

MONITORING OF TECHNOGENIC HAZARD SOURCES, ASSESSMENT OF THEIR SPATIAL DISTRIBUTION AND IDENTIFICATION OF HAZARDOUS OBJECTS BASED ON GIS IN THE SAMARKAND REGION

Ilmurodova Lobar Axmed qizi

Samarkand State University of Architecture
and Construction named after Mirzo Ulugbek
Samarkand, Uzbekistan

Keldiyarova Gulmira Farxadovna

Samarkand State University named after
Sharof Rashidov, Faculty of Geography and Ecology, Docent
Samarkand, Uzbekistan
guli_d@inbox.ru

Abstract:

The article presents the monitoring of technogenic hazard sources, an assessment of their spatial distribution and the identification of potentially hazardous objects in the Samarkand region. The relevance of the study is determined by the concentration of industrial, energy, transport and other facilities whose operation may threaten the environment, the population and infrastructure. The study combined field monitoring of selected facilities, a regional inventory of hazard objects, geoinformation (GIS) buffer and spatial analysis, a six-indicator system (T–P–E–S–M–I) and the Analytic Hierarchy Process (AHP) for weighting the indicators. The regional inventory contains 401 technogenic hazard objects, 36.4% of which are fuel and gas stations; their density is highest in the vicinity of Samarkand city (more than 24 objects per 100 km²), while the number of enterprises in the region grew from 6,800 to 10,800 between 2020 and 2026. For the Chopon-ota water intake, 7 accidents were recorded in 2022–2026 (mean 1.4 per year), which corresponds to a normalized accident-probability indicator $P = 0.70$. The proposed GIS-based approach can be used to improve

the environmental safety system, territorial planning, the creation of a digital database and the development of cadastral maps of technogenic hazard facilities in the Samarkand region.

Key words: technogenic hazard, sources of technogenic hazard, hazardous objects, monitoring, spatial distribution, GIS, geoinformation technologies, technogenic risk, environmental safety, Samarkand region.

Introduction

The development of industrial production, transport infrastructure, energy and utilities is accompanied by growing anthropogenic pressure on the environment. The operation of industrial, energy, transport, chemical and other potentially hazardous facilities increases the risk of emergencies, pollution of environmental components and damage to the population and infrastructure. In the Samarkand region, the development of industry, agriculture, energy, transport and construction contributes to the formation of various sources of technogenic hazard. Elevated technogenic pressure is typical of many industrial zones of Uzbekistan (Fig. 1).



Fig. 1. Schematic overview of industrial zones of Uzbekistan associated with technogenic pressure.

The territorial location, technical condition, probability of accidents and proximity of these sources to settlements and environmentally sensitive areas differ significantly. A comprehensive spatial assessment of technogenic risk is therefore necessary. It requires systematic collection and analysis of data on the technical condition of facilities, emergency situations, environmental impacts and the degree of proximity to the population and infrastructure. Geographic information systems (GIS) are suitable for integrating, spatially analyzing and visualizing such data: they make it possible to determine the coordinates of hazardous objects, classify them by type and degree of hazard, analyze risk factors spatially, delineate zones of different technogenic hazard levels and generate thematic cadastral maps. This creates a basis for improving mapping and the state cadastral registration of areas with a high level of anthropogenic hazard.

Studies carried out in Uzbekistan have addressed the environmental consequences of industrial activity mainly through inventories of emission sources at industrial enterprises [1], the economic efficiency of reducing the environmental impact of manufacturing enterprises [2], the calculation and mapping of pollutant dispersion fields [3], the efficiency of dust and gas treatment plants [4] and air pollution from vehicles in the Samarkand region [5]. The anthropogenic influence

of industrial zones on groundwater level has been examined for the Akhangaran river basin [6], [7], and the ecologization of urban ecosystems has been discussed in [8]. These works focus on individual environmental components or individual groups of enterprises. To the authors' knowledge, a combined spatial assessment of technogenic hazard sources that accounts for their technical condition, the probability of accidents and the exposure of the surrounding territory has not yet been developed for the Samarkand region.

