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### RESEARCH ARTICLE

## COMPUTER PROCESSING OF EXPERIMENTAL GPR DATA TO OBTAIN A THREE-DIMENSIONAL IMAGE OF UNDERGROUND ANOMALOUS AREAS

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### Abstract

Underground three-dimensional topography measured by sounding of radio waves with the help of ground penetrating radar (GPR) has been studied. Our goal is to obtain and analyze a 3D representation of experimental data on the passage of plane polarized electromagnetic radiation through real underground objects and the intensity of its reflection received by the receiver antenna. We are developing an inductive method. The radio sounding using of the GPR SDI K-5 with frequency range of 1÷10 MHz at depths of 10, 20 and 40 m and surface area 50×20 m has been researched. Experimental data of radio sounding was written in the ASCII table by microcontroller and then imported to OriginLab program. The use of computer processing by OriginLab program of experimental GPR data made it possible to obtain a three-dimensional image of the anomalous area, from which the reflected electromagnetic signal comes much weaker than from neighboring areas. Measuring the response of only the electrical component makes it possible to identify areas containing water, since water has a dielectric constant that is much higher than that of terrestrial rocks. Measuring the response of only the magnetic component makes it possible to detect anomalous regions containing materials with high magnetic permeability and significantly affecting the intensity of the reflected radio wave. The accuracy of determining the geometric dimensions is limited by our measurement step for surface(5 m) and sounding underground depths (10, 20 and 40 m). This is sufficient for large underground domain. The information content of 3D graphs and the accuracy of measurements of geometric parameters can be significantly increased.

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### Introduction:-

Innovative sensor technologies are becoming increasingly necessary in many areas of civil engineering. Non-intrusive verification of the studied materials is possible thanks to one of the most advanced sounding technologies - ground penetrating radar (GPR). GPR is widely used in various subsurface imaging applications, including

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assessment of road concrete structures, underground utilities, hazardous waste, liquid pollutants, buried archaeological sites and geological boundaries (fractures, bedding planes) [1]. The method allows detecting various underground areas invisible to humans from the surface (cavities filled with air or water, objects containing magnetic materials and other anomalies in the propagation of radio waves in the earth's crust or concrete structures) [2-4].

The technology of radio-wave method (RWM) allows survey of ground areas in terms of determination of their lithological structure by genesis, detection of horizons filtration flows of the ground waters, the minerals deposit search and, etc [5]. RWM is one of geophysical research techniques which are based on study of the process of electromagnetic waves propagation through rocks and observation of inductive effects in ground layers with different values of conductivity, dielectric permittivity and magnetic permeability. Among RM methods one may distinguish a separate group of inductive methods in which the electromagnetic field is created by of the loop with the variable current. As loops one may use small-size frames, large rectangular loops, very long cables, etc. [6,7]. Currently, relevant research is the recognition of underground objects based on GPR data and the use of convolutional and recurrent neural networks to detect hidden threats using GPR [8,9].

We are developing an inductive method, the idea of which is as follows. The primary alternating field of the loop induces eddy currents in the conducting geoelectric section, the intensity of which is determined by the resistivity of the geoelectric section and its magnetic properties, as well as the position of the loop. Currents flowing on subsurface of media create secondary magnetic field which overlaps over the primary magnetic field and creates abnormalities (responses to influence of the first magnetic field) which to measure with the help of receiving loop.

If place two small-size loops on the ground surface, and name one of them generator magnetic dipole which generates the first variable electromagnetic field, and the second one – the measuring magnetic dipole, then two such loops may compose a dipole inductive radio- wave system, which may be used for profiling and sounding of ground massif. Dipole inductive profiling (DIP) is performed without any changes in mutual position of the loops.

A big interest in such studies can be three-dimensional images of underground objects associated with various absorption and reflection of electromagnetic radiation. Similar theoretical studies were carried out by Zhdanov and, in general terms, it was necessary to find Green's tensors [10]. Integral equation method in three dimensions by electromagnetic Green's tensors can be calculated as

$$\begin{aligned} E(r_j) &= \iiint_D \hat{G}_E(r_j | r) \cdot j(r) dv = G_E(j) \\ H(r_j) &= \iiint_D \hat{G}_H(r_j | r) \cdot j(r) dv = G_H(j) \end{aligned} \quad (1)$$

where  $G_E(j)$  and  $G_H(j)$  are the electric and magnetic Green's operators [10]. Finding an accurate analytical solution for obtaining a three-dimensional image is a difficult task. Experimentally, using a selective narrowly directed antenna, it is possible to obtain transmitter signals reflected by underground objects, which differ significantly from the background signals of homogeneous earth layers.

