Vol. 16, No. 1
2025

Ecological Safety
and Balanced Use of Resources

Journal homepage: https://esbur.com.ua/en

Received: 26.12.2024. Revised: 10.04.2025. Accepted: 02.06.2025

UDC 504.556

DOI: 10.63341/esbur/1.2025.39

Assessment of anthropogenic transformation of groundwater recharge conditions in urban areas

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Abstract. A strategic priority for the sustainability of urban areas under climate change is the development of resilient and diversified water supply systems, as the altered urban hydrological cycle disrupts precipitation patterns and the overall water balance. In this context, spring water becomes increasingly valuable, yet the natural recharge of shallow aquifers is threatened by built-up development, changes in soil properties, and the loss of regulating ecosystem services. This study was focused on assessing the degree of anthropogenic transformation of groundwater recharge conditions within the urban areas of Kharkiv, where approximately 30 equipped springs are actively used by the population for drinking purposes. The article examined the extent of anthropogenic alteration of precipitation infiltration conditions in the urban area for three representative springs in Kharkiv (Park Yunist, Oleksiivske, and Hlybokyi Yar), using geospatial analysis. It was found that in typical low-rise residential areas, impervious surfaces constitute up to 29% on average, while in multi-storey residential zones they reach approximately 40% of the total area, owing to the greater space occupied by roads and rooftops. Based on these ratios, it was estimated that impervious surfaces occupy between 17% and 43% of the catchment areas of the studied springs. The findings implied a significant reduction in the natural recharge of aquifers due to the impeded infiltration on impervious surfaces. Direct measurements of the springs' discharge confirmed that the hydrodynamic regime of the springs is affected not only by the proportion of surface types but also by the technical condition of capture facilities, additional recharge from leaking water supply networks,

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Suggested Citation: Diadin, D., Shandyba, D., Drozd, O., & Yakovlev, V. (2025). Assessment of anthropogenic transformation of groundwater recharge conditions in urban areas. *Ecological Safety and Balanced Use of Resources*, 16(1), 39-50. doi: 10.63341/esbur/1.2025.39.

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and the structure of the aquifers. The proposed methodological approach and the results obtained are of high practical importance for local authorities in planning and developing adaptation measures for urban water supply systems in the context of climate change and other environmental challenges and threats

Keywords: sustainable development; urban water use; springs; impervious surfaces; infiltration; geospatial analysis

Introduction

A sustainable water supply in urban areas is one of the most pressing issues, which has become increasingly acute due to the impacts of urbanisation, demographic growth, and climate change, particularly since the late 20th century. The expansion of urban areas and a rise in population density in cities inevitably lead to increased demand for water resources, as well as impacts on surface and groundwater sources. Drinking water quality issues in large Ukrainian cities can be addressed through the rational use of groundwater and the implementation of combined water supply systems, as demonstrated in the research by O. Bondar *et al.* (2021). Under favourable hydrogeological conditions, groundwater offers specific advantages, making it a valuable resource for urban water supply. In particular, these include better protection from contamination due to natural filtration through soils and rocks, according to M.S. Siddik *et al.* (2022), reduced susceptibility to seasonal fluctuations and short-term meteorological changes; and lower evaporation losses compared to surface sources, which is especially relevant in the context of climate change, as discussed in the study by P.U. Dao *et al.* (2024). Groundwater has been shown to be more resilient to climate change than surface sources, and aquifers may provide a stable water supply during climate-induced fluctuations, as investigated by M. Filippini *et al.* (2024). Despite the considerable potential of groundwater for urban water supply, its efficient utilisation faces several challenges in the context of climate change and urbanisation, due to land-use changes, overexploitation, and pollution from various sources, as highlighted by F. Parvin *et al.* (2024).

Urbanisation significantly impacts the hydrological cycle in urban areas, altering the water balance and conditions for the redistribution of precipitation, groundwater, and surface water. According to M. Feltynowski & J. Kronenberg (2020) and B.A. Yifru *et al.* (2022), the area of impervious surfaces – which alter the pathways of precipitation migration – ranges from 30% to 70% of the territory of large cities. Significant changes in surface runoff formation occur when the total impervious area reaches between 10% and 15%. As evidenced by J.R. Avila-Carrasco *et al.* (2023), when impervious surfaces exceed 30% of the total area, a critical shift in the hydrological regime of water bodies is observed. The infiltration capacity of urban soils also differs significantly from that of natural environments. A. Riaz *et al.* (2025) noted that urban soil compaction can reduce the infiltration rate by 20-60% compared to natural soils. Chemical pollution causes hydrophobicity, degradation of soil structure, and reduced microbiological activity, all of which affect macropore formation and maintenance, thereby reducing infiltration capacity by up to 25%. E.A.O. Serrão *et al.* (2022) found that these changes lead to increased surface runoff, a heightened risk of flooding in densely urbanised areas, a 2-5-fold reduction in infiltration capacity compared to forest soils, and up to a 50% reduction in urban groundwater recharge.

J. Dutta *et al.* (2024) argued that urban areas are also subject to additional anthropogenic recharge, formed due to leakages from centralised water supply and sewerage networks. The volume of this recharge in large cities has been found to be two to five times greater than natural infiltration. The complexity of urban water balance alterations increases when inter-basin water transfers occur to meet demand, as is the case in Kharkiv. The issue of anthropogenic impacts on infiltration recharge is compounded by the direct effects of climate change – particularly shifts in precipitation seasonality and intensity, and increased evaporation – as discussed by Q. Zhang *et al.* (2020). Kharkiv's water supply system relies primarily on surface water and, to a lesser extent, on artesian groundwater, with spring water serving as an additional source. The city has up to 30 equipped springs, which are in high demand among the population, especially during wartime, when the centralised water supply system may malfunction. In urbanised areas, shallow aquifers discharged by springs are most vulnerable to anthropogenic impacts, including altered infiltration recharge. As highlighted in the above literature, the methodological and practical aspects of assessing such impacts – and their implications for groundwater balance in urban environments – remain insufficiently studied, particularly in Ukrainian cities.

