Exploration Geophysics, Remote Sensing and Environment ***XXX.2 (2023)***

DOI: 10.26345/EGRSE-001-23-201

APPLICATION OF MODERN METHODS TO IDENTIFY SOURCES OF GROUNDWATER POLLUTION WITH PETROLEUM PRODUCTS

APLIKACE MODERNÍCH METOD K IDENTIFIKACI ZDROJŮ ZNEČIŠTĚNÍ PODZEMNÍ VODY ROPNÝMI PRODUKTY

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Abstract

The article discusses the problems of the development of processes of pollution of the geological environment with petroleum products in the area around the location of the oil refinery. It is indicated that petroleum products seeping through the aeration zone enter groundwater and spread with the flow, creating powerful halos of pollution, worsening the environmental situation. The results of electrical tomographic measurements are presented, which revealed anomalous zones of low resistivity associated with local accumulations of petroleum products in the aeration zone and groundwater.

Abstrakt

Článek pojednává o problematice vývoje procesů znečišťování geologického prostředí ropnými produkty v okolí ropné rafinérie. Ukazuje se, že ropné produkty prosakující aerační zónou vstupují do podzemních vod a šíří ve směru proudění, vytvářejí silnou aureolu znečištění a zhoršují ekologickou situaci. V článku jsou prezentovány výsledky elektrických tomografických měření, které odhalily anomální zóny nízkého měrného odporu spojené s lokální akumulací ropných produktů v aerační zóně a podzemních vodách.

Keywords

Geological environment, groundwater, oil pollution, geoelectrical tomography, 2D, 3D models

Klíčová slova

Životní prostředí, podzemní voda, ropné znečištění, elektrická tomografie, 2D, 3D modely

1. Introduction

Currently, oil products, which are a complex mixture of organic substances, play an increasingly important role in the problem of pollution of the geological environment. This is due to the fact that oil pollution occurs at all stages of human economic activity, starting with oil losses during its extraction, processing and transportation, ending with leaks from surface and underground hydrocarbon fuel storage facilities (Abdullaev, 2017; Abdullaev, 1998). Thus, we can say that the flow of light fractions of oil products into the geological environment occurs everywhere and constantly.

First of all, pollution of the geological environment with oil products affects groundwater, since they are its most mobile component. This feature causes widespread pollution in the geological environment with groundwater (Mingboev, 2012). In addition, as a result of the discharge of polluted groundwater into reservoirs and watercourses, surface water is polluted with oil products, spreading in which pollutants damage environmental objects and lead to damage and destruction of ecosystems. In this study, as an object for studying this problem, the territory was chosen, within which a potential source of groundwater pollution with oil products is located - the industrial site of the Fergana Oil Refinery (FOR).

2. The history of investigation

In the early 60s, at the northern end of the Kirguli adyrs, composed of well-permeable boulder-pebble deposits with a slight fine earth cover, the Fergana Oil Refinery was built. Here, for more than 60 years of operation of the Fergana Oil Refinery, as a result of various technological failures (leaks of raw materials and finished products) and planned losses in the aquifer, a powerful blue cap of groundwater pollution has formed, characterized by the presence of oil products in liquid (floating on the surface of groundwater) and dissolved forms.

According to experts, the area of distribution of oily forms of petroleum products on the surface of groundwater was about 4.5 km^2. The area of groundwater contamination with dissolved forms of petroleum products exceeded 15 km^2.

At the same time, dissolved petroleum products were recorded in the stream at depths of up to 150 m. Analyzes of water samples taken from water intake wells of the Tashlak water and oil intake, as well as operational water intake wells located downstream, with filter installation intervals of 100 - 140 m, indicate the presence of dissolved petroleum products in concentrations from 0.4 to 3.8 mg/l. Within the contours of the lens in the 25 - 30 meter near-surface layer of groundwater, the concentrations of dissolved petroleum products increase significantly and can reach 30 - 41.97 mg/l. The average concentrations of dissolved petroleum products in water for a 15-meter thickness are 11.69, for a 30-meter thickness - 9.15 mg/l.

Since the beginning of the discovery of groundwater pollution in the Tashlak district, research work has been carried out, on the basis of which Joint-stock company (JSC) "Uzneftepererabotka" and the Fergana Oil Refinery carried out the design and construction of a complex for localization and elimination of pollution. To combat groundwater pollution by oily forms of petroleum products in 1992. the first stage of the localization system was built, focused on the interception of floating forms of oil products (Mavlyanov et al., 2003).

In order to prevent further deterioration of the environmental situation in the study area, a number of measures were recommended in 1996, including drilling and equipping bunches of the second stage of the localization system. In parallel with stage II of the localization system, the construction of stage III of the system in the form of a closed drain was started in the area of the Tashlak stadium named after A. Timur, where oil products were wedged to the surface of the earth. The drain consists of perforated pipes with a diameter of 500 mm at a depth of 3 m (Abdullaev et al., 2015).

During the first years of operation of the III stage of the localization system, a significant amount of petroleum products was recovered from the frontal part. The operation of the third stage of the localization system made it possible to shorten the contour of oil product contamination. Layers of petroleum products above groundwater levels have decreased to a few centimeters. In recent years, the flow of oil products in the peripheral part of the alluvial fan has sharply decreased. A decreasing trend is observed over the entire area of the pollution blue cap. In order to improve the method of cleaning groundwater from oil pollution and improve the ecological situation in the region in the period 2006 – 2007, the intercepting system "OASIS" was built. The OASIS site is a well row of 8 water wells (one of which is alternately under repair), and 18 oil wells (Fig. 1). At present, it is OASIS system the main facility for localization of groundwater pollution of the Altyaryk - Beshalysh by oil products groundwater deposit.

