Analysis of wireless technology in monitoring the current state of well waters

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Abstract: In the current study, it was tried to present the results of the study of well waters of the mausoleums of Arystan Bab and Khoja Ahmed Yasawi. Changes in the water level in wells are presented by measuring the location of groundwater, a constant change in the water level is visible. To determine the composition of groundwater, analytical studies were conducted in different periods of the year. According to the results of the study of the composition of well water, it was established that the concentration of sulphate, chloride ions, and other indicators exceed the standard values. According to indicators, the total water hardness in all wells exceeds the standard values. Based on the results of scientific research, based on the identified patterns, the influence of various factors and the level of their influence on the state of monuments were determined using integrated environmental monitoring. It is established that there is a correlation dependence between the state of the studied historical and cultural monuments and anthropogenic, natural-climatic, as well as other environmental factors.

Keywords: smart wireless system; control; monitoring; groundwater; sulphate.

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1 Introduction

One of the most important environmental problems today is, undoubtedly, the contamination of water by nitrates, especially in areas with significant agricultural activity, as occurs in the areas with less water resource. Otyrar is located in the Syrdarya valley, at the confluence of the Arys and Syrdarya rivers. Its geographical position is especially limited to the west by the Kyzyl Kum, which occupies the space between the two great Central Asian rivers – Syrdarya and Amudarya. The part of the right bank of the Syrdarya, which is part of the oasis, is a flat or slightly hilly steppe with poor monotonous flora. The Great Silk Road passed through Otyrar (Shirazi, 2004; Zhussupbekov et al., 2016; Mamasharipova et al., 2019).

Population, consumption pattern and use of technology are the three main and effective parameters in creating, reducing or solving environmental problems. Unfortunately, population growth, consumerism orientation and misuse of technologies have caused the available resources to be extracted with more speed and power, regardless of its consequences. But now, the depletion of groundwater aquifers (which is the second largest source of fresh water in the world) has posed a serious challenge in most countries (Roders and Van Oers, 2011; Agapiou et al., 2015; Kulgildinova et al., 2019).

Otyrar is a dry land with very little rainfall, with less than a third of the world's rainfall. Therefore, due to the scarcity of surface water resources, excessive pumping of groundwater aquifers is common. More than 25% of groundwater aquifers are in critical condition due to over-harvesting, and their numbers are increasing. Groundwater level drop and negative aquifer balance have been reported in most plains. Another unique architectural monument of the late 14th and early 15th centuries – since 2000, the mausoleum of Khoja Ahmed Yasawi has been included in the list of UNESCO World Heritage Sites and is under the protection of international organisations. The mausoleum of Khoja Ahmed Yasawi is one of the largest structures in Central Asia, with the most impressive domes. The building is 46.5 m wide and 62.5 m long. The compact layout includes 35 halls and rooms of various sizes (Fodde, 2008; Orlenko, 2017; Kurmanaliyeva et al., 2018). The preservation of these unique architectural monuments of the entire religious Islamic world, considered in their importance as the second Mecca, is an important task in the field of security and protection of world heritage. The main directions in the strategy for the preservation of cultural heritage are laid down in the declaration on the protection of cultural and natural heritage at the national and local level (Swamy et al., 2017; Dastgerdi et al., 2020), in the recommendations on the preservation and contemporary role of historical ensembles (Van Oers, 2007) and in other international regulations.

Due to the limited drinking water resources, intensive money requirements, growing population, urban change in rural areas, and the excessive use of sea resources for salt extraction has significantly worsened the water quality available to people. The objects under consideration are very resistant to external exogenous influences, including polluted precipitation, groundwater, and other factors. As it is known, every year, as a result of the negative influence of anthropogenic factors, the integrity of these unique architectural ensembles is rapidly violated (Andrei et al., 2018). Therefore, it is very important to monitor the general state of monuments of material culture and identify the main types of influences on them of natural-climatic and technogenic factors. These factors include excessive air pollution (acid and salt precipitation) and salinity of groundwater, heavy traffic (exhaust gases, vibration, etc.). In this regard, the results of our research work on preliminary monitoring of ground well water on the territory of mausoleums are of particular importance.

