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Pre-Sowing Treatment of Hawthorn Seeds

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Abstract

The genus hawthorn has a huge number of species and due to this diversity, pronounced polymorphism within the species is manifested. One of the most important indicators of the qualitative development of plants is its ability to reproduce - fruiting. For seed germination, various methods of pre-sowing treatment were tested: soaking, treatment with concentrated sulfuric acid, hydrothermal treatment, scarification, seed crushing, radiography. The studies made it possible to establish the most acceptable methods. The results of radiography and crushing were almost identical, the maximum number of the studied species have viable and good-quality seeds, and both crushing and radiography revealed larvae in the seeds of the European and Central Asian species, which had a negative effect on soil germination. Treatment of hawthorn seed covers with sulfuric acid gives good results, and hydrothermal treatment, especially at high exposures, is not always acceptable for hawthorn seeds, especially for species with small seeds. Positive results were obtained from seeds extracted from fruits that had not reached morphological ripeness. The aim of the research is to determine the soil germination of hawthorn seeds.

Keywords: hawthorn, seed quality, seed radiography, soil germination of seeds, pre-sowing seed treatment, scarification.

1. Introduction

The genus *Crataegus L.* belongs to the subfamily Maloideae Focke of the rose family Rosaceae Juss. The Latin name Crataegus comes from the words χραταιγος or χραταιγών: χρατος - strength, strength, firmness; αγειν - to lead, to act. «A tree with viscous, hard wood and strongly developed thorns» (Theophrastus, 1951). C.Linnaeus (1753) used the genus name *Crataegus L.* to designate the hawthorn species known at that time - 3 species of Sorbus and a species of Raphioleris.

There are over 80 wild and 90 introduced species growing in the CIS (Solovieva and Kotelova, 1986; Izembaeva et al., 2024). In the Baltics, R.E. Tsinovskis (1971). was the first to discover and describe 12 species, 1 variation and 4 forms of hawthorn that are new to botanical science. Cultivation continues everywhere and, consequently, the species composition is expanding.

There are 7 wild species growing in Kazakhstan: *C. almatensis A. Pojark., C. pontica A. Koch, C. turkestanica A. Pojark., C. sanguinea Pall., C. altaica* Lge., *C. transkaspica A. Pojark., C. songarica Koch. In the culture 4 species: C. maximowiczii Schneid., C. rotundifolia Moench, C. punctata Jaeg., C. submollis Sarg*. Hawthorn is widespread in the mountains of the Northern Tien Shan: Zailiysky, Dzhungarsky and Kungey Alatau. The peculiarity of the forests of the Northern Tien Shan is the presence of fruit tree plantations in them. They are located in a strip of 3-4 km along the lower parts of the slopes and in the foothills at an altitude of 800 to 1500 m. It is here among the fruit trees that some species of hawthorn grow - *C. almatensis Pojark., C. sanguinea Pall., C. turkestanica Pojark., C. altaica Lge, C. songarica C. Koch.* are also found. On the north-eastern and north-western slopes (5-100), apple-hawthorn, aspen-apple-hawthorn forests are formed. On the northern slopes, hawthorn is confined to deep and medium-deep leached mountain chernozems or mountain forest dark gray soils. On the southern slopes, *C. songarica C. Koch* is found. In the mountains of the Western Tien Shan, the hawthorn forest is located mainly on the eastern and western slopes with a steepness of up to 15-300, at an altitude of 800 to 1200 m above sea level (Kentbayeva et.al., 2022).

Numerous species of the genus Crataegus L. can be a vital source of raw materials used for medicinal and food purposes. Hawthorn berries contain vitamins, a number of organic acids, sugars, carotene, pectin and tannins, sorbitol, choline, and quercetin. Adenine, adenosine, guanine aminopurine, choline, and other substances have been found in medicinal raw materials (Izembaeva et al., 2024).

The range of arboretums of Kazakhstan includes up to 40-50 species of hawthorn. Due to its decorative properties, hawthorn is found in landscaping; in particular, according to our observations, at least 20 species grow in the city plantings of Almaty (Kentbayeva et.al., 2022).

2. Materials and Methods

The object of the study were different species of even-aged hawthorn growing on the same leveled agro- and eco-background in the arboretum of the Issyk State Dendrological Park: Central Asian species: *C. almaatensis* Pojark., *C. altaica* Lge., *C. sanguinea Pall*., *C. songarica* C. Koch; Far Eastern species: *C. schneideri* Cin., *C. maximowiczii* Schneid., *C. chlorosarca* Maxim., *C. dahurica* Koehne; Baltic species: *C. kupfferi* Cin., *C. curvisepala* Lindm., *C. insularis* Cin.; European species: *C. calicina* Peterm., *C. nigra* W.et.K., *C. volgensis* Pojark.; North American species: *C. douglasii* Lindl., *C. rivularis* Nutt., *C. calpodendron* Medic., *C. flabellate* C. Koch. In the arboretum of the Issyk State Dendrological Park, introduction activities began in 1959, where 50 local and introduced species of hawthorn currently grow (Kentbayeva et.al., 2022).

It is known that hawthorn reproduces vegetatively and by seeds. The objective of our research was to determine the best and most acceptable method of propagating hawthorns for production conditions. Widespread cultivation of hawthorns is unthinkable without data on the sowing qualities of seeds. Despite the fact that hawthorns are being introduced into culture, the quality of seeds of local and introduced species has not been sufficiently studied. Hawthorn seeds have a very hard shell, which prevents their rapid germination. To determine the optimal conditions for germination, various methods of pre-sowing seed treatment were tested. Seeds were sown in open ground on beds up to 1 m wide and up to 3 m long, sowing rows were located across the beds at a distance of 15 cm from each other, 100 seeds were sown in one row, seeds of one species were sown in 5 rows. The experiments were repeated three times.

The state standard was used to determine the mass of 1000 seeds. Experiments were conducted to determine the quality of seeds according to GOST 13056.8-68 (1977).

To determine the quality of hawthorn seeds, we developed a crushing method. Crushing was carried out until cracks appeared on the seed coat, while the embryos should not be damaged. This method involves minimal costs, is distinguished by its efficiency and low labor intensity of the process.

The X-ray method was used to determine the quality of seeds, which provides a complete description of the viability, features of internal development and structure of seeds. The analysis period is reduced to 1 day. For the experiments, 100 seeds of each variant were taken in 3-fold repetition. X-ray of seeds was performed on a REIS-D emitter with a BSI microfocus X-ray tube, which meets the radiation safety requirements: «Basic Sanitary Rules with Radioactive Substances and Other Sources of Ionizing Radiation» (OSP-72/87); «Radiation Safety Standards» (NRB-76/87). When decoding the negatives, the relevant methodological guidelines were used (Naumenko and Deryuzhkin, 1972).

3. Results and Discussion

Hawthorn is propagated by sowing seeds, root shoots, layering, grafting, and cuttings. In culture, the predominant method of propagation is seed. The seed coat of hawthorns is a stony pericarp that delays seed germination. Some species are subject to parthenocarpy (the formation of seeds without an embryo), as a result of which few shoots are formed (Solovieva and Kotelova, 1986).

Seed propagation of plants mainly depends on the quality of seeds. In scientific works of the USSR countries, such data are found for a small number of species. In foreign literature, there are very few reports on the quality of hawthorn seeds and such information is found episodic. Many scientists have studied deep dormancy and determined effective methods of pre-sowing seed preparation. For more successful germination of seeds, there are various methods of pre-sowing treatment: washing the seeds in running water, treatment with concentrated sulfuric acid, air-thermal treatment, scarification, stratification (Solovieva & Kotelova, 1986; Kentbayeva et.al., 2022).

Hawthorn seeds have a long seed dormancy, so seeds from fruits collected before their morphological ripeness germinate faster. Many researchers have conducted experiments on the germination of hawthorn seeds, but the overwhelming majority used seeds from a small number of species. To determine the quality of hawthorn seeds, which have a hard seed coat and a long germination period, the most acceptable methods were crushing and X-ray.

According to our research, the X-ray method basically confirmed the results obtained by crushing the seeds and revealed that the overwhelming majority of species have viable seeds - 44.5%, 22.2% of samples have an average indicator and 33.3% have a low level of good quality. As studies have shown, the highest percentage of good-quality seeds is produced by the species of Baltic origin *C. insularis sp. nov.* (92.0%), the minimum of full-grained seeds is in *C. chlorosarca Maxim.* (16.3%) from the Far East, the amplitude of fluctuation is very high 75.7% (Table 1).

Table 1. *Determination of the quality of hawthorn seeds*

№	Species name	X-ray, %	Crushing, %	Weight of 1000 seeds, g	Average values, M ± m, g
1	*C. almaatensis* Pojark.	82.0	82.7	74.7	0.07 ± 0.001
2	*C. altaica* Lge.	29.0	28.3	45.2	0.05 ± 0.001
3	*C. flabellate* C. Koch	27.0	28.0	49,7	0.05 ± 0.002
4	*C. volgensis* Pojark.	44.7	43.7	83.8	0.08 ± 0.003
5	*C. calpodendron* Medic.	30.3	29.3	55.1	0.06 ± 0.002
6	*C. dahurica* Koehne	88.0	86.0	56.2	0.06 ± 0.002
7	*C. Douglasii* Lindl.	35.3	34.0	27.7	0.03 ± 0.001
8	*C. chlorosarca* Maxim	16.3	16.3	23.5	0.02 ± 0.001
9	*C. curvisepala* Lindm.	86.0	87.0	136.0	0.14 ± 0.003
10	*C. sanguinea* Pall.	32.3	33.7	100.4	0.10 ± 0.004
11	*C.Kupfferi* sp. nov.	43.0	40.7	61.3	0.06± 0.002
12	*C. Maximowiczii*	53.0	52.0	34.6	0.03 ± 0.001
13	*C. insularis* sp. nov.	92.0	91.3	97.1	0.10 ± 0.004
14	*C. rivularis* Nutt.	25.7	24.7	40.4	0.04 ± 0.002
15	*C. songarica* C. Koch	57.3	59.3	70.3	0.07 ± 0.003
16	*C. calicina* Peterm.	22.3	23.0	115.4	0.12 ± 0.004
17	*C. nigra* W.et.K.	70.3	68.7	36.4	0.04 ± 0.001
18	*C. Schneideri* nom. nov.	80.7	81.3	18.4	0.02 ± 0.001
					HCP_{05} - 0.01

Depending on the origin, X-ray analysis showed that the best were the hawthorn species from the Baltic States: *C. curvisepala* Lindm., *C. insularis* sp. nov. - 86.0 and 92.0%, respectively, *C. Kupfferi* sp. nov. - 43.0% of high-quality embryos. The seeds of these samples are large, for example, *C. curvi-sepala* Lindm. has the largest seeds and is the leader among the studied species, the weight of 1000 seeds are 136.0 g. European species are in different groups, the percentage of viable seeds varies within the following limits 22.3 - 70.3%. Hawthorn seeds are large, the weight of 1000 pcs is 83.8 g for *C. volgensis* Pojark., 115.4 g - *C. calicina* Peterm., the exception is *C. nigra* W.et.K. with small seeds, but at the same time having a high percentage of good quality ones.

Local species have good seed quality indicators. For example, *C. almaatensis* Pojark. has the highest percentage of quality seeds among local species - 82.0%, with an average weight of 1000 pcs of 74.7 g. It should be especially noted that crushing and X-ray examination revealed larvae in the seeds of *C. songarica* C. Koch and *C. calicina* Peterm., which naturally affected both germination and quality. In accordance with the dispersion analysis conducted on seed weight, one can conclude that the heredity of the trait is genotypically determined.

The predominant method of propagating hawthorn in culture is seed, which is difficult due to the deep dormancy of seeds. As a result, we tested various types of pre-sowing seed treatment: hydrothermal treatment (HT), with sulfuric acid in different exposures, scarification, stratification, soaking in water for 24 hours, dry seeds served as a control.

It is well known that in fruits that have not reached morphological maturity, but already with physiological maturity of seed embryos, seed dormancy may be reduced under certain circumstances. In this case, we tested seeds of 5 hawthorn species that had not reached morphological maturity. The seeds of the studied species were sown in open ground conditions in the first ten days of August, the first shoots appeared in March, mass shoots - in April. The ground germination of seeds with different types of treatment is presented in Table 2.

