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THE PROBLEM OF WATERLOGGING IN CITIES AND ITS ANALYSIS.

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Abstract

This article explores the problems of waterlogging arising in cities during the process of urbanization, their underlying causes, and their environmental impact. The research was conducted through a comparative analysis of scientific works by international and local scholars. Primary focus is placed on the alteration of groundwater regimes and the disruption of hydrogeological balance. The role of groundwater in urban planning and design processes across international states is examined. The waterlogging issue within the territory of Gulistan city is addressed in these studies on an experimental basis. A scientific analysis of studied processes was carried out for regions including Georgia, Kazakhstan, the Russian Federation, the Rostov region, the Krasnodar and Stavropol territories, Kalmykia, and the republics of the North Caucasus.

Keywords

Urbanization, waterlogging, groundwater, drainage system, technogenic factors, hydrogeological monitoring.

Introduction. Worldwide, the issues related to the waterlogging of urban areas by groundwater have caused numerous problems [1-2]. The solutions proposed in research conducted on this matter remain a subject of ongoing discussion. In international practice, urban waterlogging is often associated with the construction of hydraulic structures on rivers or other water bodies [3-4]. For instance, in Krakow, Poland, the construction of a low-head dam on the Vistula River caused a rise in groundwater levels, leading to subsidence phenomena in urban areas and buildings. Similarly, in the Polder regions of the Netherlands, certain areas located far from the sea exhibit high groundwater levels; as a result, not only surface structures but also underground utilities are affected by waterlogging [5-6].

In many coastal regions worldwide, particularly in areas with underdeveloped natural drainage systems, a rise in groundwater levels is observed. Such phenomena typically occur on the terraces of large rivers or in proximity to distinct morphological structures [7-8].

It is noted that on a global scale, this problem has been extensively and deeply studied from scientific and methodological perspectives. At the same time, in each specific instance, the issue of groundwater saturation possesses its own unique characteristics and requires: an accurate representation of the phenomenon itself (description, modeling, etc.), identification of causes and conditions, and the acquisition of their qualitative and quantitative characteristics; furthermore, assessing the socio-economic and environmental state of the regions to determine their livability [9].

Since groundwater saturation impacts the living environment of social communities and biocenoses, specialized engineering protection is required. The foundation of such protection consists of hydraulic structures and other land reclamation measures. Therefore, the current state of the issue indicates that the conditions of the phenomenon, prevention methods, and engineering protection systems, as well as the general complex of urban water management organization, must be re-examined at a new level. This necessitates a distinct approach for every city or other developed or developing territory, adapted to the specific conditions of the country [10-11].

Abroad, the scientific and methodological aspects of the problem are evolving through detailed investigations of each saturation object, large-scale mapping (e.g., 1:10,000 or 1:500), computer modeling, preliminary calculation of engineering protection parameters, and forecasting the state of groundwater and the structures to be protected. The problem of waterlogging in the territory of Gulistan city was examined on an experimental basis in these studies, and it was proposed to implement the methods used at the Zolotordinskiy site within urban areas as well. V.A. Kartavin and S.K. Sherniyozov conducted experimental production research on vertical drainage in the city of Kogon. Between 1963 and 1968, A.K. Qurbonov, L.Ya. Breusova, the team from the "O‘zgiprovodxoz" Institute, N.N. Xo‘jiboyev, L.Z. Sherfedinov, and I.A. Sorokina addressed the issue of combating waterlogging in the city of Nukus from the perspective of geohydrological conditions [12-16]. In subsequent decades, the problem of waterlogging has been continuously studied within the framework of specialized geohydrological investigations and groundwater monitoring. In the new millennium, analysis is also being conducted through geoecological mapping [17-20].

During the 1970s, geohydrological studies were carried out in cities such as Bukhara, Denau, Kattakurgan, Yangiyer, Tashkent, Namangan, Kogon, Kushkupir, Mangit, Angor, Karshi, Kasan, Turtkul, Andijan, Chimboy, Takhiatash, Khiva, Syrdarya, Kamashi, Gallaorol, Korovulbozor, Samarkand, and others by scholars including D.A. Almuradov, A.N. Artemyev, B.B. Bazarov, V.F. Bespalova et al., G.L. Grigorova et al., V.I. Karimov, T.B. Qosimxoʻjayev and S.K.Sh. Mirzayev, R.P. Kim et al., Yu.S. Kovalenko, B. Qoshiqov, B. Qoshiqov and I.R. Ruzimbetov, S.K.Sh. Mirzayev, G.S. Mirzayeva, B.O. Otamurodov, A.V. Pahomova, I.A. Sorokina, A.S. Teshabayev, V.I. Chernuxa, A.M. Shapiro, and A.I. Shapiro. The research performed during this period met the normative requirements of the time and served to resolve issues of justifying systematic drainage as a primary element of engineering protection systems against groundwater-induced waterlogging in cities [21-24].