This study aimed to assess the degree of anthropogenic transformation of groundwater infiltration conditions within urban development areas, using the city of Kharkiv as a case study. To achieve this aim, a methodological approach was developed to determine the ratio of permeable to impervious surfaces in typical built-up urban areas of Kharkiv; to calculate the area and proportion of these surfaces within the catchment zones of urban springs; and to assess the degree of transformation of groundwater recharge conditions in built-up areas.

Materials and Methods

The distribution of different building types in the city of Kharkiv was analysed based on open vector geodata from OpenStreetMap (2025). Owing to favourable hydrogeological conditions, Kharkiv is characterised by an abundance of natural springs – more than 30 in total. These springs represent groundwater outflows to the surface, with a wide range of flow rates from 0.3 to 38 dm^3/s. They are equipped and frequently used by residents for drinking purposes. The aquifers belong to the upper water exchange zone of Cenozoic age and are located at depths of 30-40 m below ground level.

For this study, three urban groundwater springs were selected, as they are among the most popular in Kharkiv and are regularly used by city residents for drinking purposes – Park Yunist, Oleksiivske, and Hlybokyi Yar (Fig. 1). An analysis of built-up areas was conducted within the catchment zones of these springs. Their configuration and extent were previously delineated by V.V. Yakovlev (2017) using hydrogeological calculations based on long-term average spring flow rates, regional groundwater flow velocity, and the filtration properties of the aquifer.

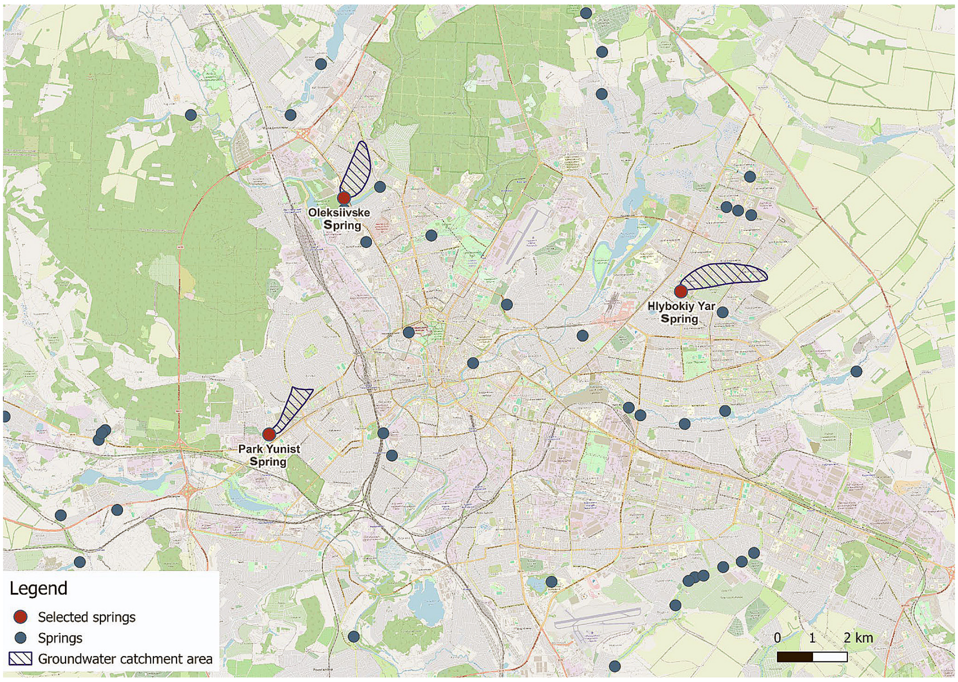

Figure 1. Map showing the location of springs in Kharkiv

Source: created by the authors

Under natural conditions, these springs are recharged by precipitation infiltration across the entire aquifer area. The Park Yunist Spring is located on the left bank of the Udy River valley. The aquifer consists of alluvial and alluvial-deluvial sandy deposits of Quaternary and Pliocene age. The spring capture structure includes four stainless steel pipes embedded in a concrete retaining wall, which ensures uniform water intake (Fig. 2). The Oleksiivske Spring is situated in the Oleksiivska Arroyo, on the left bank of the Lopan River valley. The capture comprises 12 stainless steel pipes installed in two retaining walls, supplying water from two intake wells located on both sides of the arroyo. This aquifer is composed of Obukhiv fractured siltstones. The Hlybokyi Yar Spring is located on the right-hand slope of the Hlybokyi Yar Arroyo, in the Kharkiv River valley. Its capture includes a water intake well and six distribution pipes fitted with a canopy. This spring also belongs to the Obukhiv aquifer, which consists of fractured siltstones and fine-grained sandstones.

Figure 2. General view of the studied springs

Source: created by the authors

The hydrodynamic regime of shallow aquifers is determined, among other factors, by the permeability of soil surfaces in the aquifer recharge zone. A reduction in precipitation infiltration due to the presence of impervious surfaces inevitably affects spring flow rates. To reveal possible links between these factors, the water flow rate (discharge) of the springs was measured monthly from 2018 to 2021. The measurements were carried out on site using the volumetric method, with a measuring container (5-6 litres) and a stopwatch. The time taken to fill the container was measured to the nearest second. For springs with multiple outlets, each outlet was measured separately; the values were then summed and converted into litres per second (L/s). To determine the areas of permeable and impervious surfaces in the study area, the open-source geographic information system QGIS 3.38.0 (2024) was used.