The aim of the study is to develop and test a consistent GIS-based system for monitoring sources of technogenic hazard in the Samarkand region, assessing their spatial distribution and identifying hazardous objects. To achieve this aim, the following tasks were set: (1) to carry out monitoring and an inventory of technogenic hazard sources; (2) to form a unified GIS database of the studied objects and territories; (3) to assess the spatial distribution of hazards by buffer and spatial analysis; (4) to define a system of risk indicators and determine their relative weights by AHP; and (5) to combine the indicators into an integral assessment and zone the territory by hazard level.

2. MATERIALS AND METHODS

2.1. Study area and objects

The study covers the Samarkand region at the level of a regional inventory of hazard objects and three facilities at the level of detailed monitoring: the "Chopon-ota" water intake, a pharmaceutical warehouse and a waste disposal site. This article reports the results for the Chopon-ota water intake.

The water intake is located in the Chopon-ota Hill area in the northern part of Samarkand city, near the Zarafshan River. According to available sources, the hill covers about 800 ha and rises 826 m above sea level; in historical sources the area is also referred to as Kuhak. Architectural and garden complexes, including the Maidon and Chilsutun gardens, were formed at the foot of the hill during the reigns of Amir Temur and Mirzo Ulugbek. The territory is also historically significant as the site of the Battle of Chopon-ota on May 1, 1868, after which Russian troops occupied Samarkand. In modern terms, its importance is connected not only with this heritage but also with the water supply system: the water intake located here supplies the city of Samarkand with drinking water.

2.2. Monitoring of technogenic hazard sources

At the first stage, sources of potential technogenic hazard were monitored at the facilities under study. The functional purpose of the facilities, the specifics of technological processes, the condition of the main structures and equipment, the presence of potentially hazardous substances and materials and possible sources of emergency situations were examined. Special attention was paid to technical malfunctions, probable emergencies, possible environmental impacts, the spatial distribution of hazards, material damage and impacts on the population and infrastructure. In parallel, an inventory of potential sources of technogenic hazard in the Samarkand region was carried out: the location, type of activity and main technical characteristics of industrial enterprises, water management and energy facilities, transport infrastructure and other potentially hazardous facilities were studied. The information obtained was used as initial data for the subsequent spatial analysis and assessment of the level of anthropogenic hazard.

2.3. Formation of the GIS database

To systematize the results, a geoinformation database of the studied territories was created. It combines spatial and attribute information about the sources of technogenic hazard and the

surrounding area. The data for each object were entered into a single database and the geographical coordinates of the objects were digitized in the GIS environment. The GIS layers include the boundaries of the studied objects, main technological structures, engineering communications, water intake wells, pumping facilities, reservoirs, disinfection systems, buildings, highways, water bodies, residential areas, settlements and social facilities. Attribute characteristics reflecting the functional purpose, location and potential connection with sources of technogenic hazard were formed for each object. The database provides a single spatial representation of the source data and allows the monitoring results to be combined with the analysis of the territory.

2.4. Buffer and spatial analysis

Buffer analysis was used to assess the spatial distribution of potential anthropogenic hazards. Zones of different distances were formed around the studied objects and identified hazard sources, using buffer radii of 50, 150, 500 and 1000 m. Within each zone, the location of residential areas, settlements, social infrastructure facilities, transport communications and other potentially vulnerable objects was determined. Spatial analysis was also used to establish the relative position of hazard sources and the objects that may be affected by them. In addition, environmental monitoring points were taken into account, including soil sampling sites 50 m to the west and to the east of the studied object. The results of the buffer and spatial analysis defined the spatial component of the anthropogenic hazard and were used for mapping the studied area.

2.5. System of indicators T–P–E–S–M–I

To describe technogenic hazard comprehensively, six interrelated indicators were used: T (technical) – the technical condition of the facility, its equipment and engineering systems; P (probability) – the probability of an accident, taking into account the characteristics of the object and identified hazard sources; E (environmental) – the environmental sensitivity of the territory and the possible impact on atmospheric air, soil and water resources; S (social) – the population density in the zone of possible impact; M (meteorological) – the influence of meteorological conditions on the risk level; and I (infrastructure) – the potential impact on engineering and social infrastructure.