Table 2. *Soil germination of hawthorn seeds, %*

№	Types of seed treatment	Species names				
		C. almaatensis Pojark.	*C. sanguinea* Pall.	*C. dahurica* Koehne	*C. Douglasii* Lindl.	*C. Maximowiczii*
1	HT - 5 sec.	3	2	2	1	1
2	HT - 10 sec.	1	1	0	0	0
3	HT - 15 sec.	0	0	0	0	0
4	HT - 30 sec.	0	0	0	0	0
5	H_2SO_4- 5 min.	44	14	64	51	53
6	H_2SO_4- 10 min.	52	5	83	48	64
7	H_2SO_4- 20 min.	76	24	79	38	57
8	H_2SO_4- 30 min.	68	19	57	31	54
9	H_2SO_4- 60 min.	64	10	41	19	32
10	Scarification	29	5	24	12	16
11	Water, (24 h.)	17	3	24	16	14
12	Dry seeds (control)	14	3	21	14	12

When testing hydrothermal treatment at different exposures, the results in the overwhelming majority of cases were zero; only with 5 and 10 second treatment was a small percentage of seedlings noted in some species.

Hydrothermal treatment had a particularly strong effect on hawthorn species with small seeds, the pericarp thickness of which is somewhat thinner. Even short-term exposure to high water temperatures had a detrimental effect on the embryos.

Scarification of immature seeds also showed low soil germination within 3 - 24%. It is possible that seeds with damaged pericarp spoil and are damaged by insects if left in the soil for a sufficient period of time.

Seed treatment with 96% sulfuric acid showed quite good results in all cases. The best conditions are 20- and 30-minute exposures, seed soil germination is within 24-79% and 19-68%, respectively. For example, the Far Eastern species *C. dahurica* Koehne has fairly stable results at all exposures to sulfuric acid, with germination slightly decreasing only after 60 minutes of exposure. *C. Douglasii* Lindl. reduces germination rates with increasing exposure time, which is explained by small seeds and thinner pericarp. Soil germination of local species varies widely. If *C. almaatensis* Pojark. has the most optimal results for all tested treatments, then *C. sanguinea* Pall. has low germination not only against the background of local species, but also against all studied species.

Soaking in water did not have a significant effect on the soil germination of seeds of various hawthorn species. The control variant (dry seeds) is at the level of 8 - 28%. Dry hawthorn seeds germinate mainly after 1.5 - 2 years. In this case, the early emergence of shoots was influenced by sowing seeds extracted from morphologically immature fruits.

4. Conclusion

The conducted studies allowed to establish the most acceptable methods of pre-sowing seed treatment. Thus, with the X-ray method, a complete characteristic of the viability of 18 studied species, features of internal development and structure of seeds was obtained. The results of X-ray and crushing were almost identical, the maximum number of the studied species have viable and good-quality seeds, and both crushing and X-ray revealed larvae in the seeds of *C. songarica C. Koch* and *C. calicina* Peterm., which naturally affected the soil germination. The species of Baltic origin *C. insularis* sp. nov. showed high results of soil germination (92.0%), and the minimum indicators were in hawthorns from the Far East.

Treatment of hawthorn seed coats with 96% sulfuric acid in all cases revealed quite good results, especially at 20- and 30-minute exposures. Hydrothermal treatment at high exposures is not acceptable for hawthorn seeds, especially for species with small seeds. During scarification, seeds with damaged pericarp spoil and are damaged by insects when left in the soil for a sufficient period of time, resulting in low seed germination. Positive results in the form of early and uniform emergence of shoots were obtained from seeds extracted from fruits that had not reached morphological ripeness, which is also confirmed by studies by Belarusian scientists when testing 14 species of hawthorn. Our research results are consistent with the data of foreign authors who studied pre-sowing treatment of hawthorn seeds (Gokturk and Yilmaz, 2015; Gokturk et.al., 2017; Ertekin, M., 2017; Mukhametova and Mukhortov, 2018).

Thus, for determining the quality of hawthorn seeds, which have a hard seed coat and a long germination period, the most acceptable methods were crushing and X-ray. In accordance with the dispersion analysis conducted on the weight of seeds, it is possible to conclude about the genotypically determined heredity of the trait.

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Water Resources of Azerbaijan: Their Quality Status and Utilization Features

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Abstract:

The presented article studies the possible causes for the mass death of red-necked grebes *(Podiceps grisegena)* near the village of Istisu (Khachmaz dist., Azerbaijan), while exploring the connections with the ecological state of water resources. The principal origins of anthropogenic pollution were identified grounded in an analysis of Azerbaijan’s hydrological network, the condition of transboundary rivers, and the water quality of the Caspian Sea. The main sources include heavy metals, petroleum products, and organic compounds. Hydro chemical analysis exposed the facts about threatening pollution of the Caspian Sea, which results in bird poisoning and ecosystem disruption.The water parameters of the Oguz-Gabala-Baku water supply system were explored to conduct comparison on this issue. According to the investigation, they comply with hygiene standards and displayed a high level of environmental safety. This comparative analysis underlines the contrast between polluted transboundary water systems and better-controlled water sources, highlighting the need to strengthen environmental monitoring, promote international cooperation, as well as present modern water purification technologies. The results are of practical importance for the development of strategies to preserve biodiversity and prevent environmental disasters in the Caspian region.The article also includes a comparative study of the hydrochemical indicators of mountain rivers in northern Azerbaijan (using the example of the Gudyalchay/Gusarchay rivers) and natural «Shollar» water, as well as a discussion of how river flow influences the quality of coastal waters in the Caspian Sea. The results of field and bibliographic studies on the hydrochemistry of the region, the official technical characteristics of «Shollar» water, and reports and overviews on the ecological status of the Caspian Sea were used.

Keywords: water resources, transboundary rivers, heavy metal contamination, petroleum-derived pollutants, environmental monitoring, biodiversity conservation, aquatic pollution, mass avian mortality.

1. Introduction

Azerbaijan's river network comprises 8,359 (Ministry of Ecology and Natural Resources of Azerbaijan, n.d.) rivers, most of which are small rivers of local importance. Of these, only the two largest rivers, the Kura and the Araz, are longer than 500 kilometers and form the basis of the country's river system. It should be noted that Azerbaijan has 22 rivers between 101 and 500 kilometers long, 40 rivers between 51 and 100 kilometers long, and 107 rivers between 26 and 50 kilometers long. This structure shows that there are many small and medium-sized rivers in the country. They are important for local ecosystems and agriculture, but have little impact on the country's overall water balance. Most rivers are concentrated in the Kura River basin, which has 5,141 rivers, and the Araz River basin, which has 1,177 rivers. A total of 3,218 rivers and their tributaries flow into the Caspian Sea, making it the most important collection point and final destination of the country's water cycle. The average density of the river network is 0.36 km/km², which is relatively low compared to the mountainous countries in the region, where river density is higher due to the wetter climate and complex relief.

The 21 transboundary rivers are of particular importance to the country's hydrographic structure. The most important of these are the Kura, Araz, Ganykhchay, Gabirichay, Samurchay and Astarachay. These rivers account for the majority of the republic's water resources. However, due to their transboundary nature, water use in Azerbaijan depends on the environmental policies and economic activities of neighbouring countries. This condition attaches great importance, thus any change in water consumption or water quality outside Azerbaijan directly affects state of the country's internal ecosystems and socio-economic situation.

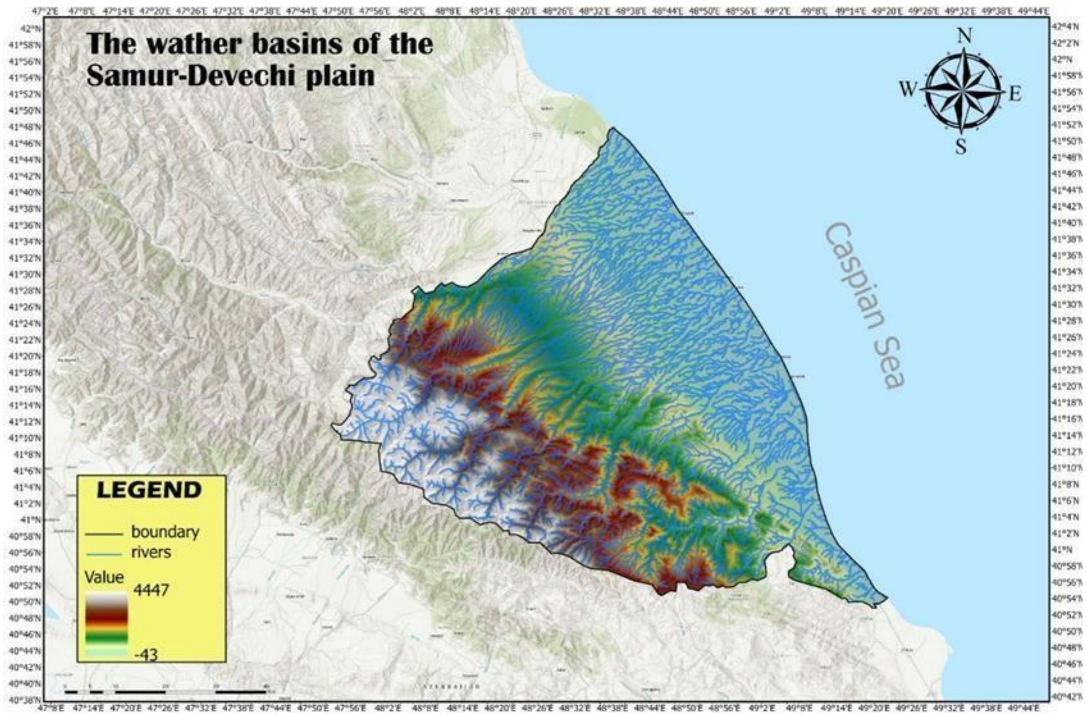

Figure 1. *Map of the watersheds of the Samur–Devechi Lowland, illustrating the hydrographic network and regional relief based on digital elevation model (DEM) data.*

The map shows the hydrographic network and relief of the Samur-Devechi plain in north-eastern Azerbaijan, along the coast of the Caspian Sea. It indicates the main watersheds and watercourses that constitute the region's surface runoff. The colour scale illustrates the differences in altitude, from the low-lying coastal areas (−43 m) to the mountainous regions in the south-west (up to 4447 m). The black line marks the boundaries of the watershed under study. The map was compiled using data from a digital terrain model (DTM) and shows the direction of watercourses and the distribution of river networks that determine the hydrological regime and ecological status of the Samur-Devechi plain.

Water status monitoring is carried out by the National Department of Hydrometeorology, which conducts stationary observations of the hydrological regime of rivers, lakes and reservoirs. There are currently 59 hydrological measuring stations in the republic, where water level, temperature, flow velocity, discharge and other important characteristics are systematically recorded. Historically, the first regular water level measuring stations were established on the Kura River at the end of the 19th century, which indicates a long tradition of investigating water resources and appreciating their significance. Gradually developing of water level network resulted in being an important tool for evaluating the dynamics of the hydrological regime and exploring the effects of human activities.

The water resources in Azerbaijan are limited, which account for only about 15% of the total water volume in the South Caucasus. Compared to its neighboring states, Azerbaijan has the lowest water supply per capita, with a total water potential of 310 billion m³ (United Nations Framework Convention on Climate Change, 2012) for the region. The total water balance of the country accounts for 30.9 billion m³, of which only 33% comes from inland waters, while 66% from transboundary rivers. This distribution sample underlines the republic's high exposure to external factors. The Kura and Araz rivers, which are the country's most important water sources, are heavily underwent to pollution in neighboring states. Industrial and agricultural wastewater containing heavy metals, pesticides, and organic compounds contaminate these water sources, leading to a deterioration in water quality and reduced suitability for drinking water and domestic use.

Rivers with a total volume from 28.5 to 30.5 km³ contain most of surface water. However, the indicated figure is prone to significant annual fluctuations. During periods of drought, the volume of surface water decreases to between 22.6 and 27.0 km³. This decline is not only due to natural causes, but also to intensive water use outside the country. The Kura and Araz rivers lose up to 20% of their water volume due to intensive water use in neighboring countries. For Azerbaijan, this means an annual water deficit of around 4 to 5 km³, which makes it really hard to supply water to the population.