The research was carried out in several stages. In the preparatory stage, basemap layers from OpenStreetMap (2025) and high-resolution satellite imagery from Microsoft Bing (2025) and Google Maps (2025), covering multiple seasons, were accessed and integrated. During the pilot site selection stage, two representative areas with multi-storey residential and private low-rise residential buildings were selected near each studied spring (six sites in total). In the vectorisation stages, vector polygon boundaries were delineated for the pilot sites, built-up areas, road surfaces (streets, pavements, parking areas), and green spaces (bare ground, lawns, parks). The vector outlines were refined using OpenStreetMap (2025) data, and where data were missing or incomplete, new boundaries were digitised based on satellite imagery. Vectorisation was performed with an estimated accuracy of up to 5 m^2. To ensure correct area representation, buildings were vectorised along the contour of the foundations to minimise errors caused by satellite image angles. Some degree of uncertainty remained in multi-storey built-up areas, where adjacent roads and pavements were partially shaded or obscured by tree canopy and could not be identified with maximum accuracy. In the database creation stage, a geodatabase was developed containing the vectorised features and their attributes. During the area calculation stage, the permeable and impervious surface areas for each site were calculated based on the vector data. Impervious surfaces included building roofs and road surfaces, while permeable surfaces comprised all other types. In the ratio analysis stage, the average proportions of permeable and impervious surfaces were identified for each type of built-up area. In the final stage, the derived ratios were applied to the springs' catchment areas to determine the total proportion of impervious surfaces in the catchment of each spring. This methodological approach optimised the research process by focusing on detailed vectorisation of limited representative areas, rather than comprehensive vectorisation of the entire catchment zones. This strategy significantly reduced the time and effort required while maintaining sufficient accuracy.

Results and Discussion

Geospatial analysis has shown that the city of Kharkiv is characterised by a variety of built-up area types. Multi-storey and private low-rise residential buildings dominate the urban landscape, together accounting for 42% of the total area. In addition, transport infrastructure – including roads, car parks, and garages – occupies 23% of the territory. A significant proportion of the city (21%) consists of green areas, while industrial (11%) and commercial (3%) buildings play a comparatively minor role in the urban landscape. Based on the vectorisation results from the pilot sites in Kharkiv, quantitative data on the distribution of permeable and impervious surfaces in areas with different types of development were obtained (Table 1).

Table 1. Areas of permeable and impervious surfaces at pilot sites with multi-storey and private low-rise residential buildings

Building type	Name of the spring	Total area of the pilot site, ha	Surface area, ha		Share of the total area, %	
			impervious	permeable	impervious	permeable
Private low-rise residential	Hlybokyi Yar	26.38	6.14	20.24	23.3	76.7
	Oleksiivske	5.63	1.83	3.79	32.6	67.4
	Park Yunist	10.16	3.14	7.02	30.9	69.1
Multi-storey residential	Hlybokyi Yar	62.49	23.62	38.88	37.8	62.2
	Oleksiivske	12.01	4.84	7.17	40.3	59.7
	Park Yunist	22.52	9.49	13.02	42.2	57.8

Source: created by the authors

Analysis of the obtained data showed that in private low-rise residential areas, permeable surfaces occupy between 67.4% and 76.7% of the total area (with an average of 71%), while impervious surfaces vary from 23.3% to 32.6% (average: 29%). In multi-storey residential areas, the proportion of permeable surfaces ranges from 57.8% to 62.2% (average: 60%), and impervious surfaces range from 37.8% to 42.2% (average: 40%). In private low-rise residential areas, impervious surfaces are mainly represented by the roofs of private houses and household outbuildings on private plots (8.7%-22.2% of the total area), as well as roads and pavements (8.8%-14.6%). In multi-storey residential areas, impervious surfaces include the roofs of multi-storey buildings (13.5%-19.0%) and a significantly larger share of road surfaces (21.3%-24.3%), comprising internal access roads, pavements along building entrances, and asphalted adjacent areas. Figure 3 shows images of the pilot site near the Hlybokyi Yar Spring, before and after the vectorisation of permeable and impervious surfaces. The multi-storey residential area is predominantly composed of typical 9-, 12-, and 16storey buildings. The low-rise area consists of residential houses and various outbuildings (sheds, canopies, garages, saunas, etc.), which are commonly found across all the studied plots within the city.

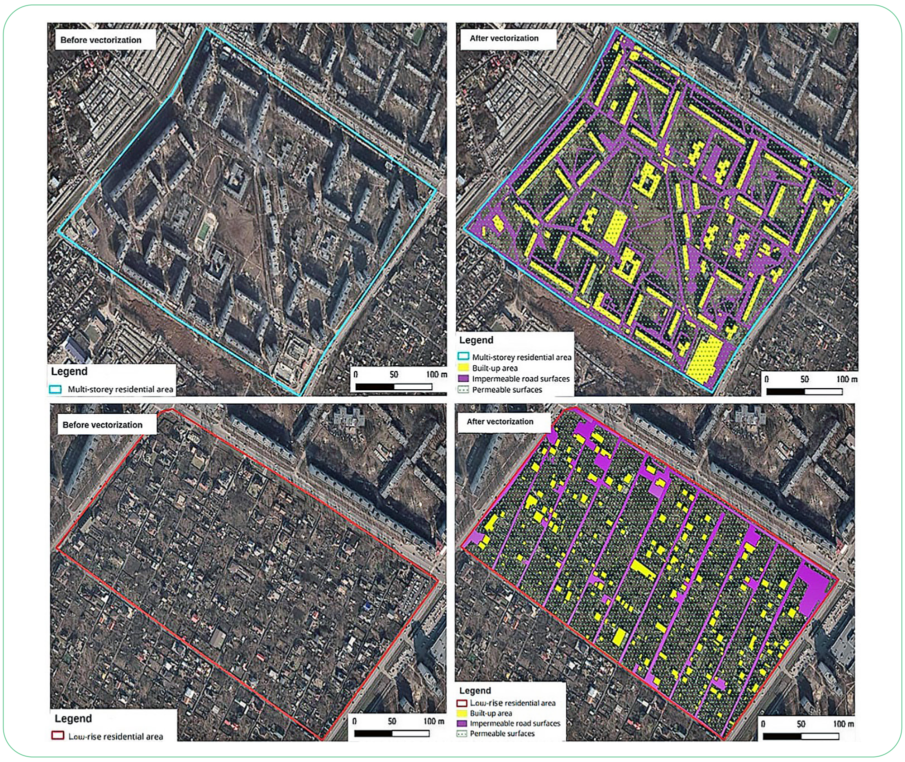

Figure 3. Pilot site near the Hlybokyi Yar Spring

Source: created by the authors

Figure 4 shows images of the vectorised surfaces at the pilot site located near the Oleksiivske Spring. The multi-storey residential area includes five-storey buildings as well as several high-rise buildings exceeding 12 storeys.

