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GROUNDWATER CONTAMINATION BY BTEX HYDROCARBONS AND PHENOL AT FORMER GASWORKS SITES IN BYDGOSZCZ

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Abstract: This paper addresses the historical environmental impact of Bydgoszcz's 'Old Gasworks,' located on Jagiellońska Street on the Brda River—one of Poland's oldest and longest-operating gas production facilities. Municipal gas derived from dry coal distillation served both municipal and industrial purposes until 1973. However, the production process, marked by significant nuisances, particularly affected the ground and water environment. Pollutants, primarily organic compounds such as aromatic hydrocarbons, including PAHs (polycyclic aromatic hydrocarbons), and BTEX hydrocarbons (benzene, toluene, ethylbenzene, xylenes), phenol and mineral oil, entered the environment through equipment failures, leaks, and the improper storage of wastewater and technological waste.

One of the major sources of contamination was inadequately executed construction activities related to the dismantling of installations and the liquidation of sewage and waste storage tanks. This paper presents the findings of a comprehensive study focusing on hydrocarbon concentrations in groundwater at the 'Old Gasworks' in Bydgoszcz and proposes effective methods for treating the water environment.

Keywords: dry coal distillation, water pollution, aromatic hydrocarbons, groundwater remediation

1. Introduction

The ‘old gasworks’ in Bydgoszcz, located on Jagiellońska Street along the Brda River, stands as one of Poland’s oldest and longest-operating gas facilities. Commencing operations on 1 October 1860, it continued to produce municipal gas until 1973 [1–3]. The gas was manufactured through the dry distillation of hard coal at temperatures ranging from 900 to 1 100°C, employing specially constructed coke ovens [4–6]. This process yielded coke (70–80%), coke oven gas (12–18%) and by-products such as post-gas water (3–5%), post-gas tar (2.5–4.5%), benzol (0.8–1.4%) and ammonia (0.2–0.4%) from coal [1, 4, 5, 7–10]. The post-gas water comprised a mixture of ammonia, ammonium salts, pyridine, phenols, and other compounds [11]. Conversely, post-gas tar is a blend consisting primarily of aromatic hydrocarbons, phenols, pyridine, and quinoline bases [5, 12]. These by-products stand as the most significant source of pollution in the areas where these plants were situated. The town gas produced within these facilities served both municipal and industrial purposes in Bydgoszcz.

However, its production was associated with a high level of nuisance, particularly for the ground and water environment. Pollutants from operational plants primarily entered the environment due to equipment failures, leaks, and improper storage of wastewater and technological waste [1, 3]. During this period, technological waste was typically stored on the gas plant site in specially prepared pits and environmentally toxic solid waste was often utilized for land levelling [13, 14].

Nevertheless, one of the major contributors to soil and water contamination at the ‘old gasworks’ site resulted from poorly executed construction works linked to the dismantling of installations and the decommissioning of sewage and waste storage tanks [1, 2, 13, 15]. The primary contaminants identified in the vicinity of such installations include organic compounds, particularly aromatic hydrocarbons such as PAHs (polycyclic aromatic hydrocarbons) and BTEX hydrocarbons (benzene, toluene, ethylbenzene, xylenes), phenol, and mineral oil.

Contaminants persisting in the soil and in inadequately decommissioned sewage and industrial waste ponds remain active sources of groundwater environment degradation [1, 3, 13]. These contaminants, moving in the direction of groundwater flow toward the Brda River, continue to pose a significant threat to groundwater and surface water quality.

2. Location of the ‘old gasworks’

The site where the facility for the production of city gas through dry coal distillation was situated is located in Bydgoszcz on Jagiellońska Street, directly adjacent to the Brda River (Fig. 1) [3, 15]. Currently, the remnants of the original industrial installation have been appropriately secured and are of a heritage nature. The existing industrial buildings have undergone renovation and are now utilized as workshops and offices. The surrounding area has been repurposed for the construction of new internal roads, footpaths, and green spaces.