The rivers of northern Azerbaijan, whose sources are in the foothills and mountains of the Greater Caucasus, contribute significantly to the hydrological regime of the Caspian Sea coastal zone. The nature and volume of river flow determine the supply of fresh water, dissolved minerals and potential pollutants to coastal ecosystems. Due to increasing anthropogenic pressure (agricultural, domestic and industrial wastewater), the potential role of these rivers in transporting pollutants to the Caspian Sea is increasing, requiring a comprehensive hydrochemical assessment (Gauthier & Reynolds, 2014; Rattner et al., 2008).

In recent decades, the situation has been further exacerbated by climate change, with an increase in average annual temperatures, and a decrease in precipitation and a stretching of drought periods. This dangerous tendency leads to a further reduction in water resources and disruption of seasonal flow patterns in rivers. As reported by the hydrological monitoring data, local stream flows decreased by 5.0 to 21.2% between 1991 and 2023, while the flow of transboundary streams reduced by 9.1 to 21%. This decline reveals a situation on deterioration of water resources because of a combination of natural and anthropogenic factors, which directly affects not only the ecological status of aquatic ecosystems, but also on the country's economy.

Complex regulatory measures are required, since Azerbaijan's water resources endure severe pressure. Although there are a lot of rivers in the territory of the country, most of them are small and cannot fully meet the population's water needs. At present, large transboundary waters depend on water supplies from neighboring countries. Pollution driven by industry and agriculture, including climate change, are aggravating the problem on water shortages and degrade water quality. Besides rivers, lakes and reservoirs also take an important part in Azerbaijan's complex hydrological system. 450 natural lakes in the territory of the republic cover a total area of about 394 km² in the country. The Lake Sarisu (the largest lake in the county-65.7 km²), contributes significantly to the surface runoff regulation and provides habitat for many waterbirds. Other crucial water systems, such as Lakes Agol, Beykshour, and Masanli, also play a vital role in managing ecosystems and climate, affecting the humidity and microclimates of neighboring regions.
Artificial reservoirs play irreplaceable role in the management of modern water resources in Azerbaijan. 136 reservoirs in the country with a total capacity of about 21,464 million cubic meters, are necessary for supplying water to the economy, households, agriculture, and energy, and also help regulate seasonal water consumption.

The Mingachevir, Jeyranbatan, Takhtakopru, Shamkirchay, Khanbulanchay and Vilajchay reservoirs, do not only provide water for human consumption and irrigation, but also constitutes the main components of the country's hydroelectric system.

In addition to their economic importance, these water bodies also fulfil ecosystem functions: they regulate groundwater levels, prevent soil salinisation and create favourable conditions for the formation of local biotopes. In recent decades, however, the influence of anthropogenic factors on water quality has increased, particularly the discharge of industrial and agricultural wastewater and transboundary pollution. The aim of this study is to compare the main hydrochemical parameters of the rivers flowing into the Caspian Sea, identify the differences between them and highlight the possible mechanisms of pollutant transport to coastal waters. Analysis of these processes makes it possible to assess the extent of anthropogenic impacts, identify ecological risks and propose measures to improve the state of aquatic ecosystems in the Caspian Sea coastal zone.

2. Materials and methods

A pathological examination of dead birds in the Caspian Sea region was carried out. The water quality of the Caspian Sea in the area around the village of Istisu was also analysed. The basic data used are the results of a comprehensive hydrochemical study of the Gudyalchay River (samples and analyses, published in Mammadova et al., 2024) (Rattner et al., 2008) and the technical characteristics of « Shollar» spring/bottled water (manufacturer's descriptions and regional documents on water sampling) (Thompson & Spurgeon, 2012). The comparison was made on the basis of the following key parameters: pH, total mineralisation (TDS), Ca^{2+}, Mg^{2+}, Na^{+}, HCO_3^-, SO_4^{2-}, Cl^- and NO_3^-. Additional information on the state of the coastal waters of the Caspian Sea was taken from reports and review articles (Gauthier & Reynolds, 2014; Ministry of Ecology and Natural Resources of Azerbaijan, n.d.).

3. Results and discussions

The ecological situation in the Republic is determined less by the quantity of water resources than by their quality. Over the last few decades, anthropogenic pollution of surface and groundwater has increased. The state of the Caspian Sea, into which most of the river water flows, is particularly worrying. The waters of the Kura and Araz rivers carry significant amounts of pollutants: hydrocarbons, heavy metals, nitrates and phosphates. Their accumulation leads to eutrophication of coastal areas, a decrease in oxygen content and the death of fish and water birds.

A significant indicator of these processes was the mass death of red-necked grebe (*Podiceps grisegena*) near the village of Istisu, in the Khachmaz district of Azerbaijan (Fig. 1). This aquatic bird, which lives in fresh and brackish waters, plays a key role in ecosystems by helping to regulate fish, invertebrate and plant populations. Besides, great crested grebe is also an indicator of water quality, as its population ratio and health are directly dependent on the water purity.

***Figure 2**. Carcasses of red-necked grebe (Podiceps grisegena) found on the shore of the Caspian Sea on January 1, 2025*

On January 1, 2025, several dead birds were detected in the Caspian region, leading to great concern among conservationists, since such cases lay down the marker of serious habitat disturbances. Conducted pathological examinations unveiled that there were no signs of contagious disease, rejecting viral and bacterial causes (Fig. 2). Nevertheless, characteristic poisoning lesions were discovered in the livers of the dead birds. During the laboratory analyses it was confirmed that heavy metals (lead, cadmium, and mercury) caused mass bird die-offs. Such elements are accumulated in ecosystems through water and the food chain, leading to devastating effects on species and ecosystems as a whole.

Figure 3. *Dissection of a red-necked grebe (Podiceps grisegena)*

The mass death of red-necked grebes observed in Istisu region of Azerbaijan, is not just an indicator of local tragedy, but also indicates about widespread environmental threat. This fact explicitly proves that anthropogenic pollution of transboundary rivers and the Caspian Sea has a direct negative impact on ecosystem stability and biodiversity. Though the Caspian Sea is exposed to petrochemical and industrial pollution, inland water bodies such as the Gabala-Oguz Canal suffer from pesticides. When these two examples are compared, it becomes clear that, while the sources of pollution differ, the result is the same: deterioration of water quality, decreased sustainability of aquatic communities, and the death of organisms, which are signs of ecosystem health.

As a consequence, the mass death of organisms underlines the necessity of systematic monitoring and comprehensive measures to reestablish aquatic ecosystems. Environmental protection measures and sensible use of water resources will help avoid further ecological disasters and protect biodiversity in both the Caspian Sea and the country's inland water sources.

4. Research methodology

Experts attended the field and laboratory studies, which were conducted in January 2025 at a veterinary clinic. The carcasses of red-necked grebe (*Podiceps grisegena*) found in the coastal area of the Caspian Sea, near the village of Istisu, were used as material for analysis. The collection and transport of biological material was carried out in accordance with veterinary and sanitary requirements and methodological guidelines approved by the Food Safety Agency of the Republic of Azerbaijan (AQTA) and the Ministry of Agriculture of Azerbaijan. Each specimen was placed in an individual sterile container and transported to the laboratory no later than 6 hours after discovery.

5. Pathological examination

The autopsy of the birds was performed in a specially equipped room, in compliance with biosafety and disinfection rules. The examination was carried out according to the standard veterinary protocol: an external examination was performed, and body weight, plumage, skin and mucous membrane condition were assessed. Then, the thoracic and abdominal cavities were opened one after the other. Particular attention was paid to the condition of the internal organs, especially the liver, kidneys and lungs. Morphological changes were recorded: liver hypertrophy, changes in tissue colour and consistency.

6. Microscopic analysis

Microscopy was performed using a Leica DM500 optical microscope equipped with an ICC50 W digital camera. Examinations were performed at magnifications of ×40, ×100 and ×400. Morphological changes were recorded by microphotography and then by digital image processing. Signs of dystrophy, necrosis and degenerative changes in liver and kidney cells were analysed.

Analyses of the water quality of the Caspian Sea near the village of Istisu in January 2025 revealed the presence of a range of pollutants. The average dissolved oxygen content was 4.8 mg/l, which is at the lower end of the normal range and represents a risk of oxygen deficiency for aquatic organisms. The ammonium content (0.15 mg/l) indicates organic pollution, and the nitrate values (0.45 mg/l) are close to the upper limit. Phosphate concentrations (0.025 mg/l) are low, but already pose a risk of eutrophication. Petroleum products (0.18 mg/l, above the permitted limit) and sulphur compounds (H_2S 0.6-1.2 mg/l), which can cause mass mortality of aquatic organisms, are of particular concern. All this confirms the strong anthropogenic influence linked to both transboundary flows and local sources of pollution (Table 1).

Table 1. *Caspian Sea Water Quality (January 2025)*

Parameter	***Average Value***	***Standard / Comment***
Temperature (°C)	*18-20*	*Seasonal fluctuations*
Salinity (‰)	*12.5*	*Moderately saline water*
pH	*8.2*	*Neutral to slightly alkaline*
Transparency (m)	*4-6*	*Decrease in silted areas*
Dissolved Oxygen (mg/L)	*4.8*	*Low level, risk of hypoxia*
Ammonium (mg/L)	*0.15*	*Indicator of organic pollution*
Nitrates (mg/L)	*0.45*	*Near the upper limit*
Phosphates (mg/L)	*0.025*	*Risk of eutrophication*
Petroleum Hydrocarbons (mg/L)	*0.18*	*Exceeding, biologically hazardous*
Iron(mg/L)	*0.08*	*Within permissible limits*
Hydrogen Sulfide (mg/L)	*0.6-1.2*	*Critically high level*

In this context, the mass death of red-necked grebe (*Podiceps grisegena*) in the vicinity of Istisu seems to be a logical consequence. Birds, which are at the top of the food chain, accumulate toxins present in water and food. Pathological examinations have shown that the cause of death was heavy metal poisoning from wastewater and industrial waste entering the water.

In order to compare the state of the Caspian Sea, an analysis of water from the Oguz-Gabala-Baku water pipeline, which is an important source of drinking water, was carried out. The values for this water differ considerably from those for the Caspian Sea: the pH is within the normal range (7.69), the electrical conductivity is low (507 µS/cm for a normal value of <2500) and the total hardness is 246 mg/l $CaCO_3$ (below the permissible value of 350). The concentrations of ammonium (<0.1 mg/l), chlorides (6.4 mg/l), sulphates (45 mg/l) and nitrates (6.9 mg/l) are well below the limit values. In addition, microbiological analysis revealed the absence of Escherichia coli and coliform bacteria, making the water safe for human consumption (Table 2).

Table 2. *Water Quality of the Oghuz–Gabala–Baku Pipeline (April 2025)*

Parameter	Result	Standard (AZS 929:2023)	Comment
pH	7.69	6.5–9.5	Within normal limits
Electrical Conductivity (µS/cm)	507	<2500	Low mineralization
Total Hardness (mg $CaCO_3$/L)	246	350	Below the limit
Ammonium (mg/L)	<0.1	0.5	Very low level
Chlorides (mg/L)	6.4	350	Within permissible limits
Nitrates (mg/L)	6.9	50	Significantly below the limit
Sulfates (mg/L)	45	500	Within permissible limits
Total Coliform Bacteria (CFU/100 mL)	0	0	Not detected
E. coli (CFU/100 mL)	0	0	Not detected

A comparison between these two bodies of water reveals a striking contrast. While the Caspian Sea suffers from complex anthropogenic pollution due to petroleum products, heavy metals, sulphur compounds and organic matter, leading to oxygen depletion and the risk of mass extinction of aquatic species and birds, the Oguz-Gabala-Baku water pipeline is characterised by a high degree of purity and meets hygiene standards. The main difference lies in the sources of pollution: the Caspian Sea is exposed to transboundary and industrial influences, while the Oguz-Gabala-Baku system, which crosses mountainous areas, is relatively isolated from industrial influences and controlled as a drinking water resource.

The study therefore highlights the need for a comprehensive approach: a combination of strict environmental controls, the introduction of purification technologies and the development of regional programmes for the preservation of the Caspian sea's ecosystems. Only such measures can prevent further cases of mass bird mortality and preserve the region's biodiversity.