Methods. This article utilizes methods of systematic analysis and a comparative literature review. During the research, the following sources were studied: international scientific journals on the modeling of hydrogeological processes, regulatory documents on engineering protection in urban planning, and fundamental studies on salinization and waterlogging in the Central Asian region. In the process of analysis, the factors of waterlogging were primarily classified into two categories: natural and anthropogenic.

Results and Discussion. In certain foreign countries, waterlogging occurs as a result of the natural rise of groundwater, while in other cases, it happens due to the influence of anthropogenic factors-specifically, water consumption by industrial enterprises, agricultural irrigation systems, and the operation of engineering-reclamation structures. Despite the abundance of information in internet sources, particularly regarding technological trends, much of the data related to engineering protection against waterlogging is commercial in nature. In the CIS (Commonwealth of Independent States) countries, the primary information regarding waterlogging in cities and industrial zones, as well as engineering protection against it, dates back to the Soviet era. Newer data is typically limited in scope or available in a paid format, which restricts free access to modern information. Nevertheless, existing sources provide a general overview of protecting urban areas from waterlogging, current problems, and development trends. Azerbaijan. Certain areas within the amphitheater of Baku's coastal terraces, specifically the Bakuloven and Zanskiy landslide massifs, are considered waterlogged. These areas are located on deluvial slopes and are prone to drainage through landslide massifs. The main cause cited is the irregular discharge of untreated wastewater from industrial enterprises. Additionally, the infiltration of atmospheric precipitation and the condensation of moisture in the ground

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contribute to the waterlogging. The waterlogging flow in Baku is estimated to be around 0.4 m^3.

Georgia. In the nation's capital, Tbilisi, waterlogging incidents have been observed to be local in character. According to research, this phenomenon emerged between 1930 and 1960 as a result of the commissioning of the centralized water supply system and subsequent failures in water distribution and sewage systems.

Kazakhstan. Analyzing the situation in Kazakhstan, the production area of a specific enterprise [noted in the study] coincides with a river valley. The river's flow is regulated by dams. Prior to construction, groundwater was located at a depth of 3 to 7 meters. Ten years after the start of construction, the groundwater table rose to a depth of 1.5–2.0 meters. The highest groundwater levels were observed in the spring months, while the lowest occurred during the autumn-winter period, a condition associated with ground freezing. The amplitude of water level fluctuations varies from 0.43 to 1.26 meters. The primary causes of waterlogging were identified as the disruption of surface runoff conditions and the leakage and discharge of technological waters.

The Russian Federation. In this country, the waterlogging of built-up areas spans a vast geography, including the North-Western, Central, and Southern European parts, the Urals, Siberia, the Arctic, and the Far East. Although the degree of waterlogging varies, it has been observed in cities such as Moscow and Saint Petersburg, the Volga region, southern territories, and other regional centers. Cases of waterlogging also demonstrate a diversity of geological structures—ranging from loams to fractured hard rocks with deep-seated groundwater.

Morphologically, the areas where waterlogging occurs are situated in landforms such as river floodplains, ravines, valley terraces, and plateau or piedmont plains.

In these regions, where groundwater was initially absent, waterlogging emerged as a result of economic activities related to urban water supply, industrial zones, and land reclamation projects.

Waterlogging is particularly widespread in the Rostov region of Russia, the Krasnodar and Stavropol territories, Kalmykia, and the republics of the North Caucasus. In these areas, hydraulic structures built for the development of irrigated agriculture and the regulation of water flow are cited as the primary factors. Not only irrigated lands but also built-up areas in these regions are suffering from waterlogging. Based on the aforementioned sources, the waterlogging landscape in these regions is very similar to that of Uzbekistan. A significant difference is that in Russia, large-scale protection measures are carried out on agricultural lands, while in cities and industrial areas, localized engineering protection systems have been implemented.

Furthermore, areas being redeveloped or reconstructed are often already waterlogged, or waterlogging occurs during the development of underground urban spaces, such as subways and strategic facilities. In such cases, the issue of implementing engineering protection arises, requiring the design of effective systems that are geologically, technically, environmentally, and economically justified. Considering that the waterlogging observed in Russia occurs under conditions typical of most climate zones in the world, these cases can serve as a basis for general conclusions.

In Ukraine, waterlogging in built-up areas is mainly observed in steppe and lowland zones, as well as in the valleys of large and medium-sized rivers. The phenomenon of waterlogging often arises in connection with the development of underground spaces in cities and other built-up areas.

In foothills and upland plains, this phenomenon is associated with the wetting of dry rocks in the aeration zone due to atmospheric precipitation and the subsequent rise of groundwater. This is observed when territories are developed for industrial, land reclamation, or hydraulic construction.