Polarized narrowly focused radio waves with a frequency of 1-10 MHz, generated by the transmitter, penetrate into the bowels of the Earth to a depth of hundreds of meters. Depending on the direction of the transmitting and receiving antennas, sounding of different depths of the underground space can be carried out. Some of the electromagnetic energy is absorbed and some is reflected, creating a signal in the receiver that can be measured as electric and magnetic field strengths. The value of the reflected energy depends on the contrast of the electromagnetic properties of the underground space that the radio waves encounter. That is, the deviation of the received signal during scanning may indicate the specific electromagnetic properties of underground domains.

Our goal is to obtain and analyze a 3D representation of experimental data on the passage of plane polarized electromagnetic radiation through real underground objects and the intensity of its reflection received by the receiver antenna. 3D topology of underground objects is little described in the current literature.

#### Experiment Results:-

The study area was 20 by 50 meters, and every 5 meters and at each point the signal was measured from depths of  $h_1=10$ ,  $h_2=20$  and  $h_3=40$  meters (Figure 1). The equipment moved along the x and y axes with a step of 5 meters

(Fig. 1). The strengths of the electric  $E_x$  and magnetic  $H_y$  were measured at each measurement point. The strengths of the electric  $E_x$  and magnetic  $H_y$  fields were measured at each gauging point. A fragment of the experimental data of radio sounding the soil mass using our GPR is shown in Table 1.

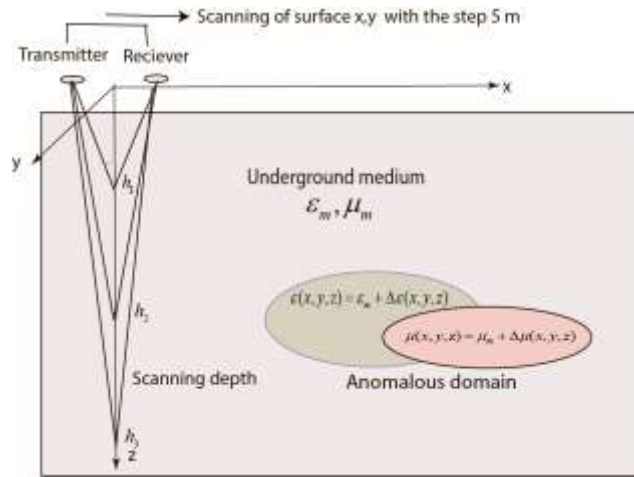


Figure 1. The study area 20 by 50 meters with the step 5 meters. The electromagnetics signals were measured from depths of  $h_1=10$ ,  $h_2=20$  and  $h_3=40$  meters at each point

Table 1. Fragment of experimental data of radio sounding using of the Ground-Penetrating Radar for the surface area  $50 \times 20 \text{ m}^2$ .

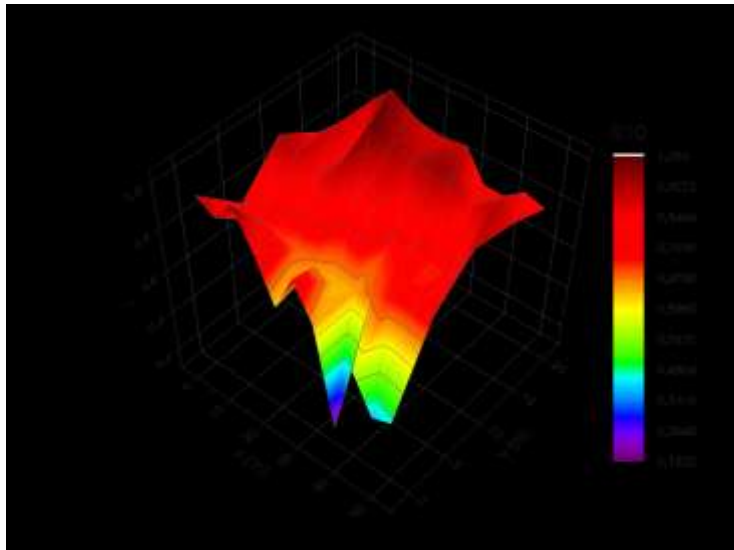
	x	y	$H_y$	$E_x$	S
1	0	0	0,3863	1,3417	0,9859
2	5	0	0,9891	1,4595	0,7916
3	10	0	0,9561	1,3404	0,7644
4	15	0	0,6206	1,2091	0,8424
5	20	0	0,6405	1,2719	0,8593
6	25	0	0,7766	1,3937	0,8459
7	30	0	0,8517	1,2982	0,7874
8	35	0	1,0977	1,5173	0,7731
9	40	0	1,182	1,3807	0,6968
10	45	0	1,1322	1,4717	0,7434
11	50	0	0,9817	1,2482	0,7238
	...				
45	0	20	0,6084	1,0451	0,8019
46	5	20	0,2661	0,9302	0,9255