According to Mammadova et al. (2024), the hydrochemical profile of the Gudyalchay river is characterised by moderate hardness, high hydrocarbon content and relatively higher concentrations of calcium and magnesium compared to typical low-mineralised spring water (Mamedov et al., 2007). According to published specifications, « Shollar» water has low mineralisation and the following indicative values: pH 6-8; Ca 6-11 mg/l; Mg 1-5 mg/l; Na 7-8 mg/l; NO3 1-2.5 mg/l; SO4 12-16.5 mg/l; Cl 2–11 mg/l; HCO3 27–60 mg/l (Mamedov et al., 2003; Costantini et al., 2020). A comparison shows that in the upper reaches of the Gudyalchai, higher concentrations of Ca (≈38-50 mg/l) and HCO3− (≈130-165 mg/l), with total mineralisation reaching 230-336 mg/l in typical samples and sometimes even higher in karstic and hilly areas (Mamedov et al., 2007).

The differences in composition can be explained by the geology of the basin: the leaching of carbonate rocks enriches the water with hydrocarbonates and calcium. At the same time, the « Shollar» forms as an artesian spring/well under conditions of limited interaction with these rocks and has a lower hardness (Mamedov et al., 2003; Costantini et al., 2020). These properties influence the behaviour of pollutants: fresh, low-mineralised water can dissolve and transport organic pollutants and dissolved metals in different proportions than hard carbonate water.

River runoff is one of the main vectors of pollutants in the Caspian Sea. According to regional studies and reports, accumulations of nitrogen compounds, phosphates, petroleum products and heavy metals from both river runoff and direct coastal sources are observed in coastal areas (Mammadova et al., 2024; İpeksu MMC, n.d.). Studies conducted in different parts of the Caspian Sea show that a significant proportion of heavy metals and organic pollutants accumulate in estuarine sediments, which has a negative impact on benthic and fish communities (Mammadova et al., 2024; GRID-Arendal, 2019).

The rivers of northern Azerbaijan (notably the Gudyalchay and Gusarchay) are characterised by local anthropogenic influences: agricultural wastewater, untreated or partially treated domestic wastewater, industrial waste and pollution from road traffic. This pollution results in high concentrations of nitrates, possibly in the presence of petroleum products and traces of heavy metals in estuaries, which, combined with the hydrochemical context of the rivers, determines the local level of pollution in the coastal waters of the Caspian Sea (Mamedov et al., 2007; Mammadova et al., 2024; GRID-Arendal, 2019).

It should be noted that changes in the flow regime due to climate change (changes in snowmelt patterns, increased extreme precipitation) also alter the transport of suspended solids and pollutants to the sea, as confirmed by regional studies on the state of the Caspian Sea (İpeksu MMC, n.d.; GRID-Arendal, 2019).

Assessing the state of freshwater and coastal waters requires regular monitoring of the following parameters: TDS, ions (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}), HCO3−, SO4 2−, Cl−, NO3−, petroleum products, heavy metals (Pb, Cd, Hg, Zn, Cu) and microbiological indicators (total coliforms and E. coli). Monitoring should be carried out by a network of stations located from the upper reaches of rivers to estuaries and coastal points, with seasonal sampling.

Table 3. *Hydrochemical Characteristics of the Goychay River and "Shollar" Water*

Parameter	***Goychay River (average/range)***	***"Shollar" Water (specification)***
pH	*6.5–8.0 (neutral to slightly alkaline)*	*6.0–8.0*
TDS (mg/L)	*230–336; up to 2000 in karstic areas*	*Low mineralization (sum of ions)*
Ca (mg/L)	*≈45.5 (38–50)*	*6–11*
Mg (mg/L)	*≈15.3*	*1–5*
Na + K (mg/L)	*≈17*	*Na 7–8*
HCO_3^- (mg/L)	*≈149.6 (130–164)*	*27–60*
SO_4^{2-}, Cl^- (mg/L)	*Tens of mg/L, depending on geology*	*SO_4 12–16.5; Cl 2–11*
NO_3^- (mg/L)	*1–5 (in upper reaches)*	*1–2.5*
Temperature (°C)	*4–12 (seasonal variation)*	*Low, spring water*

Practical measures to reduce pollution in the Caspian Sea include: improving domestic and industrial wastewater treatment systems, introducing technologies to minimise agricultural runoff (fertiliser control, buffer zones), restoring coastal wetlands and developing sustainable water resource management programmes at the river basin level (Mammadova et al., 2024; İpeksu MMC, n.d.).

7. Conclusion

The results of the studies conducted allow the following conclusions to be drawn:

1. For ecology and nature conservation – The case of the coot deaths shows that constant monitoring of the Caspian Sea and early detection of ecological hazards are necessary.
2. For water management – A comparison with the Oguz-Gabala-Baku system shows that competent management and strict sanitary controls can keep water safe.
3. For biological safety – It is essential for human and animal health to prevent further accumulation of heavy metals and petroleum products in the water.
4. For strategic policy – Inter-state measures are needed to limit cross-border pollution of the Kura and Araz rivers, which are the main sources of toxins in the Caspian Sea.
5. A comparison of the hydrochemical properties of the Gudyalchay river and the «Shollar» spring shows that the river water, in a natural geological context, has higher mineralisation and Ca^{2+} and HCO_3^- content than the spring water, which is poorly mineralised. Anthropogenic sources and changes in flow rates lead to the transport of pollutants to the coastal zone of the Caspian Sea, where they accumulate in seabed sediments and have negative effects on ecosystems. In order to preserve water quality, constant monitoring and practical measures to reduce pollutant discharges are necessary.

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Improving Minimization of Cultivation of Gray-Brown Soils in Sheki- Zagatala Economic Region

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Abtract

The objective of this research was to determine the effectiveness of minimizing tillage in resource- saving grain production technologies in the northern forest-steppe agricultural landscape. The study focused on resource-saving tillage technologies in various field crop rotations with grain crop saturation levels ranging from 67% to 100%. The research was conducted from 2020 to 2024 on an experimental field based on a permanent field trial established in 1980. Switching from annual plowing to direct seeding reduced the microbiological activity of the topsoil. This is due to a decrease in the rate of mineralization of SOM and changes in soil microflora activity. A key factor in managing weed infestation in agrophytocenoses while minimizing soil tillage is the use of a highly effective herbicide system, which ensures weed infestation levels below the harmfulness threshold. Crop rotations combined with a combined tillage system have been found to be the most effective.

Keywords: grain, bioactivity, agrophytocenoses, tillage, agricultural landscapes

1. Introduction

Simple (normal) traditional technologies are used in Azerbaijani farms with low profitability and staffing levels and are typically designed for regions with low landscape potential, primarily steppe and arid areas. In this case, the distinctive feature of the traditional technological process is the need for plowing (Kabata-Pendias, 2011). No-tillage farming involves only one contact of tillage implements with the soil during the growing season seeding. Seeding is typically done in narrow furrows 2.6-7.6 cm wide, with one or more additional operations. Herbicides are used intensively to control weeds. With no-tillage, savings can reach 60-79%. With no-till technology, seeding is carried out in the field while crop residue is preserved and evenly distributed. Stubble helps retain snow and accumulate moisture, while chopped straw provides additional biological nutrition to soil organisms and prevents evaporation (Dobrovolsky, 1983) Crop rotation plays a particularly important role in farming under this system, reducing weed growth and crop disease, eliminating insect pest problems, and increasing soil fertility and potential land profitability (Rowell, 1999). The economic situation in Azerbaijan over the past 20 years has led to a reduction in the area of cultivated land in the country. Almost half of the arable land of the Azerbaijan Republic is unused and is largely subject to secondary overgrowth by trees and shrubs (Bunyatova et al., 2025; Ismayil et al., 2025)

The Sheki-Zagatala economic region is an important grain-growing country area, producing food grain of strong and hard varieties of spring wheat (Nasirova et al., 2022). The main direction of stabilizing grain production is the improvement of generally accepted technologies for cultivating grain crops based on resource-saving and soil-protecting soil cultivation systems in field crop rotations (Mirzezadeh et al., 2025). In modern conditions, soil cultivation remains a crucial element of zonal farming systems based on agrolandscapes. Scientists believe that we must boldly experiment with various techniques to select the best. Only in this way can we universally achieve our common goal of progressively increasing soil fertility (Biswas, 2021). The crop production industry's responsibilities include growing several tons of grain, developing and implementing measures to increase crop productivity through the use of modern technology, increasing fertilizer application, and much more. Better moisture retention when plant residues from previous crops accumulate on the surface. As the area planted using this technology increases in production, research is being conducted to study the technology in a direct seeding system and obtain objective information (Adhikari, 2017; Minasny, 2011).

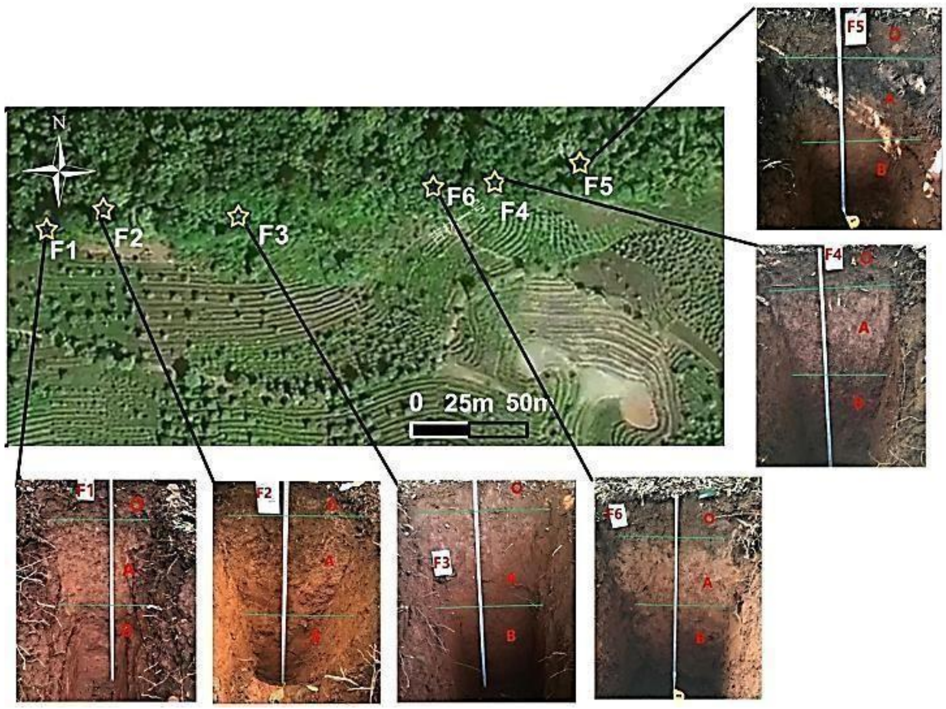
The study examined moldboard (control), combined no-tillage with plowing once per crop rotation, minimum (subsoil), and no-till tillage systems. These systems were used in a grain-fallow crop rotation with a fallow-wheat-pea-barley rotation, a crop rotation with rapeseed-wheat-pea- wheat, and a grain-fallow-grass rotation with winter rye-pea-wheat-annual grasses-barley. In the no- till system, plots were sprayed with $C_3H_8NO_5P$ 7-9 days before sowing, and an additional 16 kg of N was applied per ha of crop rotation area. During the tillering phase, grain crops in all experimental variants were treated with a tank mixture of recommended herbicides. The obtained results allowed us to determine the impact of various tillage systems on soil fertility and grain production efficiency in resource-saving technologies. Minimizing tillage in a grain-fallow crop rotation, particularly no- tillage, while maintaining stubble and a mulch layer of chopped straw, promotes the accumulation of available soil moisture. Soil bulk density measurements indicate an optimal range of 1.1-1.2 g/cm in the 0-30 cm layer for the growth and development of grain crops. The porosity of the leached gray- brown topsoil corresponded to a satisfactory estimate, amounting to 54-56%.

The studied resource-saving soil cultivation systems, focusing on minimizing the use of direct seeding in field crop rotations with varying grain abundances, are characterized by objective characteristics. Improving these elements of the farming system guarantees high yields and economic efficiency in crop production, as well as the preservation and enhancement of soil fertility in the forest-steppe.