The probability indicator P is determined from the number of accidents registered at the facility over the past five years; the frequency of accidents in each year, the recurrence of accidents, the severity of consequences and the presence of malfunctions, pre-emergency conditions and technical violations are considered as additional information. The mean annual number of accidents is calculated as

$$N_{\text{mean}} = (N_1 + N_2 + N_3 + N_4 + N_5) / 5 \quad (1)$$

where N_i is the number of accidents in year i . Because the indicators must be comparable, P is brought to the range 0–1 by dividing the mean annual number of accidents by a reference value N_{ref} :

$$P_n = N_{\text{mean}} / N_{\text{ref}} \quad (2)$$

where $P_n = 0$ corresponds to a very low and $P_n \rightarrow 1$ to a high probability of an accident. In this study N_{ref} was taken as the maximum annual number of accidents recorded at the facility during the observation period; when several objects are compared, N_{ref} should be replaced by the maximum over all objects.

2.6. Weighting of indicators by the Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) was used to determine the relative importance of the technogenic hazard factors. The criteria were systematized, compared pairwise and assigned

weighting coefficients, which made it possible to bring indicators with different units of measurement into a single assessment system. The technical component was divided into six internal criteria characterizing different aspects of the technical condition and potential danger of the facility, and a pairwise comparison procedure was carried out for them. The use of AHP reduces the subjectivity of the assessment and provides a unified approach to ranking the factors under consideration.

2.7. Integral assessment and GIS zoning

At the final stage, the results of monitoring, GIS analysis, buffer analysis, the T–P–E–S–M–I assessment and the AHP procedure were combined into a single assessment system. Before combining, the initial spatial data were reclassified to a common assessment scale. The standardized thematic layers were then combined by the Weighted Overlay method, and the integral technogenic risk was calculated as

$$R = w_T T + w_P P + w_E E + w_S S + w_M M + w_I I \quad (3)$$

where w_T , w_P , w_E , w_S , w_M and w_I are the AHP weights of the indicators (their sum equals 1). The integral indicator R was used for spatial comparison of the objects and for identifying sites with different levels of anthropogenic hazard. As a result, an integral technogenic risk map is formed in which the territory is classified into low, medium, high and very high risk levels. This makes it possible to move from the individual characteristics of hazard sources to a comprehensive assessment of their spatial impact on the population and the environment.

3. RESULTS

3.1. Regional inventory and spatial distribution of hazard objects

The regional inventory contains 401 technogenic hazard objects of twelve types (Table 1). Fuel and gas stations are the most numerous group (146 objects, 36.4%), followed by electrical substations (83, 20.7%), waste dumps and landfills (33, 8.2%), dams and embankments (30, 7.5%) and reservoirs (29, 7.2%).

Table 1. Technogenic hazard objects of the Samarkand region by type (n = 401).

No.	Object type	Number	Share, %
1	Fuel and gas stations	146	36.4
2	Electrical substations	83	20.7
3	Waste dumps and landfills	33	8.2
4	Dams and embankments	30	7.5
5	Reservoirs	29	7.2
6	Power plants	26	6.5
7	Mines and quarries	22	5.5
8	Storage tanks and capacities	16	4.0
9	Water supply and treatment facilities	9	2.2
10	Wastewater treatment facilities	4	1.0
11	Chemical and oil and gas facilities	2	0.5
12	Tailings ponds	1	0.2

No.	Object type	Number	Share, %
	Total	401	100.0

The density of high-risk technogenic objects is highest in Samarkand city and its immediate surroundings, where it exceeds 24 objects per 100 km² (Fig. 2). Zones of above-average density also form around Kattaqo'rg'on and Qashrabort and along the Samarkand–Jomboy–Bulung'ur transport corridor, whereas large peripheral parts of the region are characterized by very low density. On the map of the preliminary GIS screening (Fig. 3) the largest clusters, of 43–54 objects, are located in the vicinity of Samarkand city; each object type is assigned a three-zone protection scheme in which zone 1 (0–30% of the standard radius) is classified as very hazardous, zone 2 (30–60%) as hazardous and zone 3 (60–100%) as a monitoring area, with radii set according to the type of object in line with the regulatory documents.