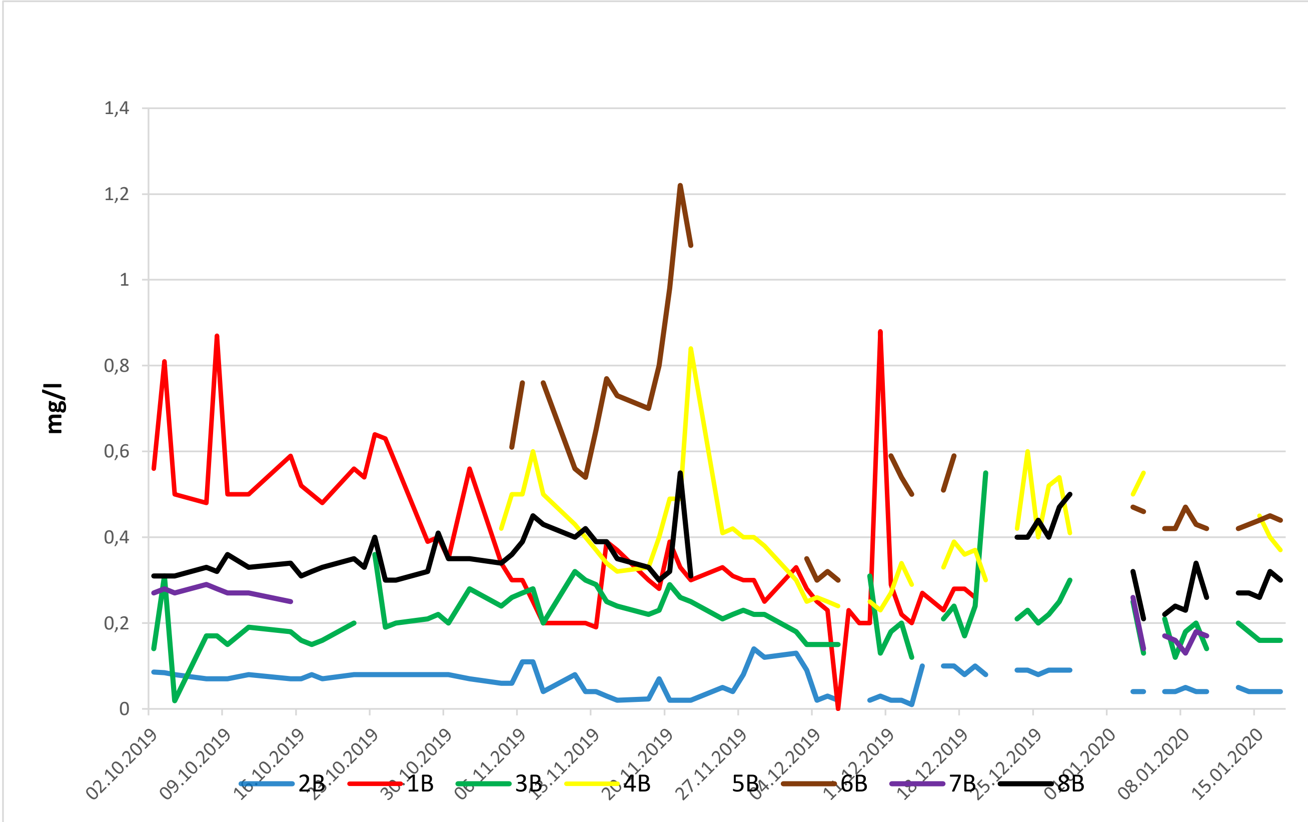

Fig. 1 Dynamics of changes in the content of dissolved petroleum products in water intake wells No. 1B-8B in the OASIS system

At present, the Oasis area is the most effective mechanism for solving the problem of pollution localization. This localization system is intended not only to eliminate existing focal seasonal manifestations, but also as an emergency measure in the form of spillage of oil products from the territory of the plant, so all facilities, pumping equipment and the protected area are maintained in working condition.

In 2020, the State Enterprise "Institute GIDROINGEO" in accordance with the agreement concluded with Limited Liability Company "Fergana Oil Refinery" (LLC "FOR") conducted research on the territory of the industrial site of the plant in order to assess the contamination of places of accumulation groundwater with oil products.

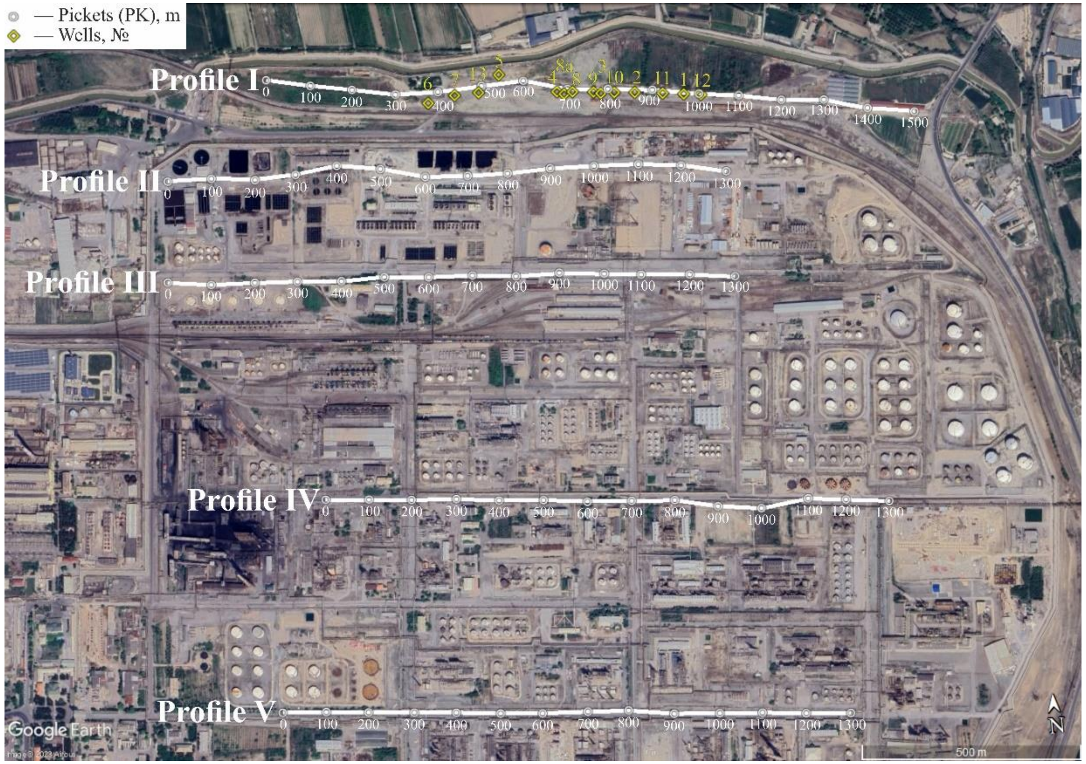

Fig. 2 Scheme of geoelectrotomographic profiles location on the industrial site

3. Work methodology

Control measurements of the groundwater level and the layer of oil products above the groundwater level (GWT) in wells and water points of the existing observation network were carried out jointly with the specialists of the Fergana Oil Refinery on a quarterly basis, in an annual cycle. All wells of the OASIS localization system were surveyed (8 water intakes, 18 oil intakes, 6 observation wells), observation wells in the industrial site with sampling. Were conducted laboratory analyzes of water to determine the content of oil products.