Some studies have also been conducted on the presence of biological components in the waters (Adamo et al., 2014; Andrei et al., 2018). Wireless sensor networks have proven to be a very effective technology for numerous environmental monitoring applications. WSNs currently enable the automatic monitoring of air pollution (Rodwell, 2008), noise pollution (Vijayakumar and Ramya, 2015), climatological conditions (Fodde, 2009), and much moreover wide areas, something previously impossible. Many well waters cannot be used in aquaculture, while others must be treated before they are used. Low pH and high concentration of carbon dioxide, iron, manganese, and sulphide are some examples of water quality issues. In ions such as potassium, calcium, or magnesium, groundwater may also be deficient. The aim of this work is to study the well waters of the mausoleums of Arystan Bab and Khoja Ahmed Yasawi to assess compliance with sanitary and hygienic requirements. So in this paper, the monitoring system based on the wireless system developed for screening the level of the waters in wells for environmental and agricultural and drinking usages.

2 Research methods

In this paper, an integrated IoT system for water level screening is conceived and customised for its demonstration and preliminary validation in wastewater treatment use case. The proposed system leverages an innovative low-cost analytical device at the close-to-market stage. The objects of research are the well and ground waters of the mausoleums of Arystan Bab, Khoja Ahmed Yasawi and the Zhuma Mosque. The studies were carried out by chemical, chemicophysical methods in accordance with the relevant requirements of GOST standards.

2.1 Objectives

To achieve this goal, it is envisaged to solve the following main tasks:

- Carrying out chemical and analytical analysis of the composition and properties of water in wells.
- Identification and assessment of the influence of pollutants that can affect the quality of groundwater.
- Determination of physicochemical properties and composition of building construction materials of monuments and ways of their unfavourable change due to the participation of environmental factors.

- Provision of new technological methods aimed at preserving the stability of monuments.

There are five wells on the territory of the Arystan Bab Mausoleum, the water of the main well, adjacent to the mausoleum, is widely used by visitors as healing and holy for drinking and other purposes. In this regard, making life safe for people using this water is one of the urgent problems. These sources have practically not been investigated, and there are no documents confirming their compliance with sanitary and hygienic requirements. The quality of water plays the most important role in the health and comfortable existence of humans. Therefore, on a global scale, special attention is paid to this natural object of the biosphere (Palmer, 2007; Pelkmans, 2007; Qu and Fan, 2010; Hao et al., 2020).

Using the method of photographic recording, it was determined that due to the high waters, the Arystan Bab Mausoleum is subject to destruction processes. This indicates that moisture wakes up to the middle of the walls and spots of permanent salts take place. In order to monitor the process of the lift of salts by groundwater and identify their causes and develop specific measures, studies of five-pointed wells to the mausoleum of Arystan Bab were carried out. The total hardness, the content of calcium, magnesium, hydrocarbonate, sulphate, and chloride-ions were determined by the titrimetric method in accordance with the relevant GOSTs (Jackson, 2001; SanPiN 2.1. 4.1074-01, 2001; Van der Aa, 2003; Golovanov, 2020). The active reaction of the waters, characterised by the pH value, was determined by the potentiometric method. The concentration of trace elements (fluoride ions) was determined according to standard methods (Winton et al., 1971; Goncharuk, 2010; Volkova et al., 2020). Organoleptic indicators were determined by the method according to the relevant GOSTs (Sperling et al., 1992; Ma et al., 2019).