2. Methods

To evaluate the effectiveness of various resource-saving tillage systems, including no-till, in field crop rotations, we are conducting a field study under State Contract No. 0771-2019-006: "Develop resource-saving crop cultivation technologies for sustainable crop production and land conservation." The research has been conducted since 2024 based on a permanent field experiment established in 1980 on a test field. The soil of the test plot is shallow, medium-loamy leached gray- brown soils with a humus content of 6.9-7.7%. Tillage systems are studied according to the following classification: moldboard (control) with plowing, combined with a combination of no-till and plowing once per crop rotation, minimum (subsurface), and no-till. Tillage systems were applied in three field crop rotations: grain-fallow (fallow-wheat-pea-barley), crop rotation (rapeseed-wheat-pea-wheat), and grain-fallow-grass (fallow-winter rye-pea-wheat-annual grasses-barley) with grain saturation from 67% to 100%. In all field crop rotations, the fertilizer system applied 20-30 kg of N and 20-35 kg of P per hectare of arable land, differentiated by crop type depending on their cultivation technology and placement in the rotation. With the no-till system, an additional 15 kg of active ingredient N is applied per hectare of crop rotation area. The total plot area was 650 m², the plot size was 122 m², the replicates were fourfold, and the placement of the variants was randomized. Crops were sown using an SS-6 seeder equipped with disc coulters and a special attachment (turbo discs) for direct seeding. The no-till system included glyphosate application 7-8 days before sowing. The plant protection system included spraying field crops with a tank mix of herbicides, fungicides, and insecticides when the pesticide threshold was exceeded. The study utilized generally accepted methods for determining agrophysical properties: soil moisture using the thermostat-weight method; soil bulk density using a Kachinsky auger with a 500 cm³ cylinder; agrochemical parameters: total humus according to

Tyurin, NO3-N and available P according to Chirikov, and pH potentiometrically in a salt extract; soil microbiological activity using the flax cloth method; crop weed infestation by specific gravity in the agrophytocenoses using the Milashchenko method (Fig. 1); crop yield measurements using direct combining with a Sampo 500, the data from which were subjected to variance analysis according to Dospekhov in the Snedeko program (Flynn et al., 2019; Malone et al., 2017)



Note: The satellite imagery was obtained from the OweMap Windows Client v10.1

Figure 1. *Study area and soil sampling locations in Yunnan Province, southwest China (soil profile, O. humus layer, greyish black, loose, plant debris; A. leachate, gray-brown, sandy loam; B. alluvium, reddish brown, sandy loam;). In the study area, six plots with different slopes, slope directions, and elevations were established and designated F1–F6 (Moldboard, Combined, Minimum, No-till)*

3. Results

A scientifically based transition to new resource-saving technologies based on minimizing tillage is based on the established principle that minimizing tillage in crop rotation does not degrade soil fertility parameters compared to plowing. Our research examining tillage systems in a typical field grain-fallow crop rotation with 75% grain crop saturation yielded the following soil fertility indicators (Table 1).

Table 1. *Fertility indicators of leached gray-brown soils depending on soil cultivation systems, 2020-2024*

SCS*	PMC in the 0- 100 cm layer, mm	SBD in the 0-30 cm layer, g/cm^3	NN content in the 0-40 cm layer, mg/kg	Soil bio-activity, %
Moldboard	125	1.14	13.0	43.9
Combined	122	1.13	12.3	43
Minimum	121	1.14	10.9	39.2
No-till	129	1.15	10.2	38.9
LSD*	20.1	0.04	3.86	9.86

*Note: SCS- Soil cultivation system; PMC - productive moisture content; SBD - Soil bulk density; NN – Nitrate nitrogen (NO_3-N); LSD - least significant difference

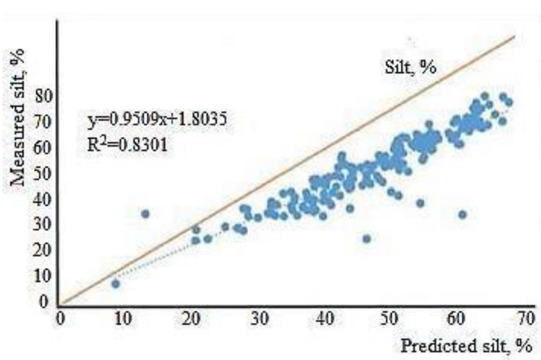
During the experimental observation period, spring moisture reserves, based on the productive moisture content in the one-meter soil layer under field crop rotation, were characterized as satisfactory. Maximum moisture accumulation was achieved with the no-till system, with mulch of crop residues left on the soil surface. The soil bulk density during equilibrium was within the optimal range for grain crop growth and development across all tillage systems (1.1-1.2 g/cm^3). This demonstrates the high resistance of gray-brown soils to compaction. The porosity of the arable layer of leached gray-brown soils corresponds to a satisfactory estimate, reaching 54%-56%. In energy- saving tillage technologies, the bulk of crop and plant residues, which provide food for soil microflora, including pathogens, is located in the upper soil layers. Observations in spring wheat crops after fallow have shown a decrease in the microbiological activity of the arable layer from plowing to no-tillage, from 43.9% to 38.8%. Minimizing tillage reduces the rate of mineralization of soil organic matter, resulting in a nitrate nitrogen (NO_3-N) deficiency, which leads to a deterioration in the nitrogen nutrition of field crops. Compensating doses of nitrogen fertilizers are required. In field crop rotations with up to 75% saturation with grain crops, the accumulation of plant residues in the form of straw amounted to 3.0 t/ha, in crop rotation - 4.2 t/ha, which in the conditions of forest- steppe agricultural landscapes is insufficient to maintain a stable state of soil fertility and to increase it. Correlation analysis between the productivity of grain-fallow crop rotations under different tillage systems and the content of NO_3-N and available P allows modeling the fertility indicators of the arable horizon of leached gray-brown soils and adjusting the application rates of mineral fertilizers depending on the preceding crops. The influence of available P content in the 0-40 cm soil layer on crop productivity in grain-fallow crop rotations averages 68-81%, with a correlation coefficient (Cc) of r = 0.82-0.89 for both moldboard and minimum tillage systems. The influence of NO_3-N content on crop productivity in minimum and no-till systems averaged 46-48%. Weed prevalence rates in various agrophytocenoses were below the harmfulness threshold for all tillage systems. Weed control of cultivated crops was achieved through the use of tank mixes of highly effective herbicides during the growing season and the application of glyphosate ($C_3H_8NO_5P$) before sowing. Minimizing soil cultivation does not worsen the fertility level of the arable layer of leached gray-brown soil and ensures sustainable productivity of field crop rotations (Table 2).

Table 2. *Efficiency of tillage systems in field crop rotations in, 2020-2024 years*

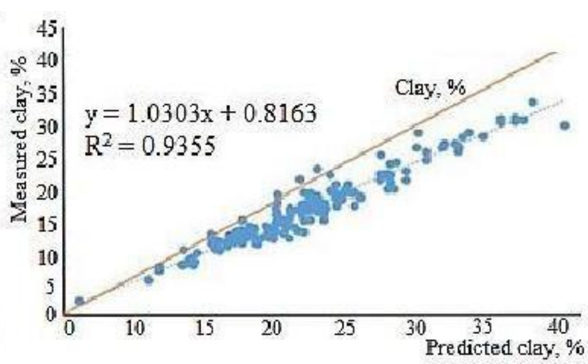
Crop rotation	SCS*	Grain crop yield, t/ha	Grain yield per 1 ha of arable land, t	Profitability, %	EEC*
Grain-fallow	Moldboard	3.17	2.35	230	3.6
	Combined	3.10	2.31	226	3.7
	Minimum	2.89	2.15	230	3.4
	No-till	2.71	2.09	148	3.6
LSD*			0.36		
Crop-replacement	Moldboard	2.31	2.48	238	2.8
	Combined	2.26	2.41	250	2.8
	Minimum	2.08	2.22	212	2.5
	No-till	2.06	2.21	132	2.6
LSD		0.23			
Grain-fallow-grass	Moldboard	3.28	2.51	210	3.5
	Combined	3.17	2.42	231	3.4
	Minimum	2.92	2.26	204	3.4
	No-till	2.93	2.28	146	3.6
LSD		$F_f > F_T$			

*Note: EEC - energy efficiency coefficient; SCS - Soil cultivation system; LSD - least significant difference

The RF-OK model refers to a predictive modeling approach that combines Random Forest (RF) with Ordinary Kriging (OK), typically used for spatial prediction tasks. This combination improves predictive performance, particularly in spatial data environments such as soil property mapping or environmental data modeling (Fig. 2 a-d).



a.



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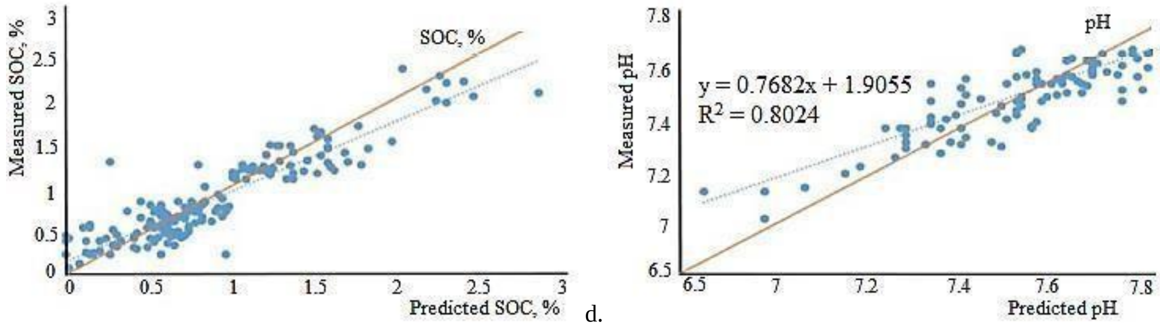

c. d.

Figure 2. Scatter plots of the predicted data based on RF-OK method for: Silt (a), Clay; (b) SOC and pH (d) in minimum tillage soil cultivation areas

Research has shown that effective production of 2.31-2.40 tons of grain units per 1 hectare of arable land was achieved in crop rotations with a combined tillage system. This system proved to be the most cost-effective. The minimum tillage system was inferior to the moldboard system in terms of crop rotation productivity by 0.20-0.24 tons of grain units per 1 hectare of arable land, but was as close to it in terms of profitability. No-till technology with direct seeding in various crop rotations ensured a grain harvest of 2.08-2.22 tons of grain units per 1 hectare of crop rotation area with a profitability of 143-148%, which is economically advantageous. The EEC for grain-fallow and grain- fallow-grass crop rotations averaged 3.5 units. For crop rotations with a crop rotation, this indicator decreased to 2.7 units, due to the relatively high energy costs of producing rapeseed and peas. Growing regionally selected grain crops allows for minimal tillage, including the use of no-till systems (Fig. 3). However, in the Sheki-Zagatala region conditions, especially for forest-steppe agricultural landscapes, genotypes that are tolerant not only to drought but also to excess drought are needed. Spring wheat varieties grown on the best preceding crops (bare and chemical fallow, peas, and rapeseed) produce grain of quality that meets Class 3 Azerbaijan Standards, while maintaining optimal mineral nutrition. When switching to a no-till system, spring wheat grain was obtained with a gluten content of 26.3% for the following preceding crops: chemical fallow (26.2%), rapeseed (26.2%), and pea (26.1%).