Geoelectrotomografic measurements were carried out using 81 - electrode electrotomographic equipment "Terrameter LS" (Sweden) (Dahlin, 2021; Loke, 2009). The geoelectrical profile consists of 4 separate segments of 100 m each. The distance between the electrodes is 5 m. The total length of one profile is 400 m. To obtain a continuous electrotomographic section along the profile to a depth of 50 – 60 m, measurements are carried out by overlapping the previous setup by 300 m.

Geoelectrotomographic measurements were carried out along 5 profiles oriented from west to east. (Fig. 2). Profile I is located within the OASIS site. Profiles II, III, IV, V are located within the territory of the plant. The distance between the profiles was 170 – 505 m. Profile I – 1500 m, Profile II – 1300 m, Profile III – 1300 m, Profile IV – 1300 m, Profile V – 1300 m. The total length of the profiles is 6700 m.

Processing and interpretation of the obtained field data was carried out using processing programs ZondRes2D, ZondRes3D. Using the ZondRes2D program, the results of measurements in 2D format were processed by data inversion and geoelectrotomographic sections were constructed. Using the ZondRes3D program, a three-dimensional interpretation of the geoelectrotomography data was carried out and three-dimensional geoelectrotomographic models were built using 5 parallel profiles (Bentley et al., 2004; Dahlin et al. 2002). Three-dimensional models are built on slices of 0 m, 10 m, 20 m, 30 m, 45 m, 55 m.

4. Results

The Ferghana Oil Refinery (FOR) is located in the junction zone of the Kirgilin adyrs in the head part of the alluvial fan of the Beshalyshsay river. The main part of the plant is located on the surface of the fan. In geological and lithological terms, the study area is represented by alluvial-proluvial boulder-pebble deposits with sand-gravel filler. The thickness of these deposits is 90 – 105 m. The cover deposits are represented by sandy loam and sand. Their thickness is 1.5 – 2.0 m.

Seasonal variability of the groundwater level is characterized by an intense rise from April to July and a slow decline from August-September to March. At the same time, the intensity of the rise is twice as high as the decline. The rise occurs within 3 – 3.5months, the decline is 6 – 7 months. Depending on the location of observation wells in the adyr part, transition zone, head and central parts of the alluvial fan, the maximum position of the groundwater level is observed from late July-early August to September, the minimum - from March to April. At the periphery of the alluvial fan, the seasonal fluctuations of GWT are somewhat different. Its maximum position is recorded from September to January, the minimum - in April-May. The amplitude of fluctuations in the groundwater level varies from 8 – 10 m in the adyr zone to 0.5 – 2.5 m in the peripheral part of the alluvial fan (Fig. 3, 4).

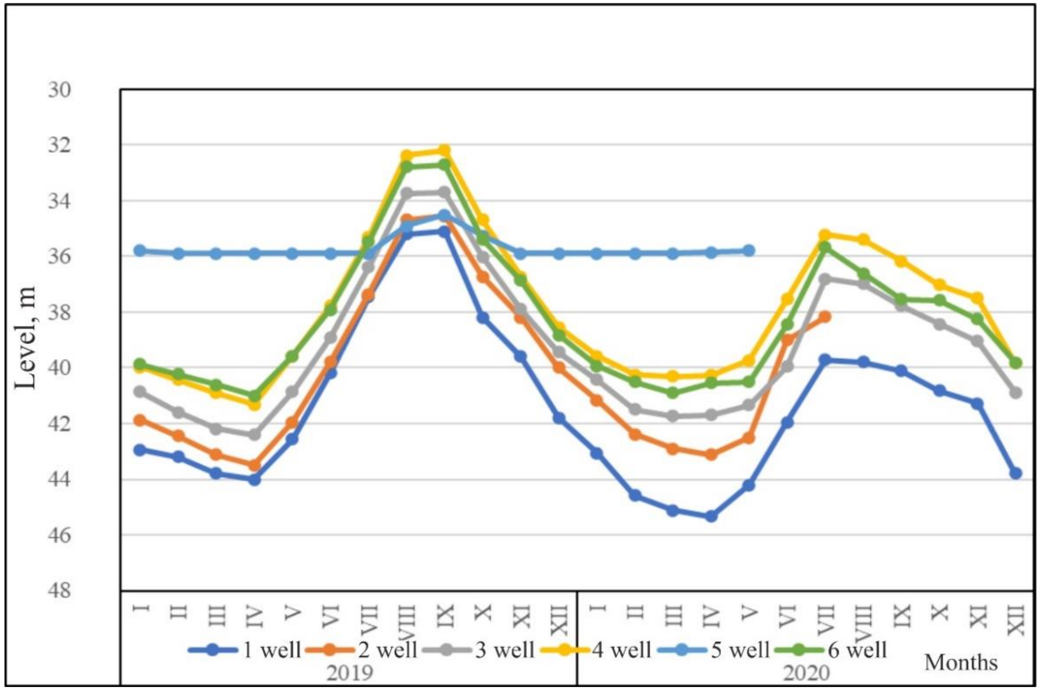

Fig. 3 Seasonal changes in the groundwater level in the observation wells of the OASIS system. Level, m - means meters below the surface of the earth

Based on the results of previously conducted geophysical studies in this area, it was established that boulder-pebble deposits, located in a natural, unpolluted state in the aeration zone (the rock thickness of the aeration zone is about 20 - 45 meters), are characterized by a specific electrical resistivity of 400 –800 Ωm. The same deposits, which are in a water-bearing state (below the GWT), are characterized by specific electrical resistances of the order of 140 – 400 Ωm.

The results of the performed geophysical surveys by the method of electrical tomography are presented in two formats - 2D and 3D. In the 2D format, the results are presented in the form of electrotomographic sections in terms of resistivity (ρ_a) and polarizability (η_a). On the sections, the values of these indicators are presented in colors with isolines. Low specific resistances of the order of 6 – 20 Ωm, correspond to the range from dark blue to blue. High resistivities of the order of 150 – 900 correspond to colors ranging from orange to purple.

Low polarizability values of the order of 1 – 2.3 % are characterized by a blue color gamut. High values of polarizability in the section are highlighted in red. When describing the measurement results, the electrotomographic section is conditionally divided into two parts by depth.

The upper part represents an area of sediments lying above the groundwater level (aeration zone). The lower part of the section characterizes the sediments lying below the groundwater level (water saturation zone), taking into account the aforementioned GWT fluctuations. GWT fluctuation amplitude in this area is 4 – 6 m.