2.2 Natural and climatic conditions of the location of research objects

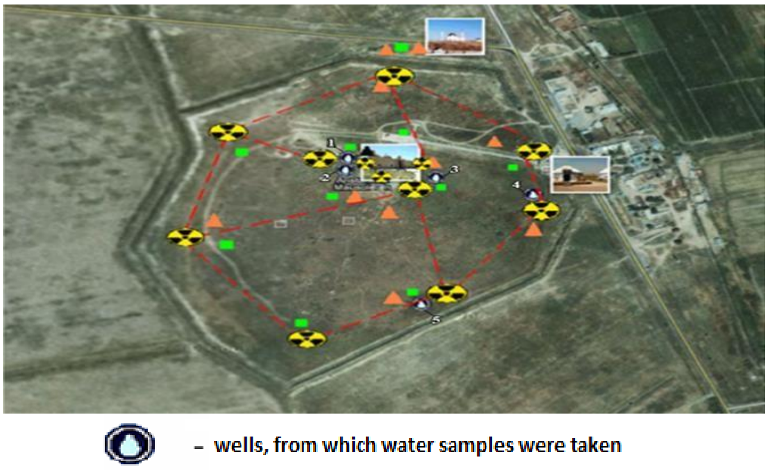
The climate of these regions is moderately continental. The average annual temperature in January is –5–7°C in the north of the region (in the north), –3–5° C in the south (in the Kyzylkum region), and 26–28°C in summer. The lowest temperature in winter is –38°C, in summer 52°C. The total annual volume of solar radiation is 3,200–3,400 h/year. The average annual rainfall ranges from 170 millimetres (in the Kyzylkum region) to 300 millimetres. Most of the wind in winter (45%) blows to the northeast, and in summer to the north (45%).

3 Results and discussion

For analysis, waters were taken from five wells located at different distances from the mausoleum: no. 1 is the main used well, located 20 m south-east of the mausoleum (depth is 10 m); well no. 2 is located on the western side of the mausoleum (depth 6 m), well no. 3 is located on the opposite side from the central entrance of the mausoleum (depth 5 m); well NO. 4 (depth 3.8 m) and well no. 5 (depth 5.8 m) are located at a distance of 350–400 m from the main gate of the mausoleum (Figure 1).

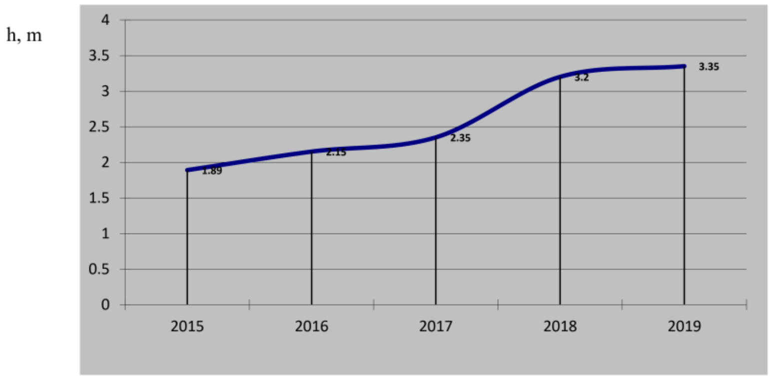
On the territory of the Arystan Bab Mausoleum, the groundwater level lies at a depth of 1.5 to 4.5 m from the ground surface.

Figure 1 Location of wells (see online version for colours)



Figures 2–3 show the changes in the water level in well no. 1 for 2015–2019, as well as indicators of the water level by quarters in well no. 1 for 2019. From this well, water is constantly used by pilgrims as a 'holy healing'.

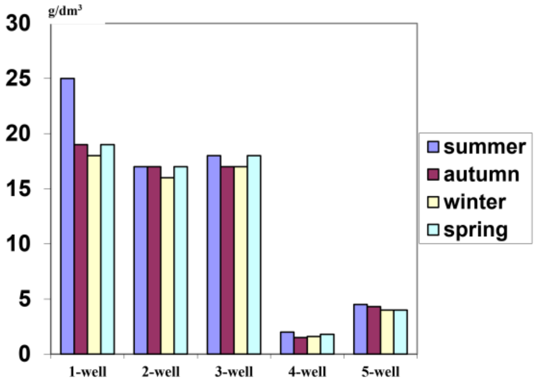
Figure 2 Change in water level in well No. 1 for 2015–2019 (see online version for colours)



The data obtained experimentally for other wells (nos. 2–5) are presented in Figures 3–5. The waters of these wells are not used for the economic needs of this facility.