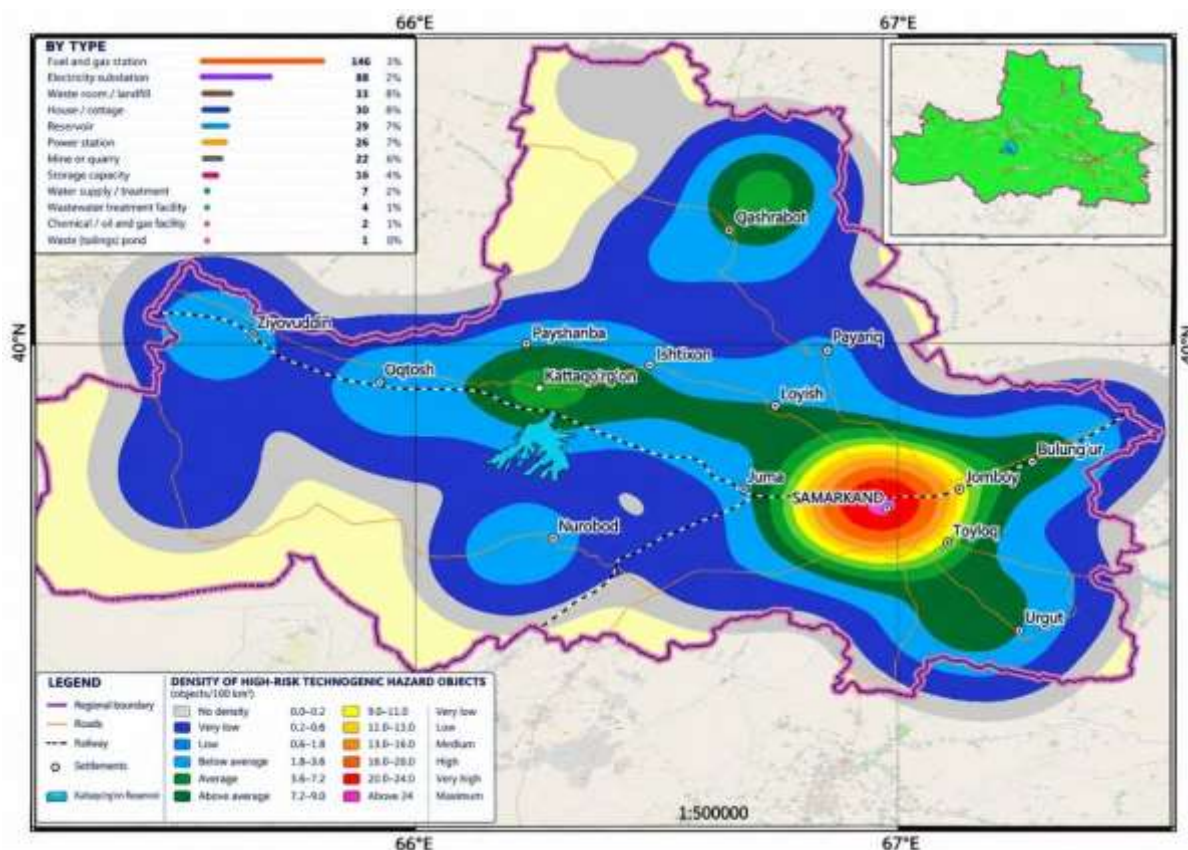


Fig. 2. Density of high-risk technogenic hazard objects in the Samarkand region (objects per 100 km²).

stable operation is essential for the uninterrupted supply of drinking water to the population. The facility was created with the development of the centralized water supply system of the city; the technical capabilities of the initial system were limited compared with modern technologies, and in the following years the water intake wells, pumping units and supply systems were gradually upgraded. The main characteristics of the facility are given in Table 2.



Fig. 5. Technological scheme of the Chopon-ota water intake (original scheme in Russian).

Table 2. Passport of the Chopon-ota water intake of the Samarkand city branch of "Samarkand suv ta'minoti".