Profile I. It is located on the OASIS site and is oriented from west to east. In the aeration zone, anomalously low resistivities can be traced from depths of the order of 10 – 12 m (Fig. 5). Basically, they are located within stakes PK280 - PK1100. The width of low resistance zones is 60 – 250 m. Low resistivities indicate the presence of hydrocarbons in the rocks.

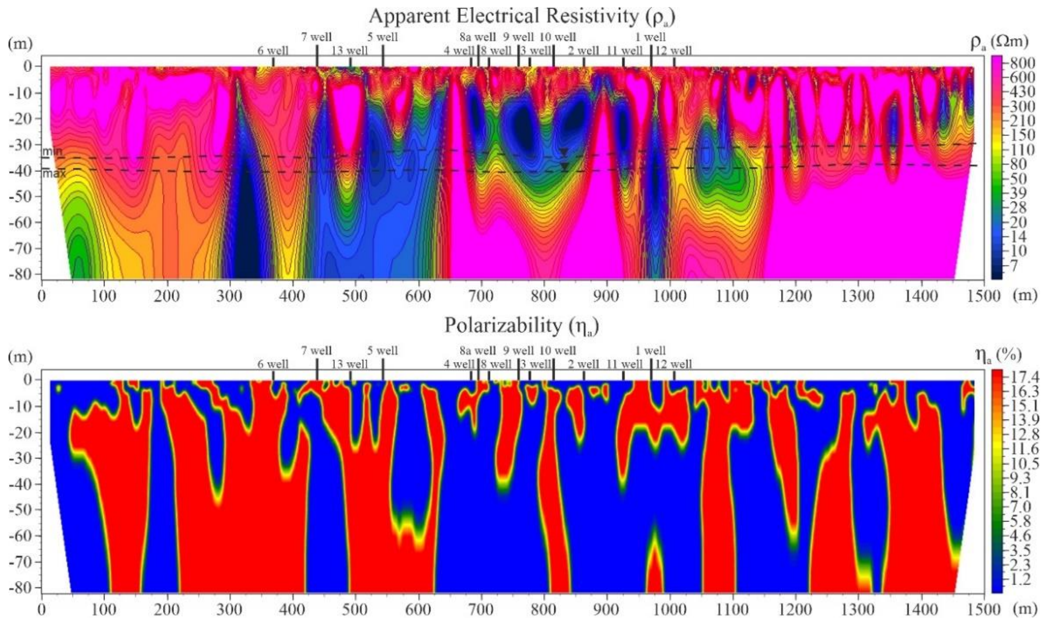

Fig. 5 Electrotomographic section along the profile I – I. Min and max boundaries are the intervals of fluctuations in groundwater levels (GWT)

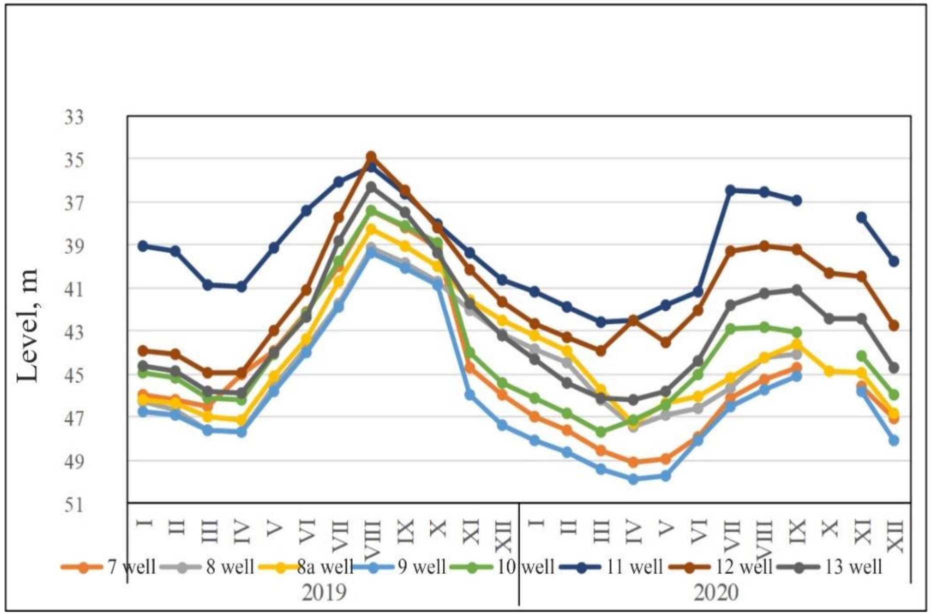

Fig. 4 Seasonal changes in the groundwater level for observation wells in the industrial site. Level, m - means meters below the surface of the earth

The most anomalously low resistivities associated with the highest content of oil products are observed in the range of stakes PK680 - PK710, PK750 - PK850, PK920 - PK940. The maximum thickness of the content of oil products in sediments is 22 – 24 m and was noted in the range of pickets PK750 - PK850.

High values of polarizability (η_a) indices along the profile can be traced everywhere. Moreover, they are confined both to the zones of distribution of low resistivity, and to the regions of distribution of high resistances. Therefore, it was not possible to unambiguously link the polarizability indices to the resistivity values. It should be noted that the nature of the occurrence of polarizability in deposits saturated with oil

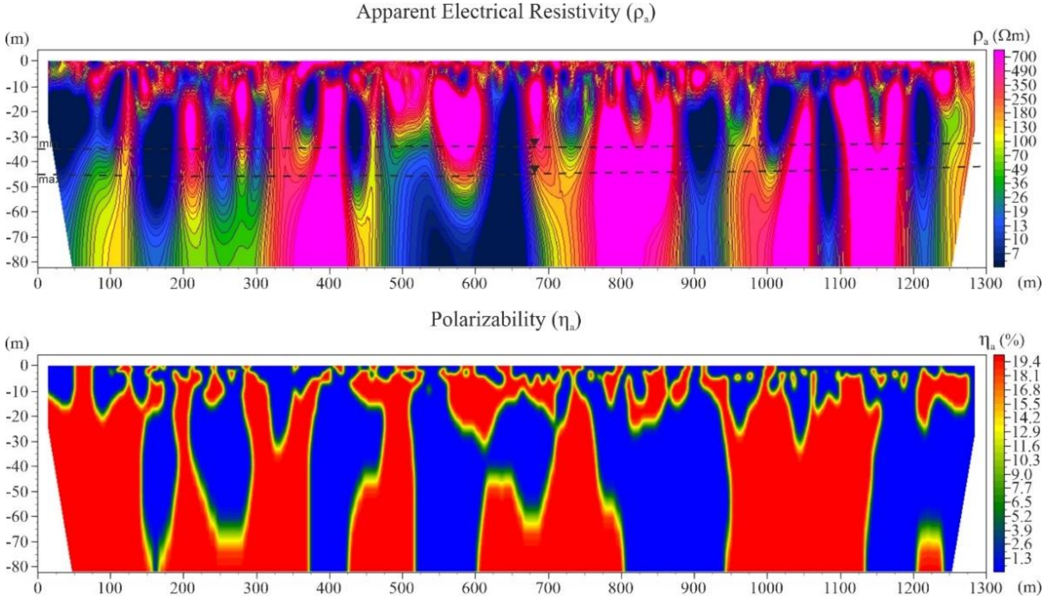

Fig. 6 Electrotomographic section along the profile II – II. Min and max boundaries are the intervals of fluctuations in groundwater levels (GWT)