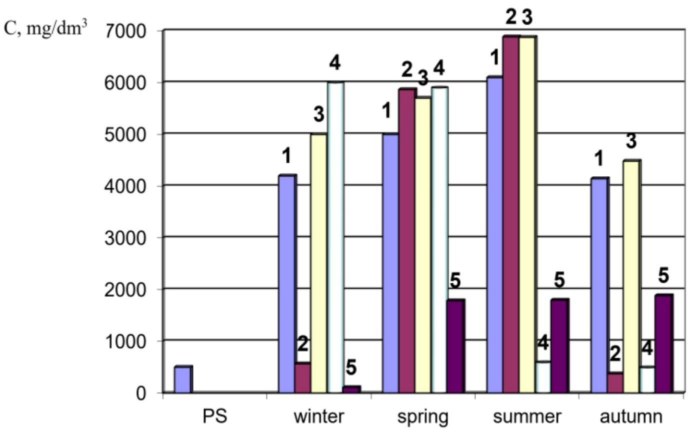
From the experimentally obtained data on measuring the location of groundwater, a constant change in the water level can be seen. Especially the maximum lift in the groundwater level is observed in spring, which is associated with the amount of precipitation and the penetration of melt water into the soil.

Figure 3 Seasonal change in the volume of salts in wells (see online version for colours)



To determine the composition of groundwater, analytical studies were carried out in different periods of the year. Figure 4 shows data characterising the qualitative and quantitative chemical, biological, and physical composition of the well water. It can be seen that there is a difference in water salinity in the wells. Depending on the salinity, the wells can be placed as follows: 3 > 2 > 1 > 5 > 4, in the wells no. 1–3 salinity of the water is 18.5–24.7 times, in well no. 5 is four times higher than the standard indicator, water from well no. 4 is at the standard level.

Figure 4 Seasonal change in the amount of sulphate ions in the water of five wells (1–5) of the Arystan Bab Mausoleum (see online version for colours)



In accordance with the pH value, the well water is weak alkaline, does not exceed the regulatory limit (pH = 6–9).

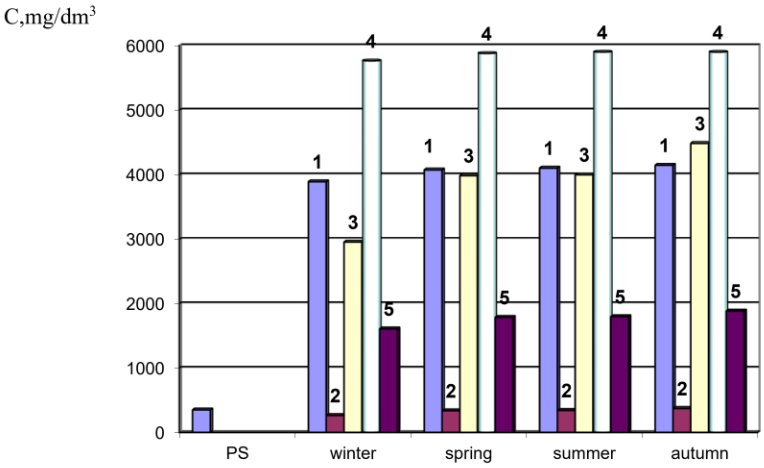
Table 1 Chemical composition of well waters (10.05.2018)

Well no.	*Organoleptic indicators*					*Indicators of chemical composition*						
	Smell, score	*Taste, score*	*Chromaticity in degrees*	*Turbidity, FTU/dm³*	*pH*	*Ca^{2+}, mg/dm³*	*Dry residue, mg/dm³*	*Permanganate value, mg·O/dm³*	*COD, mg·O/dm³*	*Sum of CO_3^{2-} and HCO_3^-, mole/m³*	*Total hardness, mole/m³*	*Chlorides, mg/dm³*
1	0	Salty	33.6	5.9	7.2	657.95	20,455.0	1.34	288.0	10.2	143.6	4,155.3
2	1	Salty	123.2	14.03	7.7	986.93	18,460.0	1.6	173.2	12.0	156.9	3,922.9
3	4	4	1,071.0	116.0	7.5	616.8	24,740.0	5.2	247.6	22.4	187.7	6,102.3
4	5	5	225.8	26.5	7.5	102.81	1,602.5	3.06	49.4	9.8	15.4	348.7
5	5	5	1,225.0	89.01	8.5	41.12	4,100.0	14.2	448.0	30.7	34.9	1,743.5
PS	2	2	20–35	2.6–3.5	6-9	180.0	1,000–1,500	5.0	-	6.5	7.0–10.0	350