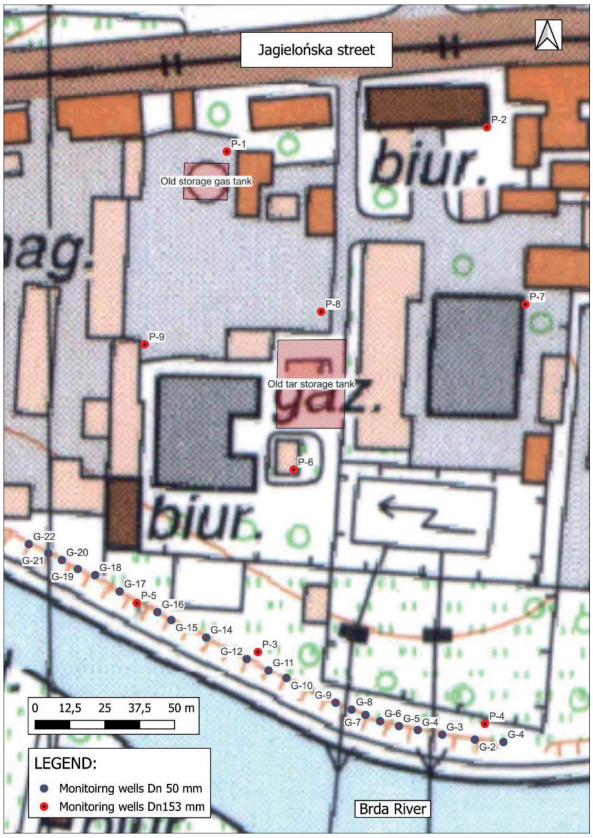

Fig. 1. Map indicating the locations of the monitoring wells used for groundwater sampling [3]

3. Characterization of geological and hydrogeological conditions

The geological structure within the vicinity of the ‘old gasworks’ in Bydgoszcz has been examined through several monitoring wells to a depth of 9.0 m below ground level [14, 16]. During these geological investigations, sandy and sandy rubble deposits were identified from the ground surface to a depth of 0.5–2.6 m. Immediately below these deposits are Quaternary sandy and clayey silts, ranging in thickness from 0.8 to 6.6 m. Further down, there are fine, medium, and coarse-grained sands containing gravel and pebbles with thicknesses varying from 0.7 to over 7.6 m. These formations rest on moraine cobbles or directly on Pliocene chert clays, drilled to depths between 6.2 and 8.7 m [13, 16].

Hydrogeological conditions in the 'old gasworks' area are characterized by the presence of a Quaternary aquifer, with the water table being free or slightly confined at depths ranging from 1.7 to 3.6 m. The aquifer primarily receives water from surface water and precipitation, with water runoff flowing in a southerly and south-westerly direction toward the Brda River. The filtration coefficient of the aquifer ranges from $3 \cdot 10^{-4}$ m/s to $8 \cdot 10^{-4}$ m/s [13–16].

4. Extent of groundwater investigations carried out at the 'old gasworks' site

Physicochemical analyses of groundwater samples taken from piezometers located in the 'old gasworks' area in Bydgoszcz were conducted in 2013, following the PN ISO 5667 standard. Water samples for the tests were collected after pumping three volumes from each observation well. This means that the samples were not collected from a specific depth [10].

To evaluate the extent of groundwater contamination with polycyclic aromatic hydrocarbons in the 'old gasworks' area, 25 groundwater samples were collected for physicochemical analyses. The locations of the monitoring wells are illustrated in Figure 1. Monitoring wells numbered P-1 to P-9 are evenly distributed across the gasworks site, while monitoring wells numbered G-1 to G-22 were strategically positioned in the test barrier along the Brda River to assess the pollutant load flowing from the site into surface water [3].

Water samples were collected following established procedures, employing a specialized pumping set from Grundfos, and placed into specially prepared glass containers. Subsequently cooled to 4°C, these samples were then transferred to the laboratory at the AGH University of Krakow for the determination of BTEX hydrocarbon and phenol concentrations

5. Test methodology for BTEX and phenol

Water samples for BTEX determination underwent extraction with pentane in separators on a KS 250 Basic shaker from IKA Labortechnik for 10 min. The prepared samples were then chromatographically analysed using a Model STAR 3400 CX gas chromatograph with a SATURN 2000 mass detector from Varian-HP-5MS 30m column, ID 0.250 mm, 0.25 μm film [3, 15].