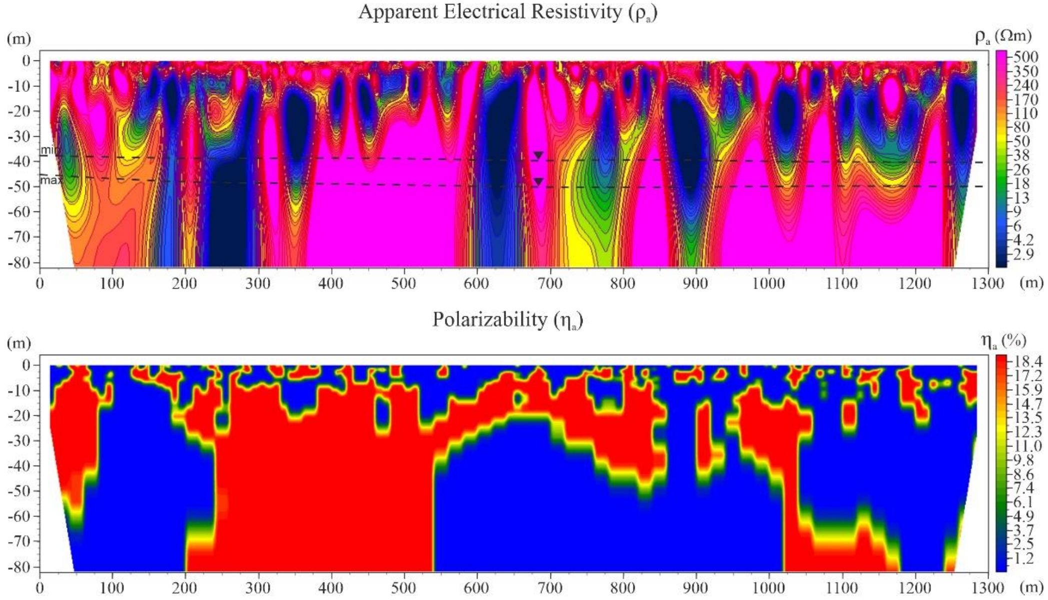

Fig. 7 Electrotomographic section along profile III – III. Min and max boundaries are the intervals of fluctuations in groundwater levels (GWT)

products, as well as the degree of their influence on polarizability, especially in pebble deposits, has not yet been fully and comprehensively studied. Therefore, the main tool for detecting the presence of oil products in a given territory, we adopted the indicator of apparent electrical resistivity (ρ_a).

In the zone below the groundwater level, low resistivity is common in the range of stakes PK280 - PK375, PK425 - PK600, PK960 - PK980. The lowest values of ρk are observed in the interval of stakes PK 305 - PK350.

Profile II. It is located on the territory of the plant, 180 m from profile I and is oriented from west to east. In the aeration zone, low resistances associated with the presence of oil products are observed already from the earth's surface (Fig. 6). Here, areas of presence of oil products are noted in the areas of pickets PK25, PK100, PK125, PK250, PK300, PK350, PK350, PK425, PK650, PK725, PK810, PK925, PK1010, PK1075, PK1210.

Low resistance anomalies have lenticular shapes, elongated in the vertical direction. In most cases, anomalies are confined to zones of GWT fluctuations. Their thickness ranges from 20 – 55 m. Some of the anomalies extend below the GWT.

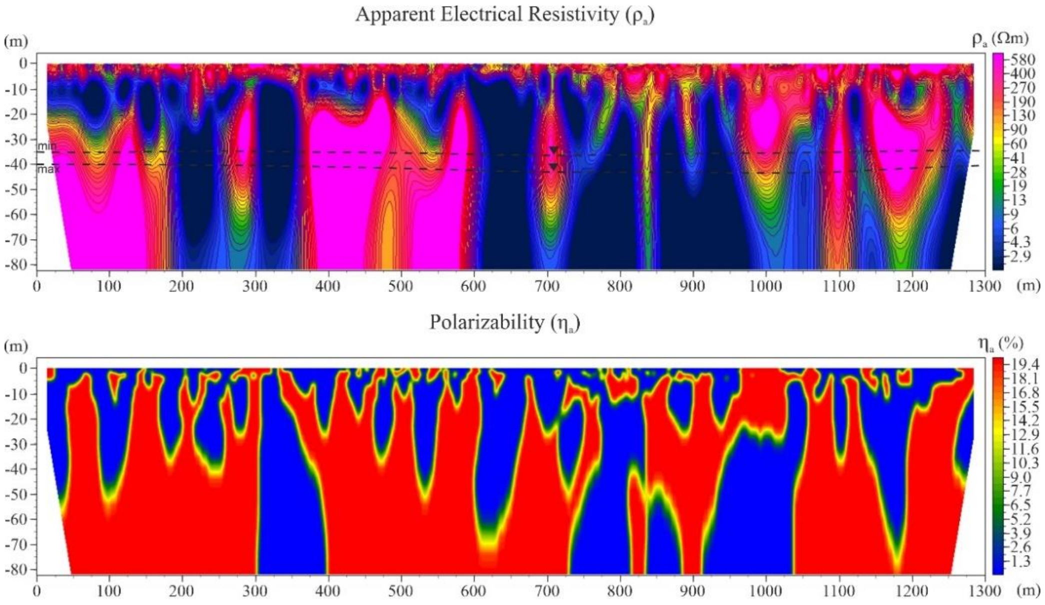

Fig. 8 Electrotomographic section along the profile IV – IV. Min and max boundaries are the intervals of fluctuations in groundwater levels (GWT)