Well no.	*Indicators of chemical composition, mg/dm3*										
	Sulphates	*Fluorides*	*Nitrates*	*Nitrites*	*Ammonium ions*	*Manganese*	*Iron*	*Copper*	*Lead*	*Cadmium*	*Zinc*
1	6,100.0	0.3	26.2	0.106	N/D	0.37	0.3	0.04	< 0.01	N/D	0.06
2	6,885.0	0.6	3.5	0.091	0.7	0.42	0.4	0.02	< 0.01	- « -	0.04
3	6,875.0	0.2	207.9	21.4	29.9	0.3	1.5	0.04	< 0.01	- « -	0.05
4	589.06	1.3	5.6	1.5	42.2	0.06	0.8	0.03	< 0.01	- « -	0.01
5	108.2	0.7	1.4	1.3	14.0	0.08	1.3	0.02	< 0.01	- « -	0.01
PS	500	1.2–1.5	45	3.0	2.0	0.1	0.3	1.0	0.03	0.001	5.0

The results of qualitative and quantitative chemical analysis are presented in Table 1 and in Figures 5–6.

Figure 5 Seasonal change in the amount of chloride ions in the water of five wells (1–5) of the Arystan Bab Mausoleum (see online version for colours)



The concentration of sulphate, chloride-ions, and other indicators exceeds the standard values. For example, in well no. 1 (the main one, the water of which is consumed by visitors), the concentration of sulphate ions is 24–25 times, and chloride ions are 15–17 times higher than the permissible standards (PS), in other wells (nos. 2–5), the excess of PS for these ions is ~4.5 and ~2.5 times, respectively. The pH value of water in the main well (no. 1) is closer to neutral, and in all other wells, it is slightly alkaline, but these indicators of the reaction of the medium are within the limits of regulatory norms (pH = 6–9).

The greatest salinity without exception for the waters of all wells occurs in the summer months, and the lowest salt content is observed in winter. The observed results are explained both by an increase in the rate of evaporation during the summer period and by changes in the solubility of salt depending on temperature.

According to the results of chemical analysis, all wells are unevenly salted, the total salt content exceeds from 3 to 24–25 times the standard indicators. The most saline is the water of the main well. Despite this, pilgrims, considering the water from this well holy, use it for drinking and treating various diseases, such as skin diseases.

According to indicators, the total water hardness in all wells exceeds the standard values; for example, in the 3rd well by ≈18 times, the water of wells 4–5 is less hard. The content of sulphate ions is 12–14 times higher than the standard value, and chloride ions are 3–17 times higher (wells 1–3). The highest content of ammonium ions in the 4th well, there is an excess of 21 times the norm. From experimental data, the excess content of Ca^{2+} was found in the waters of wells no. 1–3. The concentration of F– in all objects does not exceed the standard level. Analysing the results of chemical analysis, it can be concluded that there is a strong salinity of ground (well) water. The reason for the salinisation of the building structures of the Arystan Bab Mausoleum can be attributed to the salinity of groundwater.

Figure 6 Salt deposits on the walls of the Arystan Bab Mausoleum (see online version for colours)

Figure 7 Destruction of brickwork of the Arystan Bab Mausoleum (see online version for colours)

Figure 8 Cracks in the building structures of the Arystan Bab Mausoleum (see online version for colours)

Figure 9 Waterlogging of the foundations of the Arystan Bab Mausoleum (see online version for colours)

Figures 7–10 clearly show salt deposits and the destruction of brickwork on walls and foundations. This indicates that one of the main factors destroying building structures that reduce the stability of this architectural monument is the capillary lift of saline water through the materials of the foundations and walls. Especially with moisture, the stability of the soils of the foundation of the monument sharply decreases. It should be noted that waterlogging by both surface and ground waters took place for two to three centuries.

In addition, bacteriological analysis of water samples from the wells of the Arystan Bab Mausoleum was carried out since biological contaminants (mould, fungus, etc.) also destructively destroy building structures. Some studies have also been carried out on the presence of biological components in the waters.