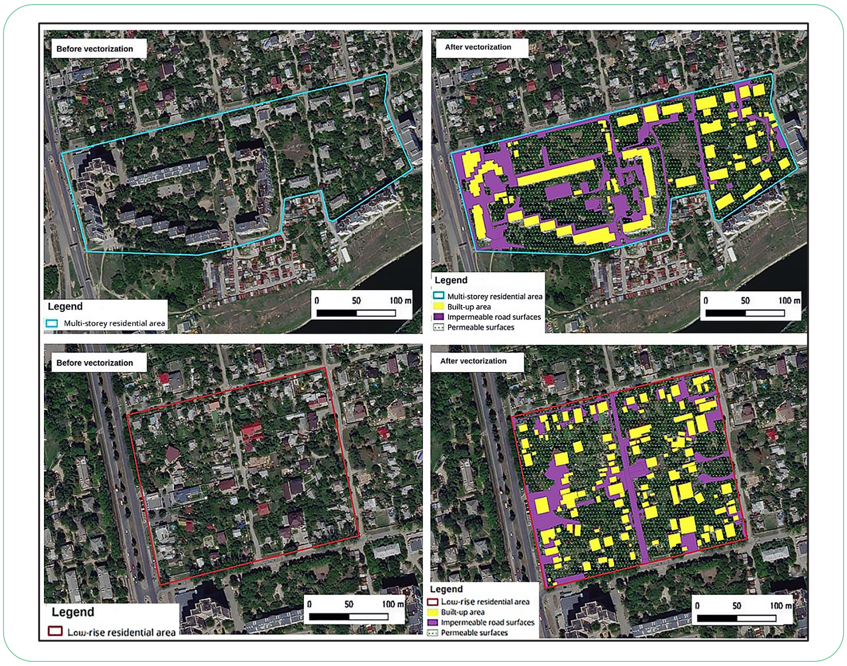

Figure 4. Pilot site near the Oleksiivske Spring

Source: created by the authors

The vectorised surfaces at the pilot site near the Park Yunist Spring are shown in Figure 5. This area features nine- and twelve-storey residential buildings, alongside three-storey social infrastructure buildings (schools, kindergartens) within the same area. Despite variations in the total area of the pilot plots, the proportions of permeable and impervious surfaces for the two analysed types of development did not differ significantly, particularly in the case of multi-storey residential areas. Therefore, both types of residential development may be considered typical across the city of Kharkiv. The derived ratios of permeable and impervious surfaces for private low-rise and multi-storey residential areas are likely to be representative of other city districts. These results make it possible to apply the average values of surface shares for rapid assessments in other urban areas without the need for time-consuming and labour-intensive vectorisation procedures. The studied springs' catchment zones varied in size from 54.5 to 124.6 ha, depending on spring discharge and hydrogeological conditions, as defined by V.V. Yakovlev (2017). Classification of satellite imagery has shown that each spring has a distinct ratio of private low-rise, multi-storey residential, and green areas within its catchment (Table 2).

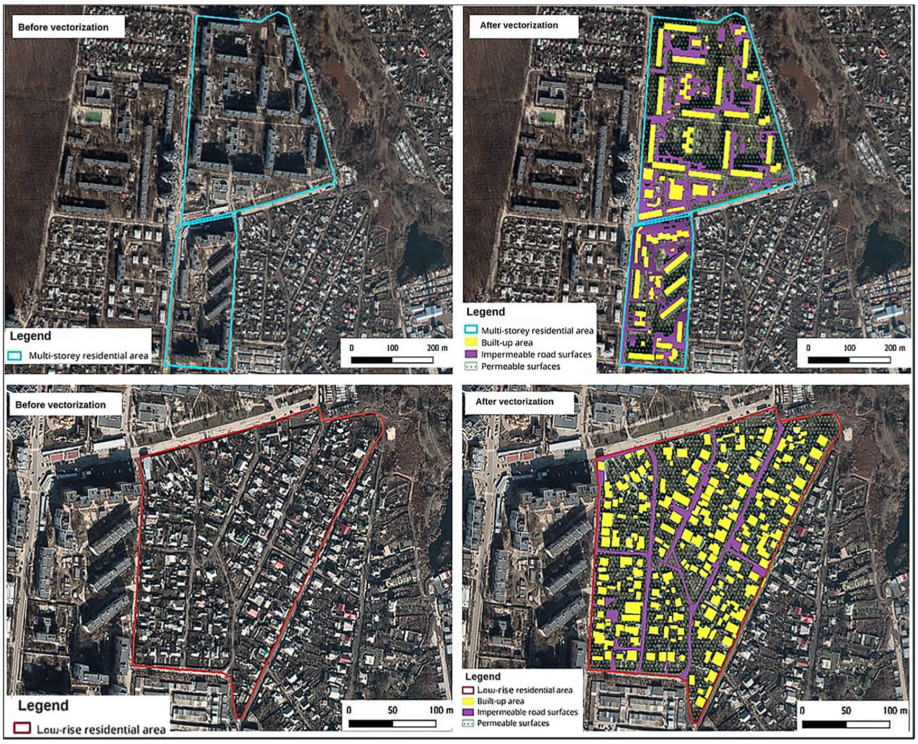

Figure 5. Pilot site near the Park Yunist Spring

Source: created by the authors

Table 2. Distribution of different built-up area types within the springs' catchment zones