No.	Parameter	Unit	Value
1	Year the facility was commissioned	year	1928
2	Total land area	ha	64.1
3	Perimeter length of the protective fence	km	11.5
4	Number of artesian wells	pcs	37
5	Water production capacity	m ³ /day	80,784
6	Number and capacity of clean water reservoirs or water towers	pcs / m ³	2 / 3,000
7	Length of water supply networks by diameter:	km	
	D-1000 mm	km	0.2
	D-800 mm	km	0.6
	D-600 mm	km	5.6
	D-500 mm	km	0.57
	D-400 mm	km	0.6
	D-250 mm	km	0.19

No.	Parameter	Unit	Value
	D-200 mm	km	0.35
8	Drinking water disinfection method (chlorinator or bactericidal UV lamp)	kg/s	10 (liquid chlorine)
9	Number and capacity of transformers	pcs / kVA	21 / 8,550
10	10 kV overhead power line	km	5.4
11	0.4 kV overhead power line	km	3.6
12	Name of the MFY (mahalla) and population served by the drinking water supply system	persons	—
13	Number of employees working at the facility	persons	27

The water intake is located on the bank of the Zarafshan River, south of the Samarkand–Tashkent highway (Fig. 6). The territory is fenced with barbed wire 1.5 m high and guarded by a special security organization under the jurisdiction of the National Guard; access is by special passes. A garden is laid out on the site and no crops are grown. Four pumps of the 600 LNN 3400 and D 1600×90 brands are installed in the main pumping room. The chlorination equipment was reconstructed and re-equipped with loan funds allocated by the French Republic, and drinking water is disinfected with chlorine gas. The chlorination room contains special emergency devices designed to prevent the release of chlorine into the environment and to eliminate the consequences of an emergency with containers and gas cylinders; all of them were in working order. The facility is supplied with electricity from the "Chopon-ota" substation through four feeders. The site has two RU-6000 kV devices, two transformers of 1000 kW and transformers of various capacities for the operation of the artesian wells. The produced drinking water is delivered to the city through two high-pressure pipelines. Access roads to the second-lift pumping station are paved, and the rest of the territory is covered with fine-grained crushed stone.



Fig. 6. Satellite image of the Chopon-ota water intake (39°40'53.0" N, 67°03'08.9" E).

One of the monitoring points on the Zarafshan River is located near the water intake. In 2021, a high-pressure water main of 1200 mm diameter ruptured near the Chopon-ota hill; 27 employees of "Samarkand suv ta'minoti" took part in eliminating the consequences (this is the number of staff involved in the accident response, not the full-time staff of the water intake). In 2022, within the investment program, the 8.1 km main water supply line from the water intake to the Ulugbek Observatory was reconstructed, together with the Chopon-ota and Dahbed water intakes, 8 pumping stations and sections of the water supply networks. In 2023, water from the Chopon-ota and Dahbed water intakes was supplied to the residential areas of Sogdiana, Beruni and neighborhoods A and B.

3.3. Accident probability indicator P

The number of accidents registered at the Chopon-ota water intake during the last five years is given in Table 3. A total of 7 accidents were recorded, which gives a mean of $N_{\text{mean}} = 7/5 = 1.4$ accidents per year.

Table 3. Accidents at the Chopon-ota water intake, 2022–2026.

Year	Number of accidents
2022	1
2023	2
2024	0
2025	2
2026	2
Total (mean per year)	7 (1.4)

A value of 1.4 lies outside the range 0–1 adopted for the indicators and cannot be interpreted directly as a high probability of an accident; it must first be normalized. Taking the maximum annual number of accidents recorded in the period ($N_{\text{ref}} = 2$), Eq. (2) gives $P_n = 1.4/2 = 0.70$. The normalized

value lies in the upper part of the scale, which indicates a moderately high probability of an accident and justifies including the facility in the monitoring system for technogenic hazard sources.