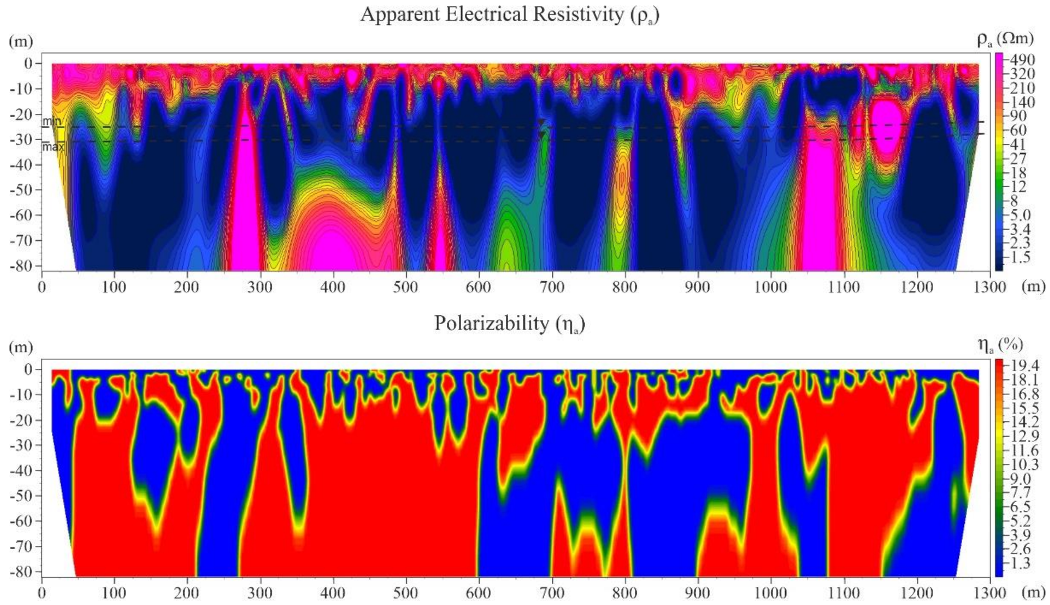

Fig. 9 Electrotomographic section along the profile V – V. Min and max boundaries are the intervals of fluctuations in groundwater levels (GWT)

In the water-saturated zone (below the GWT fluctuations), low resistivity associated with oil products is observed in the range of stakes PK160 - PK180, PK450 - PK700, PK880 - PK940, PK1060 - PK1100, PK1225 - PK1260. The most intense anomaly was noted in the interval of stake PK510 - PK650.

Profile III. Located on the territory of the plant, 210 m southwards from profile II. In the thickness of the aeration zone, anomalies of low resistance were noted in the areas of stakes PK50, PK150, PK275, PK350, PK950, PK1025, PK1060, PK1100, PK1150, PK1175, PK1250 (Fig. 7). The anomalies are lenticular in shape and elongated in the vertical direction.

Some of the anomalies are common in the zone of GWT fluctuations. In the water saturation zone (below the GWT), low resistivity anomalies associated with the presence of oil products are observed in the following intervals: PK150 - PK200, PK210 - PK300, PK600 - PK660, PK875 - PK910. The most intense anomaly was noted in the interval of stakes PK225 - PK300, PK600 - PK660.

Profile IV. It is located on the territory of the plant 450 m from profile III and is oriented from west to east. Intense low resistivity anomalies can be traced from depths of about 3 – 5 m. (Fig. 8). In the thickness of the aeration zone, low resistance anomalies are observed in the areas of stakes PK100, PK150, PK225, PK325, PK400, PK550, PK650, PK725, PK775, PK875, PK930, PK1125.5, PK930, PK1125.

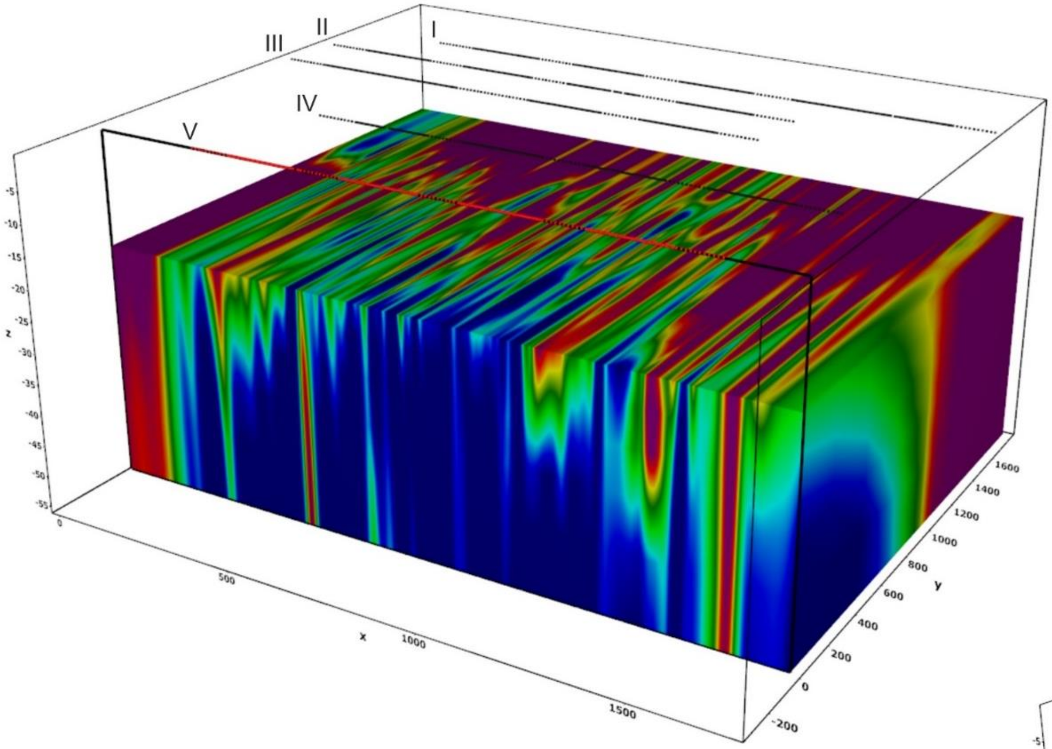

Fig. 10 Three-dimensional model for a section at depth of 10 m

Anomalies have lenticular shape and elongated in the vertical direction.

Part of the anomalies at stakes PK200 - PK250, PK300 - PK350, PK600 -PK700, PK725 - PK825, PK850 - PK975 extend the GWT fluctuation zone and propagate in the water saturation zone. In the water saturation zone along this profile, 5 areas of anomalously low resistivity were noted, associated with the presence of oil products in the rocks. The width of these sections ranges from 50 m to 225 m. At the very end of profile IV, a section of low resistance is quite clearly distinguished, the width of which was not possible to determine.