Name of the spring	Total area of the spring's catchment zones, ha	Multi-storey residential area		Private low-rise residential area		Green area	
		ha	%	ha	%	ha	%
Hlybokyi Yar	124.6	104.2	83.6	17.1	13.7	3.3	2.6
Oleksiivske	83.4	50.3	60.3	33.1	39.7	0	0
Park Yunist	54.5	32.1	58.9	11.0	20.0	11.4	20.9

Source: created by the authors

The catchment area of the Hlybokyi Yar Spring is predominantly occupied by multi-storey residential development, which is typical for the north-eastern part of the city. This development accounts for approximately 84% of the total catchment area, while private low-rise housing comprises almost 14%, and green areas occupy less than 3% (Fig. 6). In the catchment of the Oleksiivske Spring, the ratio of multi-storey to private low-rise residential buildings is approximately 60:40, with no green areas identified (Fig. 7).

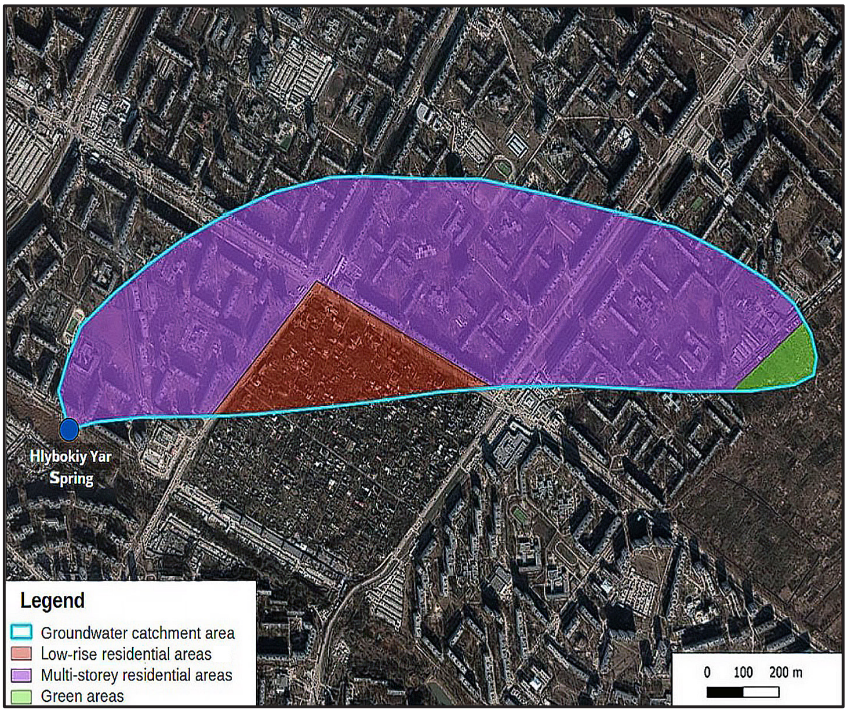

Figure 6. Distribution of built-up areas in the catchment zone of the Hlybokyi Yar Spring
Source: created by the authors

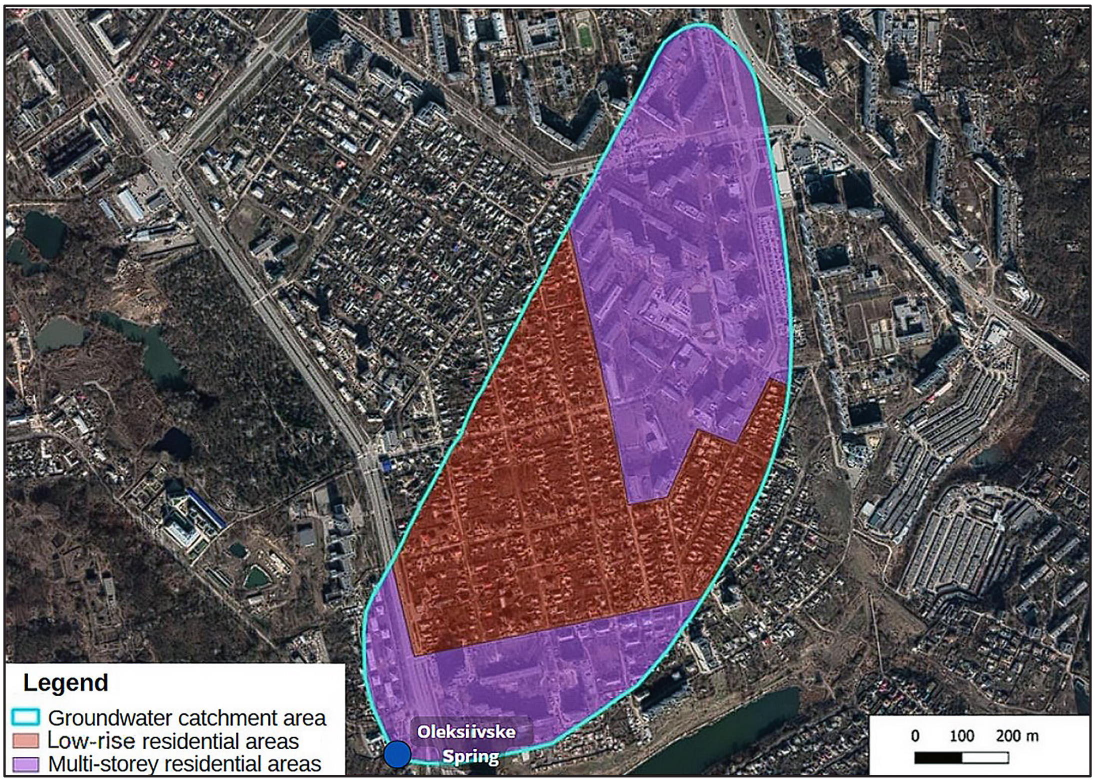

Figure 7. Distribution of built-up areas in the catchment zone of the Oleksiivske Spring
Source: created by the authors

The catchment area of the Park Yunist Spring is characterised by a relatively high proportion of green space (approximately 21%) but is still dominated by multi-storey buildings, which account for about 60% of the area (Fig. 8).