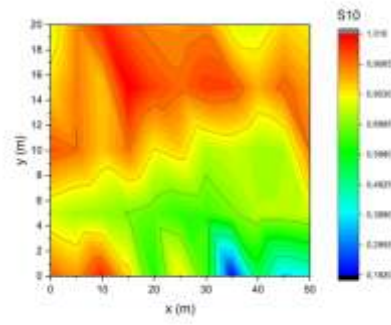
47	10	20	1,6527	0,3838	0,2085
48	15	20	1,0407	1,0629	0,6448
49	20	20	0,828	0,7698	0,6222
50	25	20	0,8789	1,1334	0,7239
51	30	20	0,8001	0,9247	0,6809
52	35	20	0,8171	1,0391	0,721
53	40	20	0,8441	0,9352	0,677
54	45	20	0,825	1,0649	0,7233
55	50	20	0,814	1,1163	0,7397

Experimental data of radio sounding using of the Ground-Penetrating Radar was written in the ASCII table by microcontroller and then imported to OriginLab program. According to the results of processing the received field data, the components of the electromagnetic field: the magnetic  $H_y$  and the electrical  $E_x$  components and the parameter S (the vector sum of the  $H_y$  and  $E_x$  components) are inhomogeneous, which indicates the presence of an anomalous electromagnetic domain.

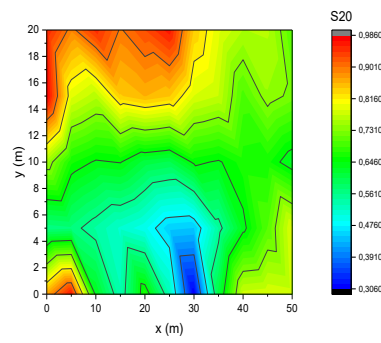
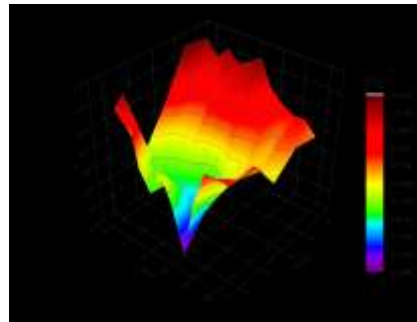
#### Computer Processing of Gpr Data To 3d Graph And Analyses of Underground Surfaces Geological Properties:-

We used a computer method for the convert experimental data to a 3D surface graph, which published in our paper [11-13]. On Figures 2-4 shows 3D and 2D graphs of the experimental data of parameter S, and the magnetic  $H_y$  and the electrical  $E_x$  components under different depths 10 m (a), 20 m (b) 40 m (c).3D images of the sections of the studied rock mass were constructed.