The results showed that in all well waters of the Arystan Bab Mausoleum, in addition to the water in well no. 1, *E. coli* bacteria and a number of small insects were found (Table 2). Thus, the population and pilgrims use clean water from a biological point of view, but, however, due to the high salinity, the water of well no. 1 cannot be classified as drinking water.

Table 2 Results of bacteriological analysis of well waters of the Arystan bab Mausoleum (2019)

No. of wells	*Sanitary and bacteriological indicators*				
	The total number of bacteria in 1 cm^3 of water				*Coliforms (Escherichia coli)*
	14.03	*16.06*	*22.09*	*20.11*	
1	40	46	45	42	Not detected
2	56	71	88	69	Detected
3	71	78	80	75	Detected
4	78	84	92	97	Detected
5	59	66	70	65	Detected
Requirements according to PS	50				-

3.1 Monitoring of groundwaters (wells) at the Yasawi Mausoleum

The amount of saline groundwater belonging to the Yasawi Mausoleum in 2019 compared to 2016 increased in water in wells in the interior of the mausoleum by about 1.5 times, and in external wells in courtyards by 2.3 times (Figures 10–12).

Figure 10 The amount of salts by quarters of wells located inside the Yasawi Mausoleum (see online version for colours)

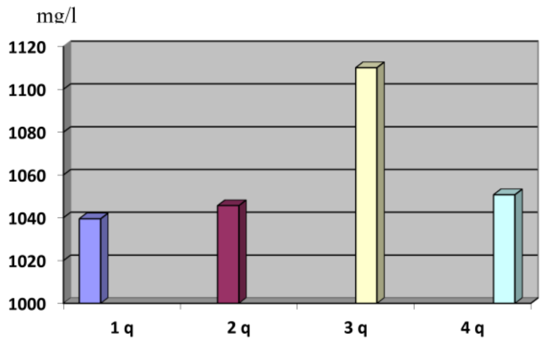
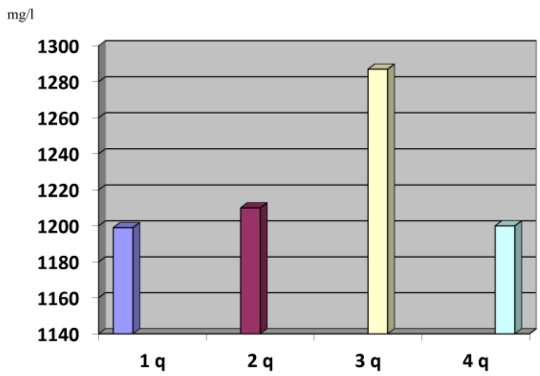
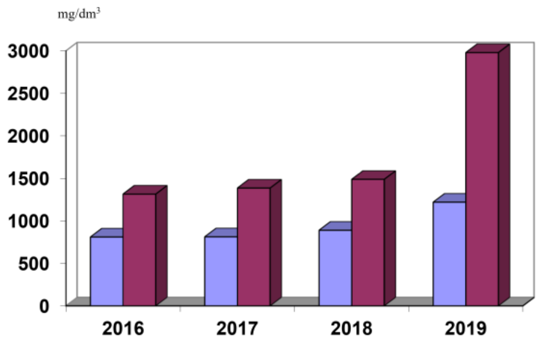


Figure 11 The amount of salts by quarters of the well of the Juma mosque (see online version for colours)



In particular, at present, due to the increase in the amount of salinisation, the mausoleum is subject to the processes of destruction of building materials (pieces, painted decorations, gesso, etc.), which affects the state of the entire monument. The salinisation process is characteristic of the brick walls of the mausoleums. Salt stains on walls and other top surfaces are caused by the evaporation of moisture between the bricks. This process is directly related to daily temperature fluctuations, that is, with a change in air humidity. For example, calcium anhydrite $CaSO_4$ at high humidity with low temperature turns into crystalline hydrate ($CaSO_4 \cdot 2H_2O$), and at high temperature and low humidity, crystalline hydrate, on the contrary, turns into anhydrous salt. In the case of evaporation of salts, the appearance of crystalline hydrate increases the volume of salts, which have a negative effect on the mausoleums. In this regard, increased pressure on wall openings and capillaries lead to its destruction. With external attention to the wall, many cracks are observed on its surface. It leads to the destruction of the laid bricks (Priemets, 2016; Ibraeva et al., 2017).