Similarly, water samples designated for phenol determination were extracted with carbon tetrachloride in separators on a KS 250 Basic shaker from IKA Labortechnik for 10 minutes. Subsequently, the prepared samples were chromatographically analysed using the same Model STAR 3400 CX gas chromatograph.

The results of the groundwater sample analyses collected from monitoring wells in the 'old gasworks' area in Bydgoszcz for BTEX and phenol hydrocarbons are presented in Tables 1 and 2. The quality of groundwater in the studied monitoring wells was assessed based on the Regulation of the Minister of Maritime Economy and Inland Navigation dated 11 October 2019, which outlines the criteria and methods for assessing the status of groundwater bodies (Dz.U. 2019 item 2148). For the monitoring wells, due to the presence of BTEX and phenol compounds, the groundwater was classified as V groundwater quality class [11]. For BTEX, Class V of groundwater quality means that the concentration of pollutants is higher than 0.1 mg/l, and for phenol, it's higher than 0.05 mg/l.

Table 1. Concentration of BTEX and phenol in water samples analysed from 7 monitoring wells located in the area of the 'old gasworks' in Bydgoszcz [3, 11]

Substation	Monitoring wells (groundwater quality class)								
	P-1	P-2	P-3	P-4	P-5	P-6	P-7	P-8	P-9
Benzene [μg/dm³]	No sampling possible (borehole filled with soil)	<0.2 (V)	1986.2 (V)	No sampling possible (borehole filled with soil)	879.1 (V)	782.5 (V)	28.4 (V)	608.0 (V)	2.2 (V)
Toluene [μg/dm³]		0.5 (V)	1173.5 (V)		547.6 (V)	491.7 (V)	31.7 (V)	320.1 (V)	1.7 (V)
Ethylbenzene [μg/dm³]		<0.2 (V)	162.2 (V)		173.3 (V)	588.3 (V)	12.1 (V)	37.0 (V)	0.9 (V)
Xylene [μg/dm³]		0.6 (V)	1086.7 (V)		716.7 (V)	509.4 (V)	33.7 (V)	228.3 (V)	1.8 (V)
Phenol [μg/dm³]		<0.5 (V)	11.3 (V)		7.1 (V)	17.3 (V)	2.4 (V)	3.0 (V)	0.8 (V)

Table 2. Concentrations of BTEX and phenol in water samples collected for testing from monitoring wells situated in the test barrier along the Brda River in the area of the 'old gasworks' in Bydgoszcz [3, 11]

Substation	Monitoring wells (groundwater quality class)																
	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	G11	G12	G14	G15	G16	G17	G18
Benzene [µg/dm^3]	28.2 (V)	4.7 (V)	56.5 (V)	43.5 (V)	31.6 (V)	12.2 (V)	312.6 (V)	2.7 (V)	1.3 (V)	82.6 (V)	1 237 (V)	2 864 (V)	3 281 (V)	1 044 (V)	657 (V)	963 (V)	837 (V)
Toluene [µg/dm^3]	<0.2 (V)	1.4 (V)	1.6 (V)	4.6 (V)	1.1 (V)	2,6 (V)	1.5 (V)	0.6 (V)	0.8 (V)	6.7 (V)	648 (V)	1 365 (V)	1 818 (V)	821 (V)	472 (V)	549 (V)	511 (V)
Ethylbenzene [µg/dm^3]	<0.2 (V)	0.3 (V)	9.7 (V)	5.3 (V)	1.4 (V)	0.5 (V)	17.4 (V)	<0.2 (V)	0.3 (V)	2.8 (V)	106 (V)	97.4 (V)	143 (V)	134 (V)	87.9 (V)	178 (V)	231 (V)
Xylene [µg/dm^3]	0.5 (V)	1.9 (V)	2.2 (V)	6.8 (V)	1.2 (V)	0.8 (V)	22.4 (V)	0.5 (V)	0.5 (V)	11.7 (V)	443 (V)	1 011 (V)	1 126 (V)	866 (V)	433 (V)	469 (V)	548 (V)
Phenol [µg/dm^3]	<0.5 (V)	<0.5 (V)	<0.5 (V)	0.9 (V)	<0.5 (V)	<0.5 (V)	0.6 (V)	<0.5 (V)	<0.5 (V)	1.1 (V)	4.7 (V)	4.8 (V)	6.1 (V)	5.4 (V)	2.8 (V)	3.6 (V)	5.3 (V)