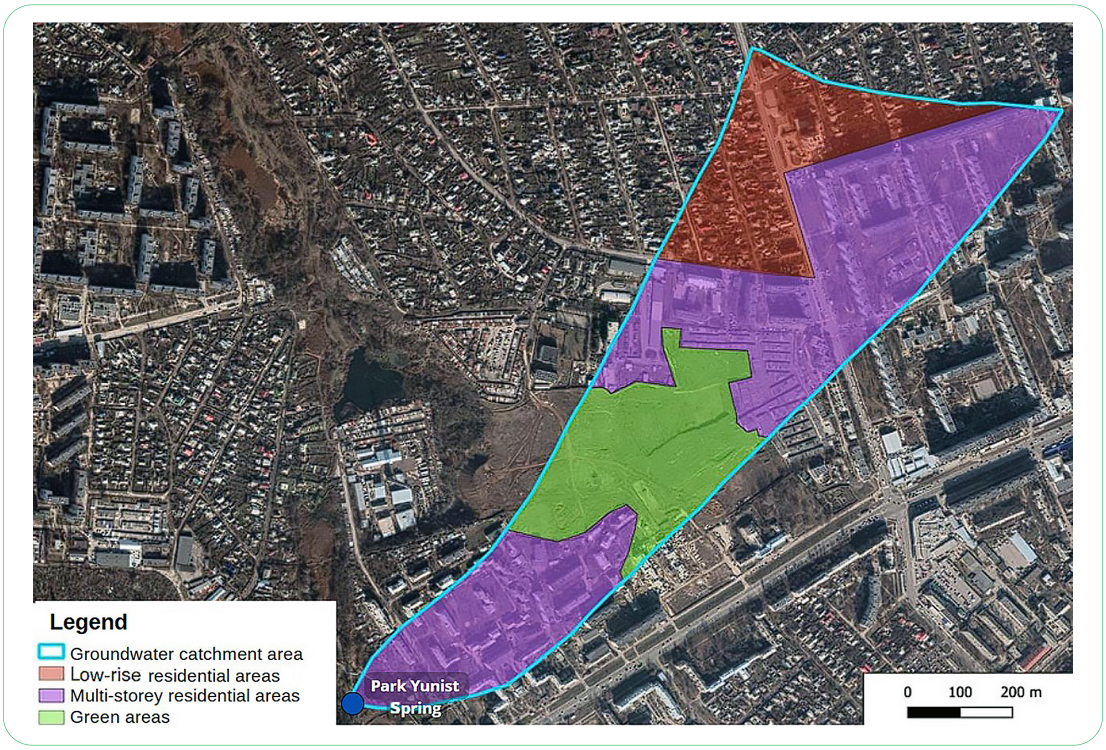

Figure 8. Distribution of built-up areas in the catchment zone of the Park Yunist Spring

Source: created by the authors

According to the present estimates, the actual share of impervious areas due to such features may be 5-10% higher than the vectorisation results obtained from the pilot sites. Based on the types of development within the catchment zones, the ratio of permeable to impervious surfaces was calculated using the average values for each type of built-up area (Table 3).

Table 3. Distribution of permeable and impervious surfaces in the springs' catchment areas

Name of the spring	Area of the spring's catchment zone, ha	Share of impervious surface area, %	Share of permeable surface area, %
Hlybokyi Yar	124.6	43.3	56.7
Oleksiivske	83.4	33.6	66.4
Park Yunist	54.5	16.9	83.0

Source: created by the authors

The results indicate that the catchment areas of the studied springs are characterised by varying degrees of anthropogenic transformation. The catchment of the Hlybokyi Yar Spring has the highest proportion of impervious surfaces (43.3%) due to the predominance of multi-storey residential development (84% of the area). This suggests the greatest level of transformation of infiltration recharge among the springs under study. The Oleksiivske Spring catchment exhibits a moderate level of anthropogenic transformation, with impervious surfaces accounting for 33.6%. This zone is characterised by a more balanced distribution of multi-storey residential buildings (60.4%) and private low-rise houses (39.6%). The catchment of the Park Yunist Spring has the lowest share of impervious surfaces (16.9%) due to a comparatively higher proportion of green space (21%) and less intensive development. The results of spring discharge measurements, which were conducted regularly over a four-year period, revealed noticeable differences between the springs (Fig. 9).

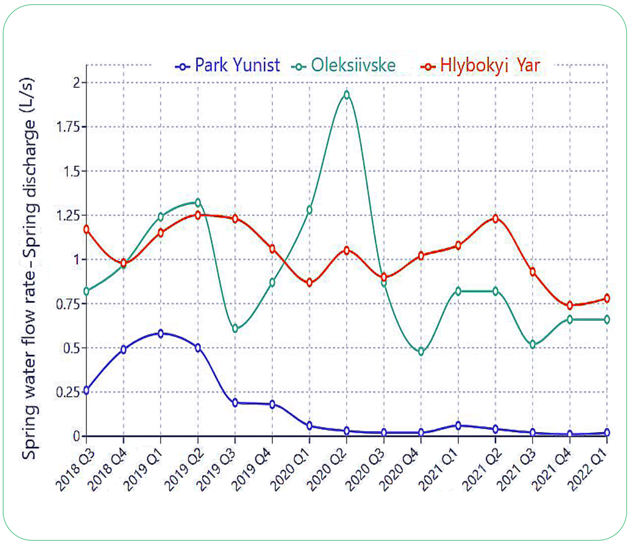

Figure 9. Flow rate of springs

Source: created by the authors

The Hlybokyi Yar Spring is one of the most powerful in the city. The average discharge during the observation period reached up to 1.0 L/s. Over the study period, the flow rate remained relatively stable, fluctuating within the range of 0.8-1.5 L/s. These fluctuations were irregular but may be associated with seasonal variations in groundwater recharge. An increase in recharge from December to April is common in the region due to more intensive infiltration of precipitation during the colder months, as established in previous studies (Vystavna *et al*., 2018). A reduction in spring discharge from May to October may be attributed to decreased precipitation, particularly lower-intensity rainfall.