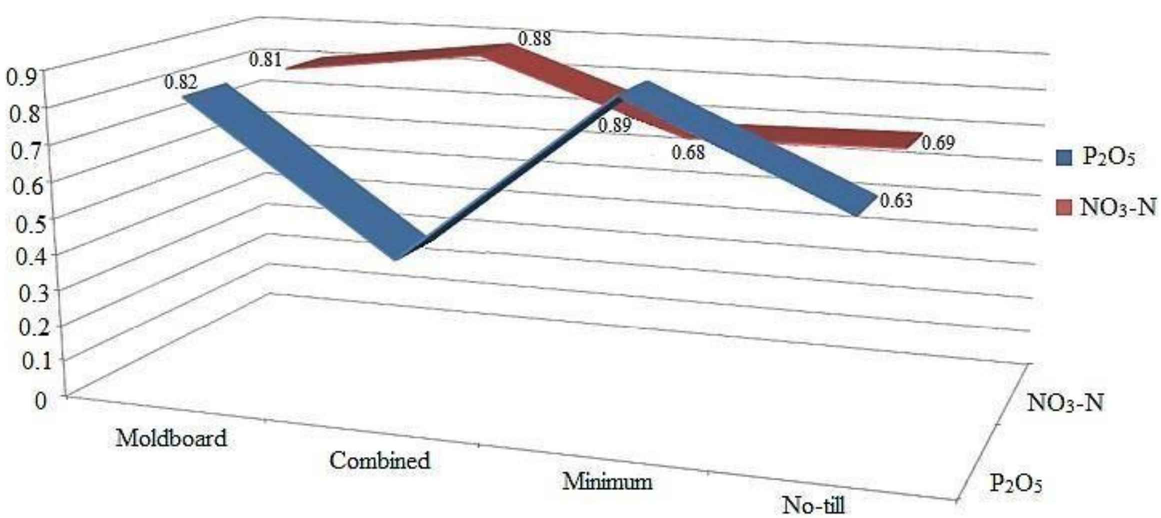

***Figure 3.** Correlation between the content of N-NO_3, mobile phosphorus P_2O_5 and the yield of crops in grain-fallow crop rotation depending on the soil cultivation systems*

4. Conclusions

The conducted research revealed the following: Minimizing soil tillage in field crop rotations, including no-tillage systems, promotes moisture accumulation, an optimal bulk density of 1.1-1.2 g/cm^3, and satisfactory porosity in 54-56% leached gray-brown soils; transition from annual plowing to direct seeding of field crops reduces the microbiological activity of the arable layer from 43.9% to 38.8%, and the NO_3-N content from 12.8 mg/kg to 11.0 mg/kg. This is due to a decrease in the rate of mineralization of SOM and changes in the vital activity of soil microflora; the regulatory factor for managing weed infestation of grain crops while minimizing tillage is the use of a highly effective herbicide system and the weed-clearing effect of pre-cultivation crops (bare, fallow, winter rye, and rapeseed). The proportion of weed vegetation in various agrophytocenoses was within the weed harmfulness threshold of up to 10% across all tillage systems; the accumulation of plant residues in the form of chopped straw in field crop rotations with a field of clean fallow amounted to 3.0 t/ha, in a crop rotation - 4.2 t/ha, which in the conditions of forest-steppe agricultural landscapes is insufficient to maintain a stable state of soil fertility and to increase it; The most effective were field crop rotations using a combined tillage system with a productivity of 2.31-2.43 tons per 1 hectare of arable land with a maximum profitability of 258% and an EEC of 3.7 for a grain-fallow crop rotation. Minimum and no-tillage systems ensured a grain harvest of 2.09-2.28 tons per 1 hectare of arable land, with a profitability of 145-147% and an EEC of 2.5-3.6, which turned out to be economically and energetically advantageous; Spring wheat grown after bare fallow, including chemical fallow, and the best non-fallow predecessors (peas, rapeseed), using various tillage systems, produces grain of AzStandart Class 3 quality. To produce high-quality grain while minimizing tillage, including no- till, balanced nutrition through the use of nitrogen and phosphorus fertilizers is essential.

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Study of the Environmental İmpact of Petroleum Product Waste Generated During Polyethylene Production at the SOCAR Polymer Plant

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Abstract

This paper provides a detailed analysis of the environmental impact of high- and low-pressure polyethylene production processes. It examines the morphological composition of waste generated during the synthesis, polymerization, and granulation stages. Particular attention is paid to the emission of volatile organic and inorganic compounds, the contamination of wastewater with heavy metals (catalyst residues), and the problem of microplastics in the form of industrial pellets. An analysis of the qualitative and quantitative composition of gaseous, liquid, and solid waste is carried out. The work contains statistical data, an analysis of waste generation dynamics, and an assessment of its toxicological impact on the atmosphere, hydrosphere, and lithosphere. The research showed that all stages of polyethylene production at the SOCAR Polymer plant comply with the standard.

Keywords*:* polyethylene, polymerization, petrochemical waste, volatile organic inorganic compounds, wastewater, Ziegler-Natta catalysts, microplastics, recycling**.**

1. Introduction

The production of synthetic polymers is one of the fastest growing sectors of the global chemical industry. Polyethylene (PE), thanks to its unique physical and chemical properties, low cost, and versatility, occupies a leading position among all plastics produced (Kayumov et al.203). Global polyethylene production exceeds 100 million tons per year and continues to grow, driven by demand for packaging materials, pipes, insulation, and consumer goods. In developed countries, per capita consumption was 85-90 kg per person, and this figure continues to grow annually. Along with the growth in polyethylene production, its negative impact on the environment has also increased (Kayumov 2014).

The technological cycle for producing polyethylene includes the processes of hydrocarbon pyrolysis, gas separation, polymerization (at high or low pressure), degassing, and granulation. Each of these stages produces specific types of waste: gaseous emissions containing ethylene and solvents; liquid effluents contaminated with oligomers and catalytic sludge; solid waste in the form of defective polymer, “lumps” and dust. Polymer materials are usually multicomponent systems created using various polymer components. Technological waste in the production of polymer materials arises during their synthesis and processing. They are divided into recyclable materials and technological waste that cannot be recycled. Such waste accounts for 5 to 35%. Based on the insoluble basis of the waste, the raw material is of high quality, not differing from the properties of the original polymer. No special equipment is required to process this waste, which is produced at the same plant. Waste generated during production is used in the processing of various products in addition to various products used as raw materials. In the production of multicomponent polymers, as well as in their practical use, there are processes of separating a number of harmful low-molecular substances from materials (Kayumov et al. 2014, Kayumov 2015).

Polymer materials with physical, chemical, structural, and technological properties based on various plastics and elastomers are widely used in various areas of the economy and medicine. This is associated with the generation of waste at all stages of the production and processing of polymer materials. Therefore, their disposal is a pressing issue, and their negative impact on human health and the environment has always been a global problem. The solution to environmental problems has led to strict requirements: the production of polymers must be environmentally friendly or at least have a minimal impact on the environment (Kayumov et al. 2018).

The purpose of this work is to identify harmful substances emitted into the atmosphere at SOCAR Polymer production facilities, study their concentration in the air, and assess the environmental impact of each of them on the surrounding environment.

2. Materials and methods

Polyethylene is the most widely used polymer in the world, accounting for more than 30% of the total plastics market (Kayumov B.A. et al .2019). The chemical formula of the monomer is ethylene (CH_2=CH_2).

$$nCH_2 = CH_2 \xrightarrow{P,t,cat} [-CH_2 - CH_2-]_n$$

Despite the chemical inertness of the product itself, the technological processes involved in its production (polymerization, separation, granulation) are associated with the generation of significant amounts of waste. Technological stages and sources of waste generation Polyethylene production is divided into two main types: LDPE (low-density polyethylene): Radical polymerization at high pressure. HDPE (high-density polyethylene): Ion-coordination polymerization at low pressure using catalysts (Almatayev et al. 2019). Specific types of waste are generated at each stage. The use of organometallic catalysts (Ziegler-Natta, chromium) leads to the formation of toxic sludge containing heavy metals.

In various countries, the production of polyethylene results in the release of many tons of waste into the atmosphere, which severely pollutes the environment. Fig. 1.

Figure 1. Emissions into the atmosphere during polyethylene production

Industrial pellets (Nurdles): This is one of the most pressing problems. Small granules of raw material (2-5 mm in diameter) often spill during transportation and packaging, ending up in storm drains and from there into rivers and oceans. Fig. 2.

Figure 2. *Emissions of pollutants into the atmosphere during polyethylene production (Karimkhojaev et al. 2020)*

The ethylene production process and the stages of atmospheric pollutant emissions are shown in Figure 3.

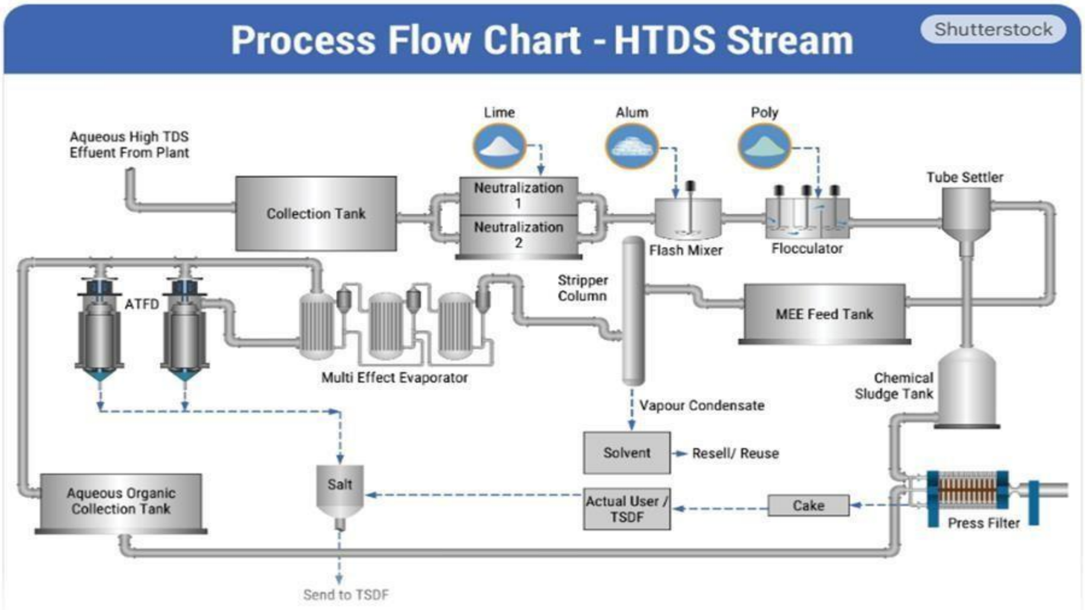

Figure 3. Schematic diagram of waste generation sources in the process of ethylene suspension polymerization.

We have access to information on the dynamics of polyethylene production from 2009 to 2023 (Claudia et al. 2020). The graph clearly shows that the growth in the production of plastic materials is increasing significantly year after year. Naturally, this is also a source of environmental pollution.

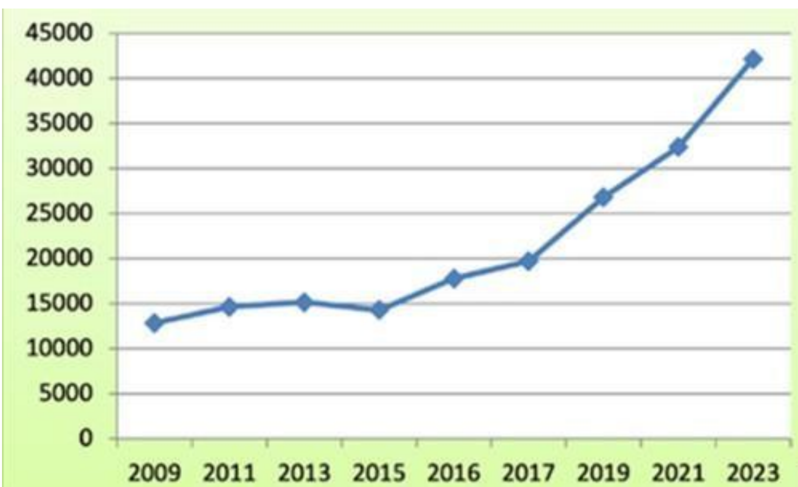

Figure 4. Dynamics of polyethylene production in Azerbaijan in 2009-2023.

The technological process of polyethylene production consists of three main stages. The first stage involves the preparation of raw materials, namely the purification of raw materials from impurities and contaminants, as well as the regeneration of catalysts used in purification. This stage is characterized by the highest formation of harmful substances that have a negative impact on the environment (Table 1). The data available in the literature on the total amount of pollutant emissions in polyethylene production is shown in table 1 (Pavlov et al. 2020).

Table 1. *Emissions of pollutants into the atmosphere during polyethylene production*

Pollutant	Hazard class	Mass of pollutant emissions per ton of product, kg/t	
		Minimum value	Maximum value
Suspended solids	-	-	0,072
Ethylene	4	2,45	6,7
Carbon monoxide	4	-	0,93
Butylene	4	0,011	0,053
Aliphatic	3	0,040	0,31
Hydrocarbons C1-C5 (excluding methane)	3	-	0,022
Aliphatic	3	0,0012	0,093
Hydrocarbons C6-C10	3	-	0,00018
Nitrogen dioxide	2	0,00021	0,16
Acetaldehyde	1	-	-

The second stage involves the synthesis of polyethylene in a reactor using initiators and catalysts – this stage is the main stage in the production of polyethylene. During the ethylene polymerization process, ethylene oxide may be formed, which can be purified and sold as a by-product, as well as benz(a)pyrene, which is classified as a Class I hazardous substance. It should be noted that pollutant emissions during the second stage are most often associated with malfunctions in the technological equipment.