Figure 12 Salinity content in the internal and external wells of the Yasawi Mausoleum (see online version for colours)



Note: In blue – an internal well and in red – a well in the courtyard.

Due to moisture, capillary lift, and evaporation containing salts, it aggravates the porosity of building materials, crystallises and leads to the destruction of the stone, which leads to gradual subsidence of the mausoleum and deformation of the walls (Murray et al., 2020; Parfenov et al., 2019; Nurzhanov, 2020). The composition of the waters in the wells of the Yasawi Mausoleum is shown in Tables 3–5.

As the water depth increases, pumping water from lower depths will require more energy, the amount of which is directly related to the amount of overdraft from the aquifer and the drop in water level. In this study, based on calculations performed due to declining groundwater levels, the amount of energy consumption to extract groundwater from all aquifers in the area, over a period of five years, is close to 100,000 megajoules (equivalent to 1,160,000 kilowatt hours of electricity). This amount of energy consumption, in addition to energy loss and environmental detrimental effects, is to provide water of lower quality and nitrate, which is not very suitable for agricultural use. In groundwater-dependent areas, the risk of depletion of aquifers and catastrophe will increase if water resources are reduced and prolonged droughts. In aquifers with high reserves, in case of drought and reduction of aquifer nutrition, it is possible to spend the drought period without harming the agriculture of the region by using the available water reserves. It is obvious that during the wet season, the extra harvest during the drought can be compensated. Therefore, the richer the aquifer, the better it will withstand the effects of drought.

Table 3 Composition of the wells of the Yasawi Mausoleum (the inner well of the mausoleum, depth 3–5 m)

No.	*Analysis name*	*Content of components in water*	*Method sensitivity*	*LOC*
1	Chromaticity in degrees	2.3	-	30
2	Turbidity, FTU/dm³	5.6	-	2.6–3.5
3	Smell, taste, score	0	-	2–3
4	pH	8	0.2	6.5–9.0
5	Dry residue, mg/dm³	1,230.0	1.0	1,000–1,500
6	Permanganate value, mg·O/dm³	3.64	0.01	4.0
7	Total hardness, mole/dm³	9.7	0.05	7.0
8	Carbonates, mg/dm³	Traces	0.1	6.5
9	Hydrocarbonates, mg·eq/dm³	0.8	0.1	6.5
10	Calcium, mg/dm³	159.8	0.4	180.0
11	Ammonium and ammonia ions, mg/dm³	0.4	0.05	2.0
12	Nitrites, mg/dm³	0.04	0.01	3.0
13	Nitrates, mg/dm³	4.9	0.1	45.0
14	Iron, mg/dm³	0.3	0.01	0.3
15	Fluorides, mg/dm³	0.3	0.02	1.2
16	Chlorides, mg/dm³	62.3	1.0	350.0
17	Sulphates, mg/dm³	50.0	1.0	500.0
18	Manganese, mg/dm³	0.02	0.01	0.1

Table 4 Composition of the wells of the Yasawi Mausoleum (water from the well in the courtyard of the mausoleum, depth 7–10 m)

No.	*Analysis name*	*Content of components in water*	*Method sensitivity*	*LOC*
1	Chromaticity in degrees	3.7	-	≤ 30
2	Turbidity, FTU/dm³	17.7	-	2.6–3.5
3	Smell, taste, score	1	-	≤ 2–3
4	pH	8	0.2	6.5–9.0
5	Dry residue, mg/dm3	2,880.0	1.0	1,000–1,500
6	Permanganate value, mg·O/dm³	2.7	0.01	4.0
7	Total hardness, mole/dm³	27.0	0.05	7.0
8	Carbonates, mg/dm³	Traces	0.1	6.5
9	Hydrocarbonates, mg·eq/dm³	1.4	0.1	6.5
10	Ammonium and ammonia ions, mg/dm³	0.8	0.05	2.0
11	Nitrites, mg/dm³	2.3	0.01	3.0
12	Nitrates, mg/dm³	29.3	0.1	45.0
13	Iron, mg/dm³	1.3	0.01	0.3
14	Fluorides, mg/dm³	1.0	0.02	1.2
15	Sulphates, mg/dm³	1,360.0	1.0	500.0