The Oleksiivske Spring exhibited the most complex discharge dynamics. Until June 2019, its flow rate remained relatively strong, comparable to that of the Hlybokyi Yar Spring (0.8-1.4 L/s). Subsequently, sharp and uneven changes in discharge were recorded, ranging from 0.6 L/s to 2.0 L/s. In 2021, fluctuations continued but occurred within a relatively stable and lower range of 0.5-0.6 L/s. The survey indicated that the primary factor behind these changes is likely to be additional water abstraction from the intake well for commercial filtration and sale, as well as technical faults in the spring capture facility. The average discharge at the spring over the entire observation period was 1.1 L/s.

The Park Yunist Spring has the lowest flow rate among the studied springs, which can be attributed to the lower capacity of the Quaternary aquifer, located near the surface and characterised by faster water exchange. At the start of the monitoring period, the average flow rate was 0.5 L/s. Since the summer of 2019, there has been a gradual and sustained decline in discharge, reaching 0.020.03 L/s. The most probable cause of this reduction is a failure in the spring's capture structure.

The above findings regarding the impact of impervious surfaces on urban groundwater regimes are consistent with contemporary international research on urbanised areas. For instance, G. Nazari *et al.* (2023) confirmed that urbanisation markedly reduces the potential for groundwater recharge. In highly urbanised watersheds, up to half of the water inflow is diverted from infiltration, doubling the proportion of surface runoff in the urban water budget from approximately 15% to 30%. These data support the argument concerning the critical influence of impervious surfaces on groundwater recharge processes. Furthermore, the trend of expanding built-up areas, which further exacerbates the disruption of urban groundwater recharge, is evident in various global contexts. A study by M. Minnig *et al.* (2018) in Switzerland documented an 80.3% increase in impervious builtup areas, alongside a 16.4% decrease in vegetative cover, reflecting a broader urbanisation pattern in European cities. Similar trends have been observed in Asian cities by M. Ahmad *et al.* (2023), where interactions between groundwater and the urban environment are becoming increasingly significant. These changes impact both recharge and flow, as impervious surfaces reduce infiltration by enhancing surface runoff.

Studies utilising Gravity Recovery and Climate Experiment (GRACE) satellite data (NASA, 2023) from 2003 to 2020 have demonstrated that impervious surfaces limit rainwater infiltration and hinder natural groundwater recharge. However, the present study's measurements of spring discharge suggest that these losses may be partially offset by specific local factors. Notably, leakage from water mains, which is believed to be widespread in Kharkiv and likely in other major Ukrainian cities, may play a compensatory role. This assumption is supported by current research. Indeed, the construction of impervious surfaces and artificial drainage channels accelerates the direct flow of precipitation to streams, thereby bypassing groundwater recharge and accumulation. Nevertheless, the Hlybokyi Yar spring, despite having the highest percentage of impervious surfaces (43.3%), exhibits a relatively high and stable discharge (averaging 1.0 L/s). This may be attributed to its large catchment area (124.6 ha) and specific geological conditions, namely the presence of a locally highly conductive zone in the aquifer (fractured Obukhiv siltstones), as well as a relatively constant input from leaking tap water mains in the multi-storey built-up area that predominates in the catchment. Previous estimations of recharge fractions based on isotopic mixing signatures, conducted by D. Diadin & Y. Vystavna (2020) for this particular spring, revealed a noticeable anthropogenic input from the centralised water supply network – up to 29%. Studies from other locations confirm that leakage from water supply systems can significantly increase localised groundwater recharge, as noted by D. Owen (2021) and in the California Water Plan Update (2024).

Meanwhile, the Oleksiivske Spring, with a moderate 33.6% impervious surface coverage in its catchment, demonstrated the most unstable discharge regime. Observations suggest that this instability is likely influenced by additional factors, such as technical interventions (e.g. water abstraction for commercial use) and structural deficiencies in the spring's infrastructure. The Park Yunist Spring, although having the lowest share of impervious surfaces in its catchment area (16.9%), nonetheless exhibits the lowest discharge among the springs studied. This is primarily due to the relatively lower capacity of its Quaternary sandy aquifer compared to the aquifers of the other springs, its smallest catchment area (54.5 ha), and evident structural issues with the spring capture, particularly observed *in situ* during 2019-2020. Thus, anthropogenic impacts on the capacity of springs as water sources involve not only the alteration of surface permeability and natural recharge but also discharge instability resulting from technical deficiencies and specific patterns of water use.

Another essential aspect of the research is the assessment of spatial heterogeneity in urban environments, a topic explored in various international studies, such as those by L. Chelleri & A. Baravikova (2021). Contemporary strategies for improving urban hydrology categorise interventions into three groups, including "impervious surface-focused strategies" aimed at disconnecting non-porous surfaces from direct drainage systems. The differences in surface ratios across the studied springs' catchment areas (ranging from 16.9% to 43.3% impervious surfaces) presumably reflect varying levels of pollution risk to spring-fed groundwater. Permeable surfaces in low-rise residential zones may serve as pathways for polluted runoff and irrigation water from private households. Combined with leakage from sewage networks and individual septic systems, these factors are typical of many urban areas with private housing, as shown by F. La Vigna (2022) and V. Tiwari *et al.* (2024). Urban stormwater represents another underestimated pathway for the spread of mixed contaminants into shallow groundwater. For this reason, many researchers, including A.D. Steinman *et al.* (2022) and A. Geraldes *et al.* (2024), emphasised the importance of monitoring and managing the quality of additional anthropogenic recharge.