At the final stage of production, called "granulation," polyethylene chips may form in the air, which when heated can release organic acids, formaldehyde, and acetaldehyde, as well as ethylene oxide. All these substances, when exceeding the maximum permissible concentration, lead to acute and chronic poisoning (V.A. Zaitsev 2018).

The Polypropylene and High-Density Polyethylene production areas at the SOCAR Polymer plant are designed to produce 200,000 tons of polypropylene and 120,000 tons of high-density polyethylene per year, respectively. Measurements were conducted by our team at 5 selected points in the production area of the SOCAR Polymer plant for PM10 (particulate matter), background radiation, dust, volatile organic compounds (VOC), sulfur dioxide (SO_2), nitrogen oxides (NOx), and noise levels in the ambient air. The coordinates of the measurement points were determined and the corresponding records were kept (Aliyev et al.2014, Claudia et al. 2020).

Environmental monitoring was organized in two phases (active and passive). The results of the studies conducted with mobile devices are presented in Table 2. For the determination of volatile organic compounds, Camsco tubes were used during passive monitoring; the gravimetric method was used for the determination of dust particles; and during active monitoring, a remote sensor "Qrawulf" device was used for the determination of CO, SO_2, NO, and NO_2 (Ivanov 2020, Johnson 2019). The collected samples were analyzed at Azecolab Company LLC, and the results of the laboratory analyses are presented in tables 2 and 3.

Table 2. *Results of laboratory analysis conducted by Azecolab.*

Sernumber	Date	06.10.2025	Station indicators					Mobile device
1.	Parameters	Unit of measurement	Lesson 1. Between zones 02 and 03.	Section 2. Between units E-2 and E-5.	3. Between zones 01 and 05	4. Between object S-3 and zone 05	5. Near the nitrogen plant.	Gas analyzer
2.	NOx (nitric oxide)	mq/m^3	0,02	0,02	0,0	0,0	0,02	
3.	SO_2	mq/m^3	0,001	0,000	0,001	0,001	0,001	
4.	CO	mq/m^3	0,07	0,07	0,07	0,07	0,07	
5.	VOC	mq/m^3	0,02	0,02	0,02	0,02	0,02	
6.	General dust	mq/m^3	0,001	0,005	0,071	0,001	0,001	Dust meter
7.	Radiation	mkR/saat	11-13	10-12	10-11	11-13	10-11	Dosimeter
8.	Noise	dB	56-63	60-65	76-80	80-82	90-95	Sound measurement

Table 3 *Results of surveys conducted using mobile devices in polymer production areas.*

Gas sample								
Act No.	Date of analysis		Note					
	Started	Finished						
Order	06.10.2025	06.11.2025	Sample code					Regulatory document
	Parametrlər	Ölçü vahidi	St. 1. 19/00040	St. 2. 19/00041	St.3. 19/00042	St.4. 19/00043	St. 5. 19/00044	İSO 6976 ASTM D1945
1.	VOC	ppm	<1.00	<1.00	<1.00	300-990	9-17	
2.	CO carbon monoxide	Volume %	<0.01	<0.01	<0.01	<0.01	<0.01	
3.	SO_2 sulfur dioxide	Volume %	<0.01	<0.01	<0.01	<0.01	<0.01	
4.	N_2 (nitrogen)	Volume %	78,08	78,08	78,08	78,08	78,08	
5.	O_2 (oxygen)	Volume %	20,9	20,9	20,9	20,8	20,9	

Tables 4 and 5 show that nitrogen and volatile organic compounds, particulate matter, and nitrogen oxides in the air stream generated during the use and regeneration of catalysts in the technological process, which are mainly formed as a result of fuel combustion and contained in flue gases, are emitted into the atmosphere. If we consider the technological characteristics of the burner and the indicators of internal gas emissions in the process, we will see that they comply with environmental standards.

The tables below present the results of research and monitoring work on the topic "Study of the environmental impact of gas emissions generated during the production of polymers in the petrochemical industry" at SOCAR Polymer plants, which produce SOCAR polymers and are the most environmentally advanced project. An environmental analysis was conducted based on the results of the research work.

Table 4.

Composition of fuel gas (V,%) объемных процентах)) ilə)	
N_2	1,33
CO_2	4,11
CH_4	87,32
C_2H_6	3,22
C_3H_8	1,6
$n\text{-}C_4H_{10}$	1,01
H_2	1,41

Table 5.

The volume of waste gases sent for incineration in October.					
PP			YSPE		
Total (t)	431,67 ton	100%	Total (t)	286,15 т	100%
Propylene (t)	376,79 ton	87,29%	Ethylene, Ethane (t)	156,27 т	54,61%
Propane (t)	28,99 ton	6,72%	Hexene, Hexane (t)	3,81 т	1,33%
Hydrogen (kg)	69,75 kq	0,02%	Isobutane (t)	58,38 т	20,40%
Nitrogen (t)	6,40 ton	1%	Hydrogen (kg)	357,00 кг	0,12%
Ethylene (t)	16,20 ton	4%	Nitrogen (t)	67,05 т	23%
Others (isobutane, pentane, ethane, methane, etc.), (t)	3,22 ton	0,75%	Others (methane, butane, acetylene, etc.), (t)	0,29 т	0,1%

As can be seen from the tables, the measurement results at specified points at the polymer production plant are within acceptable limits for all parameters studied. Noise intensity was recorded at 80-

82 dB (slightly above normal). The noise level was recorded at 90-95 dB. The indicators for other measured parameters, including background radiation (10-13 μR/h) and total dust content (0.001-0.071 $\mu g/m^3$), are within the norm for the plant's territory. When considering hourly, daily, monthly, and annual indicators at SOCAR Polymer plants, they comply with the environmental standards set by the European Union (Kostin 2021).

The report scientifically substantiates the economic and environmental significance of organizing stationary or continuous environmental monitoring every two hours using a Hi-Flow sampler, personal Drager X2 gas analyzers with infrared cameras during the storage, transportation, and production of raw materials at a polymer manufacturing plant, gas leaks into the atmosphere from tank breathing valves and pipelines (flange connections), as well as the prevention of explosions, fires, and environmental pollution (Melnikova 2013).

3. Conclusion

The composition of harmful gases emitted into the atmosphere from SOCAR Polymer production areas and the concentration of each of them in the air were determined using modern gas analyzers: "Flow Meter," "Kamsko Tube," "Arex," and "Graewulf." PM10 dust particles, NOx, SO_2, CO, harmful gases, and volatile organic compounds were identified in the waste gases emitted into the atmosphere from the production areas, and environmental analyses were also carried out . It was established that the neutralization of waste gas mixtures produced during technological processes using a regenerative thermal oxidizer (RTO) burner, currently used in polymer plants, at the required level is of great environmental importance for the protection of atmospheric air. The implementation of a "zero emissions" strategy is an achievable goal for companies in the industry by 2030.

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Analysis of Physical-Chemical Parameters of Takhtakorpu-Ceyranbatan Canal Water

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Abstract

The Takhtakorpu-Jeyranbatan Canal is a strategic link in the water supply chain of the Absheron Peninsula: the ionic composition, mineralization level, and acidity-alkalinity balance of water along the course directly affect both the stages of drinking water treatment and the use of water for irrigation purposes. In this study, the physicochemical parameters of a water sample taken from the Jeyranbatan Canal (Baku, Jeyranbatan settlement) were analyzed based on a laboratory report, and the results were compared with the standard parameters (WHO, AI, GOST, and Absheron average parameters) presented for the Jeyranbatan reservoir. The analysis includes major ions (HCO_3^-, Cl^-, Na^+, K^+), total hardness, pH, electrical conductivity (EC), total dissolved solids (TDS) and dry residue indicators. The results show that the mineralization of the water according to the selected parameters is at a medium-low level, and the chloride and sodium concentrations are in line with both the limits given for drinking water and the classification criteria for irrigation water. At the same time, given the seasonal variability across the system and the fact that some biogenic indicators (e.g. ammonium/nitrite) may be elevated at individual locations, it is considered risky to limit monitoring to "major ions". In this context, the analysis both evaluates current results and provides a reasoned approach to optimizing measurement frequency and indicator selection from a management perspective.

Keywords: Physico-chemical parameters, water reservoir, water channel, drinking water, safety

1. Introduction

Water is one of the most important and vital chemical compounds for the population. Water is a major component of both plants and animals, as well as the human body. 60-95% of the mass of plants and animals, and 60-70% of the mass of the human body, consists of water. Although 71% of the world is covered in water, 97.5% of it is salt water. Fresh water is difficult to use because some of it is in polar ice caps and some is deep underground. The amount of surface water available for drinking is only 0.3%. In Azerbaijan, reservoirs are mainly used to meet the demand for drinking water. One of them is the Jeyranbatan reservoir, which meets the drinking water needs of Baku and the Absheron Peninsula, where the country's population is more densely populated. The Jeyranbatan Reservoir was created in natural conditions, is 9.1 km long, 2.1 km wide, has an area of 13.90 km², and a volume of 0.186 km³. The main source of nutrition for the reservoir is the Samur-Absheron Canal, which originates from the Samur River. The Takhtakorpu Reservoir was built on the canal to eliminate the limitation in supplying water from the Samur River to this canal, the dependence on the country through which the Samur River passes, and to regulate the changes in water during seasonal changes. In addition, in order to increase the water supply of the reservoir, a certain part of the water of the Gusarchay, Gudyalchay, Guruchay, Agchay, Jagajugchay and Velvelachai rivers in the region is discharged into the reservoir through the Velvelachai-Takhtakorpu canal, which is part of the Samur-Absheron canal system. The water collected in the Takhtakorpu reservoir is transferred to the Jeyranbatan reservoir through its own flow through the Takhtakorpu-Ceyranbatan canal. The length of the Takhtakorpu-Ceyranbatan canal is 112 km, the slope coefficient is 1.5, the inclination is 0.0003, the bottom width is 4 m, the water depth is 3.12 m, the flow rate is 40 cubic meters per second, and the flow speed is 1.48 m per second (Pashayev & Hasanov, 2010, p.5).

The Takhtakorpu–Jeyranbatan aqueduct system is not only a hydraulic infrastructure, but also a route through which “quality is transported”: the chemical composition of water can change under the geochemical background of source waters, along-stream mixing, seasonal flow regime, and anthropogenic influences. These changes are especially important in terms of reliable drinking water supply on the Absheron Peninsula. The Jeyranbatan reservoir is fed by the Samur-Absheron canal, and the water processed here plays a major role in the supply of Baku and Sumgait, as well as a number of administrative territories of Absheron; water quality requirements are moving towards harmonization with regional standards as well as international norms.

The expansion and modernization of this system from an engineering perspective also makes the issue of water quality a more “manageable” issue: components such as the construction and financing of the Velvelechay-Takhtakorpu canal within the Samur-Absheron projects have served precisely to ensure the sustainability of water supply. Since the channel-storage-processing line operates as a whole, quality decisions must be made as a whole: which parameter changes faster, which indicator plays the role of an “early signal”, at what stage does the risk increase – the answer to these questions is formed by the correct selection and interpretation of monitoring data (AGROLAB, 2025).

Hydrochemical studies conducted on the Takhtakorpu-Ceyranbatan canal and related water bodies show that mineralization and hardness vary depending on the season and location, that the water moves in the interval from “soft to medium hardness” and that mineralization generally remains within a satisfactory range; however, it is emphasized that there are zones prone to pollution along the stream and that some indicators may increase in certain periods (Ganbarov, et al., 2020, p.17). This requires evaluating the indicators measured on a specific sample with a systemic approach, rather than as a "one-time good result."

The purpose of this article is to interpret the physicochemical parameters of a sample taken from the Jeyranbatan canal based on laboratory results, compare the results with the normative comparison framework presented for the Jeyranbatan reservoir, and assess the risks (corrosion-sedimentation potential, salinity/soda tendency, taste-organoleptic impact probability) from a practical perspective in a general logical chain (AGROLAB, 2025).