4. DISCUSSION

The results show that technogenic hazard in the Samarkand region is spatially uneven and is concentrated where economic activity is densest. The highest density of hazard objects coincides with Samarkand city and its transport corridors, and it is in this area that the number of enterprises has grown most steadily (by 58.8% over 2020–2026). The structure of the inventory is also important: fuel and gas stations and electrical substations together make up more than half of all objects (57.1%). These are numerous, dispersed and closely tied to residential areas, so their cumulative contribution to risk is determined less by the severity of a single accident than by the number of people and facilities exposed within the buffer zones. Larger objects such as reservoirs, dams, waste dumps and mines are fewer, but the consequences of their failure may be considerably more extensive.

The Chopon-ota water intake illustrates the second group of risk factors – the technical condition of long-operated critical infrastructure. The facility has operated for almost a century according to its passport data, and wear of equipment, reduced efficiency of pumping units, the condition of pipelines and the stability of power supply require constant monitoring. These factors affect not only the uninterrupted supply of water but also the technogenic safety of the facility itself. The use of chlorine gas for disinfection adds a hazard to the population in the neighboring areas, which is partly mitigated by the emergency devices that were found in working order. At the same time, the accident record (7 accidents in five years, with an accident in four of the five years) and the rupture of a 1200 mm main in 2021 show that an emergency at this type of facility is a real rather than a hypothetical scenario. The reconstruction carried out in 2022 did not eliminate this risk, since accidents were recorded again in 2025 and 2026.

Methodologically, the study shows that individual indicators measured in different units can be combined into a single assessment only after normalization. The case of the indicator P is typical: the raw mean value of 1.4 accidents per year is not a probability, and only after rescaling to the 0–1 range can it be used in the integral indicator R together with the other factors. AHP weighting makes the contribution of each indicator explicit and reduces the subjectivity of the assessment, although the weights still depend on expert judgment and should be checked by a consistency test and, if possible, by several independent experts. The combination of AHP, buffer analysis, reclassification and Weighted Overlay is a transparent and reproducible procedure that can be applied to other facilities and updated when new data appear.

The practical significance of the approach is that it moves the assessment from a list of objects to a spatially differentiated picture of risk. Territories with a very high or high risk level can be given priority in monitoring, preventive measures and environmental control, and the same GIS database can serve as the basis for a digital cadastre of technogenic hazard objects. Recent developments in technical safety point to the further step of replacing a static cadastre with a dynamic one, in which data from sensors and automated monitoring systems are continuously fed into the GIS. Such systems can, for example, stop equipment automatically when a person enters a hazardous zone, and monitor the state of workers in real time. This reflects the general transition from the registration of hazardous objects to quantitative risk assessment, geoinformation analysis and real-time monitoring.

The study has several limitations. First, the detailed assessment is based on one facility, and the accident record covers only five years, the last of which (2026) may be incomplete; the

normalization of P against the maximum annual value of the same facility is therefore provisional. Second, the regional inventory is a preliminary screening whose hazard classes and protection-zone radii depend on the standard adopted for each object type. Third, the weights of the T–P–E–S–M–I indicators are based on expert pairwise comparison. Future work should extend the detailed assessment to the other studied objects (the pharmaceutical warehouse and the waste disposal site), compare the objects by the integral indicator R, validate the zoning against environmental measurements, including the soil sampling points, and establish a regular updating of the digital database.

5. CONCLUSION

Using the example of the Samarkand region, sources of technogenic hazard were monitored, their spatial distribution was assessed and potentially hazardous objects were identified. The regional inventory contains 401 objects, dominated by fuel and gas stations and electrical substations, with the highest density (more than 24 objects per 100 km²) in Samarkand city and its surroundings, where the number of enterprises increased by 58.8% in 2020–2026.

A system of six indicators (T, P, E, S, M, I) was proposed for the integral assessment of technogenic risk; the relative importance of the criteria was determined by the Analytic Hierarchy Process, and the indicators were brought to a single scale by reclassification and combined by the Weighted Overlay method in the GIS environment. For the Chopon-ota water intake, 7 accidents were recorded in 2022–2026 (1.4 per year), and the normalized accident-probability indicator is $P = 0.70$, which indicates the need to keep the facility under priority monitoring.

The results can serve as a scientific and methodological basis for improving the monitoring of technogenic hazard facilities, the spatial zoning of the territory and the formation of a digital cadastral database of technogenic risks in the Samarkand region.

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