Profile V. Located on the territory of the plant, 450 m from profile IV and oriented from west to east. The presence of oil products is noted from depths of about 1.0 – 1.5 m (Fig. 9). The aeration zone is characterized by almost ubiquitous anomalously low resistances indicating the presence of oil products. A significant part of the zones with low resistances propagate vertically downward, covering the zone of GWT fluctuations and the zone of water-saturated rocks.

In the zone of complete water saturation (below the GWT), low resistivity is also ubiquitous. The most intense anomalies are noted in 12 sites. Their width varies from 75 m to 450 m.

To analyze the spatial distribution of low resistivity in rock deposits in the aeration zone and, accordingly, the presence of oil

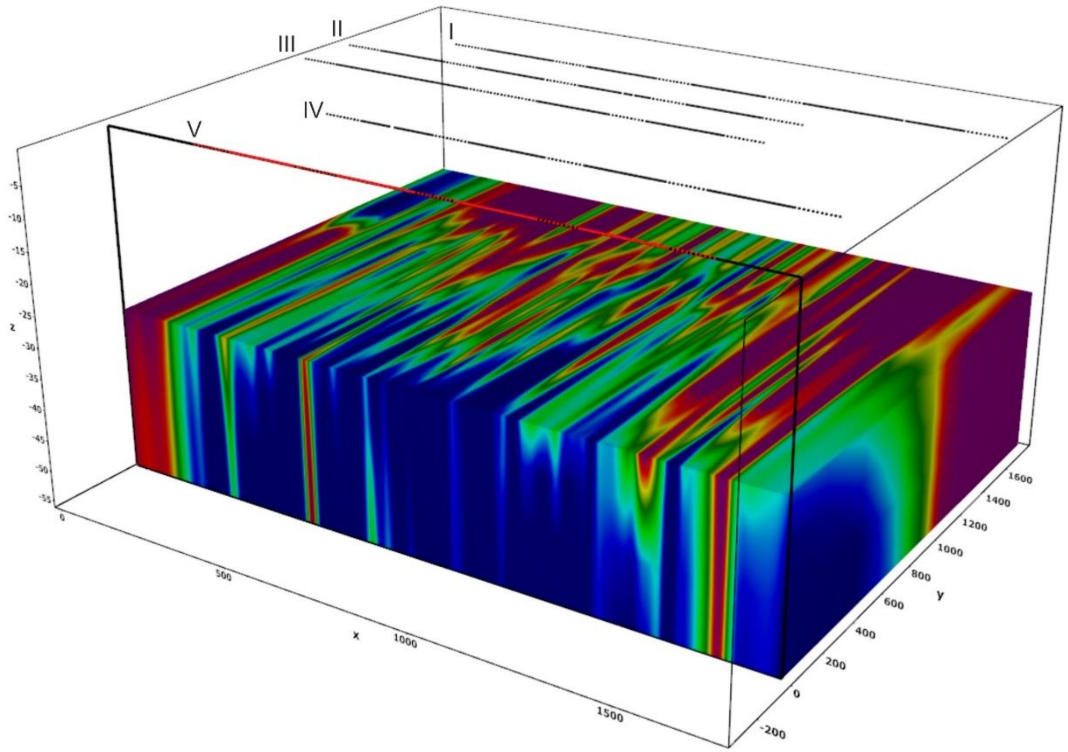

Fig. 11 Three-dimensional model for a section at a depth of 20 m

products, three-dimensional models were built at various depths (Fig. 10 – 13).

The constructed three-dimensional model on a slice of 10 m and 20 m characterizes the zones of distribution of low resistance and, accordingly, the presence of oil products in the aeration zone, i.e. in sediments lying above the GWT (Fig. 10, 11).

As can be seen from the figures, the intensity and horizontal thickness of the low resistance area at a depth of 10 m is greater than at a depth of 20 m, moreover, on profiles located on the territory of the plant (Profiles IV, V). The number of low resistivity anomalies is much greater than on other profiles.

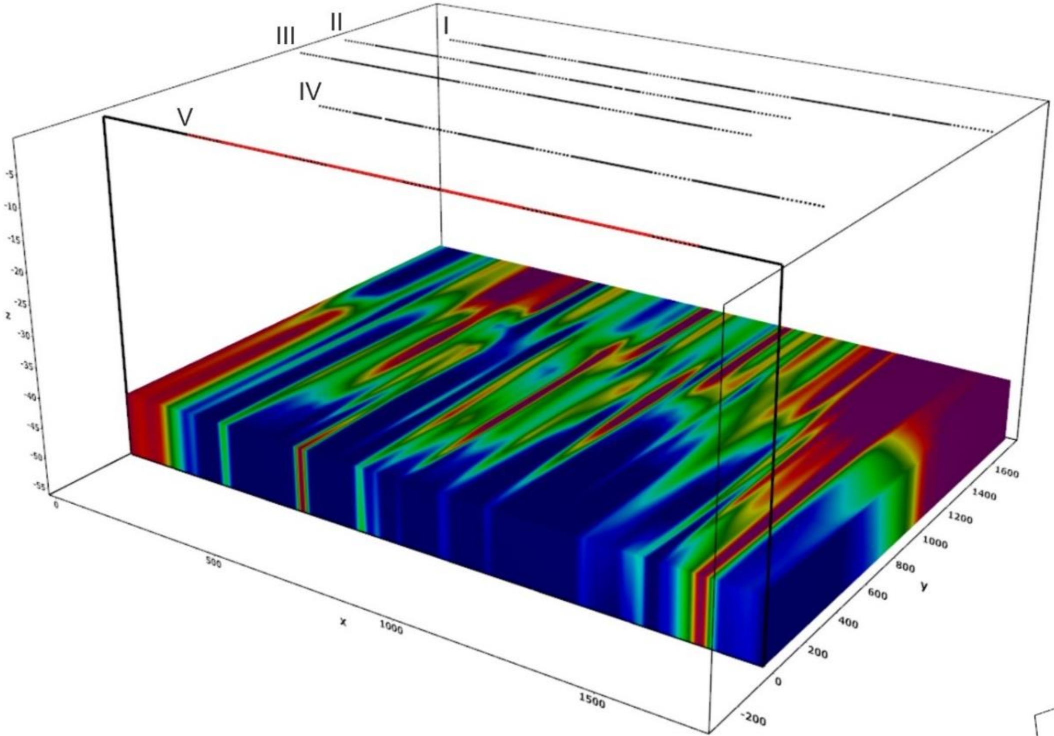

Fig. 12 3D model of the section at a depth of 45 m

At the same time, the minimum number of anomalous zones is observed on profile I, located on the OASIS site. This situation is explained by the fact that in the zone of the industrial site there is a source from the surface of the earth. The anomalous zone identified in the industrial zone is elongated from south to north. Apparently, in the aeration zone with depth, there is an increase in the migration of oil products in a northerly direction.

