure) (Table 1).

Moreover, the low standard error values (SE = 0.15–1.02) and the statistical significance of the correlation ($p < 0.05$) confirm the reliability of the research results and their compliance with established standards. The significantly lower cation content (11.41) compared to the anion content (13.30) in the lake waters may be attributed to the presence of certain trace elements or organic compounds that were not assessed in this study and remained outside its scope. According to the research results, the strong correlation between the artificial lake waters and the underlying groundwater ($r > 0.90$) indicates that the aquatic environment and its hydrochemical composition are primarily formed by groundwater.

It was also observed that the mobility—specifically the transformation (Km)—of ions within the hydrochemical composition of the artificial lake water occurs with varying degrees of intensity. In particular, while sulfate ions (0.34) and chloride ions (0.30) exhibited a high degree of mobility, sodium and potassium ions (0.29), as well as magnesium ions (0.18), were found to be relatively selectively retained within the soil-filtration layer.

Based on the research conducted in the Ulugnor district of the Andijan region, an analysis of the hydrochemical formation processes in artificial lakes specialized in fish farming has revealed a strong inter-ionic correlation between groundwater and artificial lake water ($r = 0.92$–0.94). This indicates that the chemical composition of the aquatic environment in such lakes is not determined solely by wastewater originating from drainage canals (collectors); mineralization indicators also undergo significant fluctuations due to groundwater seepage.

Conclusion: It has been established that due to the infiltration of groundwater into artificial lakes—specifically through percolation from the subsoil through the soil layer and subsequent mixing with the lake water—varying states of mineralization can be observed across several lakes, even when they are fed by the same drainage canal. This phenomenon occurs independently of the chemical and hydrochemical composition of the wastewater supplied by the collectors, which serve as the primary source of water for these bodies.

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