Table 5 Chemical composition of the water in the well of the Zhuma mosque

Samples	*kmg/l*	*pH*	*Indicators of chemical composition, mg/dm³*								
			CO_3^{2-}	HCO_{3^-}	Ca^{2+}	Mg^{2+}	Cl-	SO_4^{2-}	NO_{3^-}	NO_{2^-}	NH_4^+
Zhuma mosque	1,199.0	6.9	-	3.3	173.4	-	58.24	514.8	12.83	0.018	-

Artificial aquifer nutrition and prevention of contamination at groundwater values are among the measures that can help protect groundwater aquifers. Using surface water distribution methods, using natural pits for water infiltration, using feeding ponds, increasing the natural infiltration of water in the riverbeds and canals, injecting water into the aquifer by injection wells and creating trenches horizontally on the ground, artificial feeding can be done.

4 Conclusions

The system proposed in the current research is an efficient, inexpensive IoT application for online water quality and quantity monitoring. The results obtained from a real conditions wireless sensor network monitoring of the wells in Arystan Bab and Khoja Ahmed Yasawi, indicated that the developed system provides monitoring the level, quality and management of wastewater quality parameters. In the course of the research work, a comprehensive monitoring method was applied, the level of influence of natural and anthropogenic factors representing a particular environmental hazard was assessed:

1 High salinity of groundwater was revealed on the territory of the Arystan Bab Mausoleum.

2 In four wells of the Arystan Bab Mausoleum, except for well no. 1, *E. coli* bacteria were found in the water.

3 Based on the analysis of the chemical composition of the well water of the architectural complex of Kh.A. Yasawi, it was established that the waters under consideration are sufficiently saline.

4 The observed salinisation of groundwater can have a significant negative impact on the state of monuments. Moisture containing salts, due to capillary lift and evaporation, saturates the pores of building materials, crystallising destroys the structure, i.e., destruction of the foundations occurs, and this leads to a gradual settlement, deforming the walls. This factor is subject to further research in order to take concrete measures to increase the resistance of the building materials of the mausoleums.

5 Recommendations

- In order to reduce or eliminate the adverse impact of groundwater located near the ground surface on the mausoleums of Arystan Bab and Khoja Ahmed Yasawi, it is necessary to restore and put into operation waste drainage systems to reduce their level.

- Based on the ecological state of soils and plants, it is necessary to provide technical conditions that prevent the lift of groundwater since they are associated with groundwater.
- In order to use the waters of wells belonging to the mausoleums of Arystan Bab and Khoja Ahmed Yasawi, as well as to reduce their impact on monuments, it is necessary to organise inter-well drainage.
- In accordance with the requirements of the Environmental Code of the Republic of Kazakhstan, environmental monitoring, regardless of the form of ownership, should be carried out on an ongoing basis. In this regard, it is necessary to carry out comprehensive studies of the mausoleums of Arystan Bab and Khoja Ahmed Yasawi.
- For a better and aesthetic perception of the architectural, historical, and cultural heritage, landscaping, and restoration of the protected zone should be carried out.

Existing complex ecological anthropogenic factors have a negative impact on the natural environment and the state of monuments of cultural architecture. Using complex research methods, it is possible to comprehensively determine the overall ecological state of architectural monuments. The research work of the authors was carried out using visual (photographic recording), chemical, physical, physicochemical and other methods.

Based on the results of the study, it was established that the assessment of the state of ground water of the architectural complexes of Khoja Ahmed Yasawi and Arystan Bab is possible only by the method of integrated monitoring, which makes it possible to develop methods for monitoring and regulating the state of the environment related to architectural complexes. The mechanisms and ways of the impact of natural-climatic and anthropogenic environmental factors on the state of monuments are very complex and the need for continuous systemic ecological research to create favourable conditions for the preservation of mausoleums is obvious.

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