The study results demonstrate a significant impact of urban development on the recharge conditions of shallow groundwater. According to the data obtained, even in areas dominated by private low-rise residential buildings, up to 30% of the land is occupied by impervious surfaces that impede the natural infiltration of precipitation. In multi-storey residential areas, this share rises to 40%. Such a high proportion of impervious surfaces may significantly alter groundwater recharge processes.

Conclusions

The study has shown that urbanised areas are characterised by a significant alteration of the natural conditions for shallow groundwater recharge. These challenges are particularly acute in areas where groundwater is used for drinking purposes, especially from equipped springs, as is the case in the city of Kharkiv. Based on geospatial analysis of satellite imagery, it was found that impervious surfaces (such as roofs and roads) constitute 29% of private low-rise residential areas and 40% of multi-storey residential areas in Kharkiv. The established ratios of permeable and impervious surfaces enabled the estimation of the degree of anthropogenic transformation of groundwater recharge within the catchment areas of three springs in the city. Specifically, impervious surfaces account for approximately 17% of the catchment area of the Park Yunist Spring. For the Oleksiivske and Hlybokyi Yar springs, these figures are 33.6% and 43.3%, respectively, indicating a significant reduction in natural atmospheric recharge of the aquifer. Continued expansion of impervious surface coverage may lead to an irreversible decline in the discharge of springs, which are actively used by city residents as an alternative source of drinking water.

Measurements of the water flow rates of the studied springs during 2018-2021 confirmed that spring discharge is, to a certain extent, proportional to the size of the catchment area. However, the long-term discharge dynamics varied considerably: a relatively stable flow from the Hlybokyi Yar Spring (0.8-1.5 L/s); an unstable flow from the Oleksiivske Spring (0.3-1.4 L/s); and a gradual decline in the flow of the Park Yunist Spring (0.5-0.02 L/s). The study demonstrated that in urban environments, the hydrodynamic regime of springs is influenced not only by the ratio of permeable to impervious surfaces in the catchment area, but also by several other critical factors: the technical condition and design of spring capture facilities; the presence of additional recharge from tap water leakage; localised water abstraction at the spring site; and the specific characteristics of the aquifer.

Based on the proportion of impervious surfaces in the springs' catchment areas, it may be concluded that in the urbanised districts of Kharkiv, natural infiltration-based recharge of shallow groundwater has decreased by 17%-43% compared with the natural state, depending on the type of built-up area. Under such conditions, both the qualitative and quantitative characteristics of urban groundwater are affected by the intensity and nature of additional anthropogenic recharge. These findings highlight the necessity of implementing measures to enhance the natural infiltration of precipitation in urban areas. The adverse impact of impervious surfaces on groundwater recharge can be mitigated through the application of nature-based solutions such as permeable road surfaces and green car parks, rainwater harvesting systems, infiltration basins and rain gardens, and green roofs. The applicability and effectiveness of these measures, along with further refinement of the quantitative assessment of infiltration degradation in built-up areas, should be prioritised in future research. Sustainable urban water management, underpinned by nature-based solutions, will strengthen climate resilience and improve water security in urban environments.

Acknowledgements

The research was carried out in the framework of research project 0122U201499 "Sustainable development of urban systems in the context of climate change" (2023-2027) at O. M. Beketov National University of Urban Economy in Kharkiv and under the coordinated research project 25055 "Combined Application of Nitrate Isotopes and Contaminants of Emerging Concern to Understand Anthropogenic Impacts on Groundwater and Surface Water in Urban and Rural Areas of Eastern Ukraine" with the support of the International Atomic Energy Agency (IAEA).

Funding

None.

Conflict of Interest

None.

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Оцінка антропогенної трансформації умов живлення підземних вод урбанізованих територій

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Анотація. Стратегічним пріоритетом для забезпечення сталого розвитку міських територій в умовах зміни клімату є створення стійких і диверсифікованих систем водопостачання, оскільки змінений міський гідрологічний цикл порушує режим опадів і загальний водний баланс. У цьому контексті джерельні води виступають цінним ресурсом, проте, природне поповнення неглибоких водоносних горизонтів перебуває під загрозою через забудову міських територіі, зміни властивостей ґрунту та втрату регулюючих екосистемних послуг. Дослідження було зосереджено на оцінці ступеня антропогенної трансформації умов живлення підземних вод у міських районах Харкова, де налічується близько 30 обладнаних джерел, які активно використовуються населенням для питних цілей. У статті зосереджено увагу на оцінці ступеня антропогенної зміни умов інфільтрації опадів у міській забудові для трьох репрезентативних джерел у Харкові (парк Юність, Олексіївське та Глибокий Яр) із використанням геопросторового аналізу. Було встановлено, що в типових приватних одноповерхових житлових районах непроникні поверхні в середньому становлять до 29 %, тоді як у багатоповерхових житлових забудованих районах вони в середньому досягають 40 % від загальної площі через більшу частку площ, зайняту дорогами та дахами. На основі цих співвідношень було підраховано, що непроникні поверхні займають 17-43 % площі зон живлення досліджуваних джерел. Висновки свідчать про зменшення природного поповнення водоносних горизонтів через перешкоджання інфільтрації на непроникних поверхнях. Шляхом безпосереднього вимірювання дебіту джерел було підтверджено, що на гідродинамічний режим джерел впливає не тільки співвідношення поверхонь, а й технічний стан водозабірних споруд, додаткове живлення від протікання водопровідних мереж та структура водоносних горизонтів. Запропонований методологічний підхід та отримані результати мають важливе практичне значення для органів місцевого самоуправління під час планування та розробки заходів з адаптації міських систем водопостачання в контексті зміни клімату та інших екологічних викликів і загроз

Ключові слова: сталий розвиток; міське водокористування; джерела; непроникні поверхні; інфільтрація; геопросторовий аналіз