In the Donbas region, the flooding of decommissioned coal mines has led to a rise in groundwater levels, resulting in the waterlogging of populated areas. The primary causes of waterlogging are identified as follows: the disruption of surface water runoff conditions, the excessive saturation of groundwater by atmospheric infiltration, and the proximity of impermeable or poorly permeable layers to the surface. In these assessments, the groundwater balance—consisting of infiltration, inflow, evaporation, and outflow—is calculated using a modified form of G.N. Kamenskiy's equation in finite differences. In source, indicators for "long-term groundwater recharge" are provided in meters per day (m/day) for periods ranging from one to eight years. These indicators vary between $0.4 * 10^{-4}$ and $36.5 * 10^{-4}$ m/day depending on the research objects and years. However, since the assessment methodology is not fully disclosed, it is difficult to discuss its significance, particularly in relation to the "average annual rate of groundwater table rise" (m/year). In the territory of Uzbekistan, the problem of waterlogging caused by groundwater has existed since ancient times in modern understanding. During the ancient and medieval periods, urban construction was typically carried out on higher ground or artificially elevated foundations. This urban planning technology is observed in the ancient parts of cities such as Andijan, Bukhara, Kokand, Namangan, Samarkand, Tashkent, Khiva, Shakhrisabz, and others. These cities were built relatively higher than the surrounding irrigated lands. The problem of waterlogging took on a modern character in the 20th century, becoming clearly visible in sites such as the Gur-e-Amir Mausoleum in Samarkand, the Samanid Mausoleum in Bukhara, the Ichan-Kala complex in Khiva, and other locations.

The study of urban waterlogging as a distinct subject of geohydrological research has been conducted since the middle of the last century. The research by G.D. Antonova and colleagues focused on exploring the possibilities of using vertical drainage for the reclamation of irrigated lands located in the north-eastern part of Western Fergana Valley, Uzbekistan. These studies successfully addressed the technology of constructing vertical drainage wells and testing them within an experimental-industrial system, specifically at the Zolotordinskiy (Oqoltin) site.

Table 1. Description of construction areas and drainage norms

Construction Characteristics	Drainage Norm, m
Territory of large industrial zones and complexes	Up to 15
Territory of medium and small industrial zones and complexes	5
Residential construction areas of urban and rural settlements	2
Territory of isolated objects, service, and recreational facilities	1
Territory of recreational and protective zones (public green spaces, parks, sanitary-protection zones)	1

According to the regulatory document SNiP 2.06.15–85, "the classes of structures protecting against groundwater saturation are determined based on Table 2, depending on the drainage norm and the calculated level of groundwater table drawdown."

Table 2.Calculated groundwater level drawdown for drainage norms and classes of protective structures

Drainage Norm, m	Calculated Groundwater Level Drawdown, m – by Structure Class			
	Class I	ClassII	ClassIII sinf	Class IV
Up to 15	Over 5	Up to5	-	-
5	-	Over3	Up to3	-

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2	-	-	-	Up to 2

Many scholars emphasize that water leakage (filtration) resulting from malfunctions in urban water supply and sewage systems can cause groundwater levels to rise by 0.5 to 1.5 meters per year.

The deep foundations of modern multi-story buildings serve as a "dam" (barrier) to the natural flow of groundwater. This leads to water accumulation in specific areas and the formation of waterlogging hotspots.

Table 3: Consequences of Waterlogging

Sector	Type of Impact	Consequence
Infrastructure	Corrosion	Subsidence and deterioration of building foundations
Ecology	Increased humidity	Proliferation of pathogenic microorganisms and insects
Economy	Reconstruction	30-40% increase in utility and maintenance costs

According to SNiP 2.06.15–85 standards, it is established that the classes of protective structures are substantially correlated with the degree and character of groundwater saturation within a given territory.

Analysis indicates that merely laying drainage pipes does not fully resolve the problem. The "Smart City" concepts presented in the literature propose the use of permeable pavements and the implementation of closed-cycle systems for rainwater utilization.

Conclusion. The problem of urban waterlogging requires a complex, integrated approach. Based on the literature review, the following conclusions have been drawn: It is essential to install sensors for real-time monitoring of groundwater levels. In building construction, the use of a new generation of waterproofing materials and the development of vertical drainage systems are necessary. Furthermore, it is advisable to ensure natural evaporation and filtration by preserving open soil areas within the city. The analysis of groundwater saturation in urban areas at both global and national scales should conclude with a discussion on the tasks of improving the methodology and technology for protecting against this phenomenon.

It can be stated *a priori* that a strategy for protecting cities from groundwater saturation can only be effective if the following conditions are met:

• Minimizing Uncertainty: Ensuring the accuracy of the process dynamics and its environmental characteristics;

• Technical and Technological Adequacy: Sufficient provision of engineering protection systems from a technical and technological standpoint;

• Professional Expertise: High qualification levels of the specialists executing all phases of the work.

In the cases reviewed, the potential reason for the inefficiency of measures against groundwater saturation (waterlogging) is likely related to the insufficient study of the process mechanisms and its specific manifestation characteristics.

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