Slices 45 and 55 characterize the zones of distribution of low resistivity and correspond to the distribution of oil products in the water-saturated zone (below the GWT) (Fig. 12, 13).

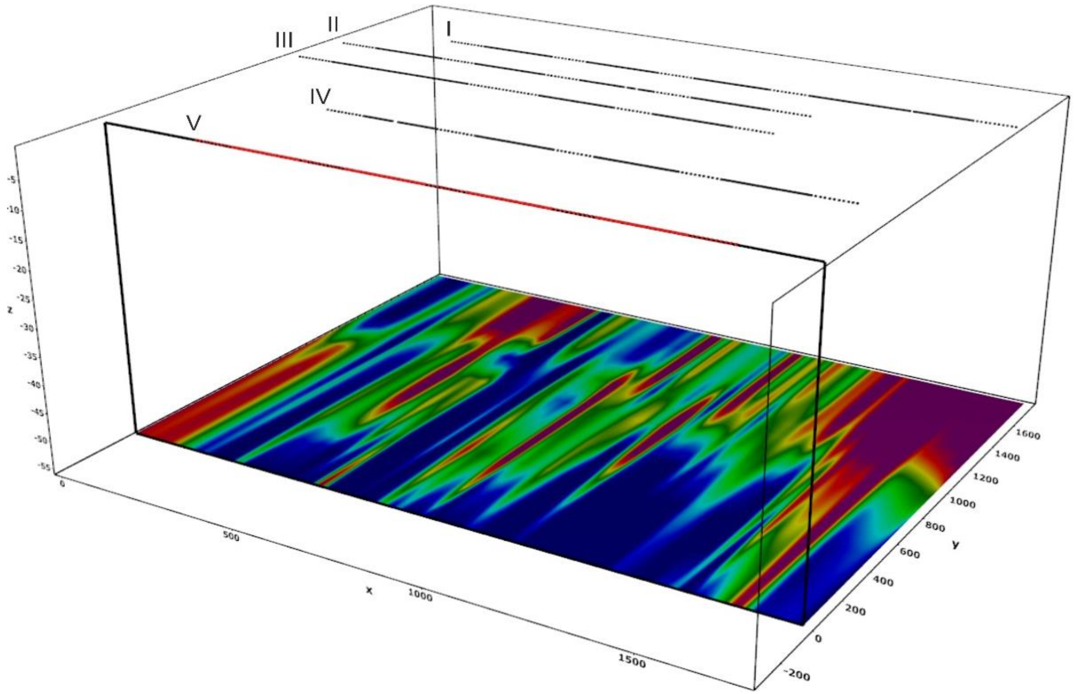

Fig. 13 3D model of the section at a depth of 55 m

As can be seen from the figures, the most intense oil pollution in the water-saturated zone is observed on profiles IV and V. They are almost ubiquitous. The highest intensity is observed on profile V. Further to north (Profile IV), the width of the most intense zones decreases. A decrease in intensity is also observed on profiles III, II, I. The minimum intensity of propagation of low resistances is noted on profile I, where zones are identified that spread in the western and middle parts of profile I. It follows from the foregoing that oil products entering the aquifer from surface sources in the areas of profiles IV and V migrate along with the flow to the north, along several channels confined to well-permeable rocks. Filling the pores of pebble deposits, they are the cause of low resistivity.

5. Conclusion

1. The entry of oil products into the geological environment entails the formation of long-term foci of pollution, characterized by the saturation of rocks with their sorbed forms, the formation of developing lenses of oil forms on the surface of groundwater, the intensive migration of dissolved forms with the flow of groundwater, as well as the formation of combustible and toxic gaseous products. The elimination of the formed sources of pollution should include, first of all, the elimination of oily forms of petroleum products from the surface of groundwater.

2. The fight against oil pollution in Uzbekistan has been going on for decades, but the scale of this phenomenon is growing and from local objects reaching regional limits. The fact of this nature of the “development” of the phenomenon of oil pollution of water bodies was tracked by their monitoring, but no scientific explanation was received. Obviously, understanding and explaining this fact from scientific and practical positions is both relevant and significant, especially if we take into account the specifics of the country's natural conditions and the environmental and social situation.

3. Areas of anomalously low resistivity, and identified in the study area, are associated with the presence of oil products in the thickness of boulder-pebble deposits. The most intensive distribution of oil products both in the aeration zone and in the water saturation zone (below the GWT) is observed on the territory of the plant on profiles IV and V. In the north direction from the plant, a decrease in the presence of oil products is observed. The distribution of oil products in water-saturated rocks occurs through several channels confined to permeable rocks. In them, part of the oil products are deposited in the rocks and accumulate there.

4. Observation wells of the monitoring network as a whole require optimization by conducting a study of the dynamic change in the blue cup of groundwater pollution by oily and dissolved forms of oil products. To obtain full information on the development of the pollution blue cup and make a decision, it is necessary to monitor groundwater both at the industrial site and within the contour of the pollution blue cup. To do this, it is necessary to solve the issues of cleaning and restoring observation wells of the monitoring network.

5. It is necessary to carry out experimental and filtration work to determine the effective operation of the system for localization and elimination of all queues. Encrteasing of the layer of oil products above the GWT in the territory of the OASIS begins from January to May, when the groundwater level decreases. This circumstance is associated with natural and man-made factors that require a detailed study. The

water intake and observation wells of the left flank of the OASIS do not work at the proper level due to a technical malfunction that reduces the efficiency of this system.

6. To assess the efficiency of the OASIS localization system, it is necessary to regularly monitor the size of the groundwater pollution blue cup and assess the environmental hazard of geological environment pollution. At the same time, the localization system should work as oil forms of oil products accumulate above the groundwater level.

7. In general, in the Tashlak area, in addition to the zone of distribution of the layer of petroleum products above the groundwater level, groundwater is everywhere polluted with dissolved forms of petroleum products, exceeding the maximum standards by 3 – 10 times, the area of which is more than 15 square kilometers, which requires a detailed study to make a decision.

8. The rocks of the aeration zone in the area of the industrial site of the plant are contaminated with oil products and are a secondary source of oil products entering the groundwater (with fluctuations in the level and infiltration of atmospheric precipitation), it is necessary to study the volumes and forms of accumulation of oil products in the pore space of soils under the pollution source. Contaminated soils of the aeration zone at the border with the groundwater level remain potential sources of groundwater pollution with oil products, forming a powerful secondary source of pollution.

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