6. Evaluation of study results

The laboratory test results of BTEX and phenol contaminant concentrations in groundwater, as presented in Tables 1 and 2, indicate significant contamination in the area of the 'old gasworks' in Bydgoszcz [10]. The spatial distribution of the individual contaminants in the groundwater stream shows considerable variation. Among the samples studied, elevated concentrations of hydrocarbons in groundwater were notably identified in monitoring wells P-3, P-5, P-6, and P-8, as well as in test monitoring wells G7 and G10 to G18.

The total BTEX concentrations in groundwater samples exhibited a wide range, from 1.1 µg/dm^3 (P-2) to 6 368 µg/dm^3 (G14). Notably high total BTEX values were also observed in water samples from monitoring wells P-5 and P-6 at 2 316.7 and 2 371.9 µg/dm^3, respectively, and in monitoring wells G7 (353.9 µg/dm^3), G11 (2 434 µg/dm^3), G12 (5 337.4 µg/dm^3), G15 (2 865 µg/dm^3), G16 (1 649.9 µg/dm^3), G17 (2 159 µg/dm^3) and G18 (2 127 µg/dm^3). Among the identified BTEX components, the highest concentrations were found for benzene, ranging from <0.2 µg/dm^3 (P-2) to 3 281 µg/dm^3 (G14), toluene (<0.2 µg/dm^3 in monitoring well G1 to 1 173.5 µg/dm^3 in monitoring well P-3), and xylene (0.5 µg/dm^3 in monitoring well G1 to 1 086.7 µg/dm^3 in monitoring well P-3). In contrast, phenol concentrations in the water samples were significantly lower than those of BTEX, ranging from <0.5 to 17.3 µg/dm^3.

7. Conclusions

The groundwater studies conducted in the 'old gasworks' area in Bydgoszcz revealed that the groundwater in each case was classified as Class V of groundwater purity according to the Regulation of the Minister of Maritime Economy and Inland Navigation of October 11, 2019, concerning the criteria and method for assessing the status of uniform parts of groundwater. The highest concentrations of BTEX compounds and phenol were observed in monitoring wells located near the Brda River in the central part of the former gasworks area. This is due to the movement of pollutants towards the river in accordance with the flow of groundwater.

An analysis of the results obtained for the BTEX aromatic hydrocarbon and phenol studies in collected groundwater samples indicates that the investigated area is heavily degraded and should undergo a remediation process in the near future, utilizing methods that allow for the effective cleansing of the soil-water environment.

From an analysis of the available literature [4, 8, 9], it is evident that various methods have been employed worldwide for the remediation of contaminated areas after 'old gasworks'. However, in cases where the dismantling of the technological installation and its accompanying buildings was possible, one of the more effective remediation methods was the use of both 'ex-situ' and 'in-situ' methods. In this process, heavily contaminated soil was first mechanically removed and transported for cleansing or disposal, and then a selected 'in-situ' method was employed for the 'in-place' remediation of the soil-water environment.

In the case of 'old gasworks' in Bydgoszcz, such a procedure is not applicable due to the fact that the surface area is still occupied by old but renovated buildings, which are under the supervision of the conservator of monuments. Moreover, numerous underground installations within the property prevent the use of the 'ex-situ' method. Under these circumstances, only the 'in-situ' method is feasible, allowing for on-site soil and groundwater remediation. For effective environmental remediation of hydrocarbons, it would be advisable to employ several integrated remediation methods.

Due to the very high concentrations of pollutants, it would be appropriate to initiate environmental remediation using a physical or chemical method and then continue the purification process using a biological method.

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