2. Theoretical foundations of the study

80% of diseases in the world are caused by poor water quality. Considering that water enters the Takhtakorpu-Ceyranbatan canal from various sources, it can be noted that the physicochemical composition of this water is variable and heterogeneous. As a result of the combination of waters from sources with different hydrological, geological, and anthropogenic characteristics, the pH, degree of mineralization, hardness, and other physicochemical parameters of the water along the canal acquire different characteristics. This causes the composition of the water of the Takhtakorpu-Ceyranbatan canal to be complex and diverse. The cause of 80% of diseases spread in the world is due to poor water quality. For example, high levels of lead entering the human body damage the nervous system, brain development, and cause kidney diseases (Ganbarov, et al., 2020, p.19)

3. Sample and measurement framework

The main source of information for the analysis is the test report on the water sample received from the “AGROLAB” Agricultural Testing Laboratory (Report No. Sa-020/25). The area where the sample was taken is indicated as Jeyranbatan Canal (Baku city, Jeyranbatan settlement); the sample was taken on 04.12.2025, the analysis was conducted on 08.12.2025, and the report was compiled on 09.12.2025 (AGROLAB, 2025).

4. Measured parameters

The report provides results for the following indicators: hydrocarbonate (HCO_3^-), chloride (Cl^-), total hardness (Ca^{2+} and Mg^{2+}), sodium (Na^+), potassium (K^+), pH, electrical conductivity (EC), TDS, and dry residue.

5. Analytical methods

The laboratory report specifies the methods according to GOST standards: determination of chlorides (GOST 4245-72), determination of hydrocarbons (GOST 23268.3-78), determination of total hardness (GOST 31954-2012), determination of EC and pH (GOST 26423-85), dry residue (GOST 18164- 72), potassium (GOST 23268.7-78) and sodium (GOST 23268.6-78) (Gidayatzade, 2022).

6. Comparison base and normative framework

The comparison is based on two directions:

1. Maximum permissible limits for drinking water given in the report (such as 200 mg/L for Na, 10 mg/L for K, 1000 mg/L for dry residue, and a pH range of 7–8).
2. Table presented for the Jeyranbatan reservoir: The norms of various organizations (WHO, European Union, GOST) and the average indicators for the Absheron Peninsula are compared in the same table (for example, 250 mg/L (WHO/EU) for Cl^-, 350 mg/L (GOST), 2500 µS/cm in the EU for EC, 6.5–8.5 in the WHO for pH, etc.).

The initial assessment for irrigation purposes was conducted based on the "irrigation water quality classification" criteria (class I–III) given in the laboratory report (Gidayatzade, 2022).

Overall result table

The table below summarizes the results for the example and the key thresholds used for comparison.

Table 1.

Parameter	Unit	Result (canal water)	Permissible Limit for Drinking Water	WHO/Aİ/GOST (Jeyranbatan comparison table))
pH	—	7.67	7–8	6.5–8.5 (WHO), 6–9 (Aİ)
EC	mS/cm	0.66 (≈660 µS/cm)	<2.5	2500 µS/cm (Aİ)
TDS	mg/L	330	1500	—
Dry residue	mg/L	665	1000	—
HCO_3^-	mg/L	116	300	— (presented separately in the table))
Cl^-	mg/L	78	350	250 (WHO/Aİ), 350 (GOST)
Total hardness	mg/L ($CaCO_3$)	54 (≈1.08 meq/L)	350	1.2 meq/L (Aİ), 7 meq/L (GOST)
Na^+	mg/L	115	200	—
K^+	mg/L	4	10	—

The results in the table was taken from the laboratory report.
The normative comparison indicators are based on the table fragment presented for the Jeyranbatan reservoir.

7. Mineralization and salinity indicators: EC, TDS and dry residue

Mineralization is a group of key indicators that characterize the “total load” of water. In practice, EC (electrical conductivity) is considered a “operational indicator” that is quickly measured, since it is directly related to the ionic composition of water; TDS and dry residue act as different measurement approaches to the same process. The EC in the sample is at 0.66 mS/cm (approximately 660 µS/cm). This figure is significantly lower than the 2500 µS/cm given for the EU in the comparison table for the Jeyranbatan reservoir (GOST, 1982). TDS was measured at 330 mg/L and dry residue at 665 mg/L. Since the maximum permissible limit for drinking water in the report for dry residue is 1000 mg/L, the result of 665 mg/L remains within this limit. The same logic applies to TDS: 330 mg/L against the 1500 mg/L limit indicates a low mineralization level (Ganbarov, et al., 2020, p.18). To understand these results on a more "systemic" scale, it is useful to look at the hydro-chemical ranges along the Takhtakorpu–Ceyranbatan canal. The relevant hydrochemical study shows that the normal mineralization for the Takhtakorpu-Ceyranbatan canal varies in the range of approximately 312.3–461.2 mg/L. The TDS output of 330 mg/L in the sample coincides with the lower part of that interval and can be interpreted as a fit indicating that the overall background of mineralization in the channel has stabilized in the "low–medium" range. At the same time, the fact that the dry residue indicator is higher than the TDS increases the possibility of differences in measurement approaches (for example, some non-volatile fractions have a greater share in the dry residue, while the TDS is given as an instrument calculation); such differences increase the need for method unification when comparing between systems. Regarding the risk of irrigation in terms of salinity, the value of 0.66 mS/cm for EC in the laboratory classification falls within the class I range (<0.75) (GOST, 1982). This can be taken as a "sign" that the risk of salt accumulation in the soil is low at an early stage. The key point here is that the risk in irrigation is not limited to EC alone: the relative share of sodium, the mechanical composition of the soil and the irrigation regime are equally crucial. Therefore, while a good EC output creates a positive background, maintaining a wide range of control parameters is a more sound approach (IWRA, 2018).

8. pH and Hydrocarbonate: acidity-alkalinity balance and stability

pH is one of the main parameters indicating the acidity-alkalinity environment of water and affects the risks of both corrosion and sedimentation (e.g. carbonate deposits). In the example, the pH is 7.67. This value corresponds to the range of 7–8 given in the report for drinking water. At the same time, the comparison table for the Jeyranbatan reservoir gives ranges of 6.5–8.5 for WHO and 6–9 for EU, with 7.67 being in the central part of these ranges. Hydrocarbonate (HCO_3^-) was measured at 116 mg/L. Hydrocarbonate forms the alkalinity reserve of water and helps to keep the pH "constant"; therefore, the combination of pH 7.67 and HCO_3^- 116 mg/L indicates that the buffer system in the water is working. This is important from a technological point of view in two ways: first, the reduction of rapid pH fluctuations makes it easier to control in processes such as chlorination/ozonation; second, the strengthening of the carbonate system can increase the tendency for sedimentation in some installations (especially when the hardness is high). Here, however, the sedimentation risk does not appear to be "acute" since the total hardness is low. The fact that pH remains within generally accepted norms on a system scale is also noted in hydro-chemical studies of the Takhtakorpu-Ceyranbatan canal and related facilities: pH and a number of chemical indicators are reported to be within the normative range. This consistency reinforces the logical appearance of the pattern not only "locally", but also within the context of the overall system.

9. Chloride (Cl^-): taste, corrosion, and source effects

Chlorides are among the ions that can affect the taste of water and also increase the risk of corrosion in metal structures. The Cl^- in the sample is 78 mg/L.

10. My analysis results

This value is lower than the limit of 250 mg/L given for WHO and EU in the Jeyranbatan comparison table, and the limit of 350 mg/L given for GOST. It also creates a safety margin of 78 mg/L against the 350 mg/L limit specified for drinking water in the laboratory report (IWRA, 2018). This has two consequences. First, chloride does not appear to be the "first suspect" for complaints about taste and saltiness. Secondly, the role of chloride in terms of corrosion should be assessed in conjunction with other factors (pH, oxygen regime, temperature, total mineralization of the water); here, since the pH is close to the neutral zone and the mineralization is not high, the possibility of chloride exacerbating the corrosion risk seems low. Again, this conclusion does not exclude the possibility that the situation may change in individual parts of the system (for example, in zones without steady flow).

11. General roughness: sediment potential and technological impacts.

Hardness (related to Ca^{2+} and Mg^{2+}) is one of the main indicators that changes the technological "behavior" of water. In the example, hardness is given as 54 mg/L. When this indicator is taken as $CaCO_3$ equivalent, it is approximately 1.08 meg/L and is close to, but lower than, the 1.2 meg/L indicator given for the EU in the Jeyranbatan comparison table. This indicates that the water has a "soft-low hardness" character. Hydrochemical research on the Takhtakorpu-Ceyranbatan canal also shows that the hardness varies in the range of 3.1–4.5 mg-eq/L (depending on the season and location). The sample yield of 1.08 meg/L is below that range, and this may indicate either a "softer water window" for the time and location of collection, or a difference in measurement unit/method (IWRA, 2018). The important point here is that the hardness indicator should not only be used as "below/above the norm", but also as a "mode parameter" for optimizing processing processes. For example, very soft water can in some cases increase the tendency to corrosion; very hard water can increase the risk of sedimentation and rapid clogging of filters. Since the hardness in the sample is low, the source of the sedimentation risk should be sought more in other parameters such as turbidity and suspended solids (World Bank, 2011).

12. Sodium (Na^+) and potassium (K^+): salinity trend and sanitary framework in terms of irrigation

Sodium was measured at 115 mg/L and potassium at 4 mg/L. Since the report provides limits of 200 mg/L for Na and 10 mg/L for K for drinking water, both indicators are within those limits. In terms of irrigation, sodium assessment is more sensitive because the issue here is not concentration alone, but the ratio of sodium to calcium-magnesium (indices such as SAR). Since the available data do not separately provide the Ca^{2+} and Mg^{2+} required for SAR, the "soda effect" of sodium can only be interpreted at a preliminary level. However, given that the laboratory classification specifies a Class I cutoff for Na as ≤180 mg/L, a result of 115 mg/L falls into the low-risk zone. This reduces the likelihood that sodium alone is a limiting factor, especially in normally drained soils. However, from a practical management perspective, this result does not mean "no risk": factors such as the salinization tendency of the soil, the amount of irrigation water, and the salinity of the soil solution must be monitored simultaneously (Pashayev & Hasanov, 2010).

13. Interpretation of results in a normative context and risk mapping

The indicators selected in the sample for the Jeyranbatan canal (pH, Cl^-, Na^+, EC, TDS, dry residue, hardness) are generally consistent with both the drinking water limits given in the report and the regulatory comparison framework for Jeyranbatan. This consistency indicates that the water has a stable and controllable quality background in terms of "major ions". However, the real risks to water quality often lie beyond the "essential ions." The hydro-chemical study conducted on the Takhtakorpu-Ceyranbatan canal and related facilities highlights the fact that biogenic indicators such as ammonium ions may increase in some periods, rivers may take on pollution loads when passing through densely populated areas, and this affects the hydro-chemical regime. This indicates that indicators that are not measured in the current example, but are critical to the system (NH_4^+, NO_2^-, NO_3^-, PO_4^{3-}, BOD_5/COD, microelements and microbiological parameters) must also be included in the program. Another important issue is monitoring frequency. It is noted that in the study conducted on the Jeyranbatan reservoir, more frequent measurements (daily/monthly/quarterly) showed clearer results and that more frequent measurements were appropriate for some parameters (Ganbarov, et al., p.25). This approach is particularly important for channel lines: as the water flow rate and mixing regime change, "peak" events can occur for a short time and then disappear. It is possible to miss this peak in single measurements. Therefore, a risk-based approach seems more workable: for example, operational indicators such as pH, EC and turbidity can be measured more intensively; heavy metals and some trace elements can be measured at longer intervals.

14. Result

Physico-chemical analysis of a sample taken from the Ceyranbatan Canal (part of the Takhtakorpu–Ceyranbatan aqueduct system) shows that the water quality is generally satisfactory according to selected indicators: pH is close to the neutral zone (7.67), electrical conductivity is in the low-medium range (0.66 mS/cm), chloride and sodium concentrations are both within the limits set for drinking water and fall into the low risk zone according to the irrigation water classification. The results do not contradict the hydro-chemical background of the Takhtakorpu-Ceyranbatan channel: against the background of seasonal changes in mineralization and roughness throughout the system, the measured mineralization indicator corresponds to the lower part of the general range. At the same time, assessment limited to "major ions" is not sufficient for sustainable water quality management. Since system studies have shown that some biogenic indicators can increase in certain periods and that anthropogenic impact along the stream affects the hydro-chemical regime, the monitoring program must include nitrogen forms, phosphates, BOD_5/COD, microelements, and microbiological indicators. It is also important to differentiate the measurement frequency by parameter: more frequent monitoring makes the results clearer and allows you to capture risky "peak" events.

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