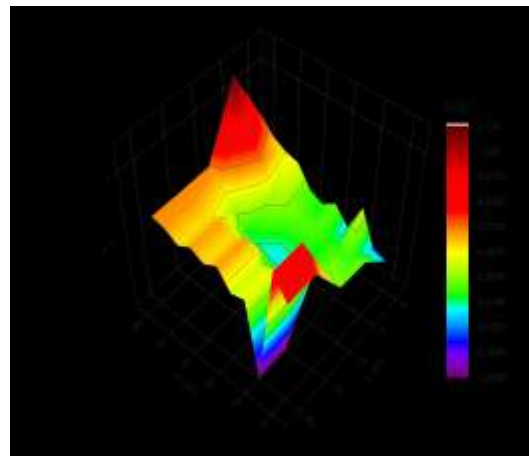


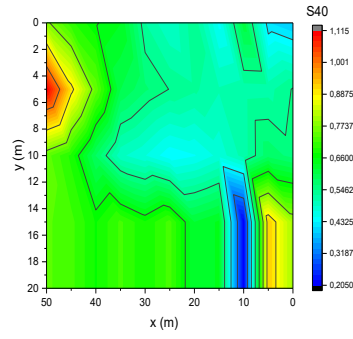


a)



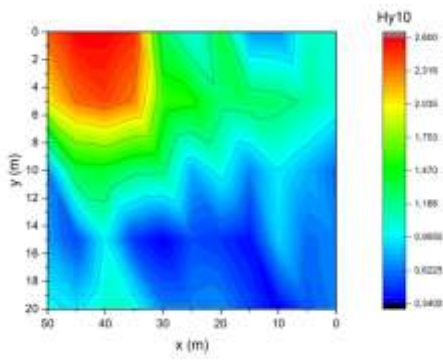
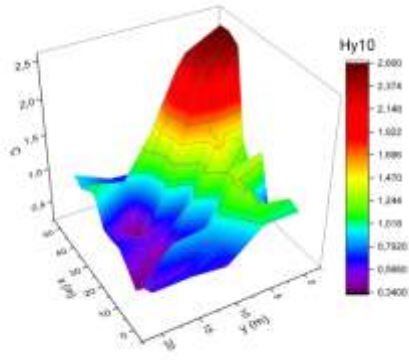
b)



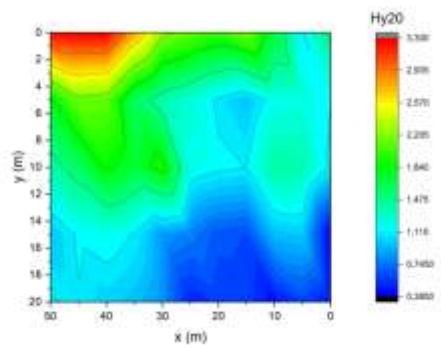
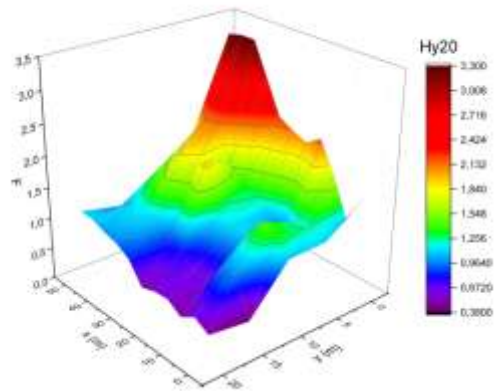


c)

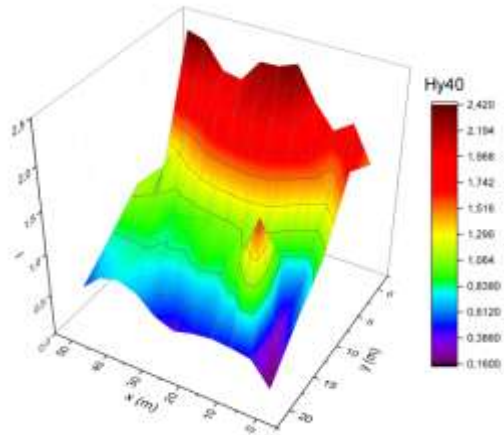
Figure 2. Graphical representation of the experimental data of parameter S for different depths 10 m (a), 20 m (b) 40 m (c)

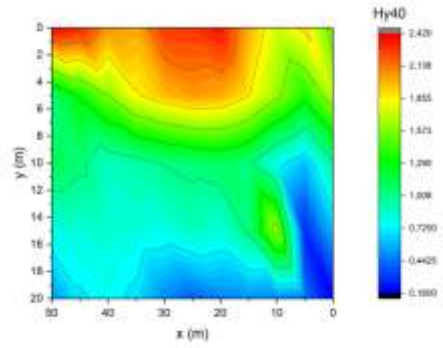


a)



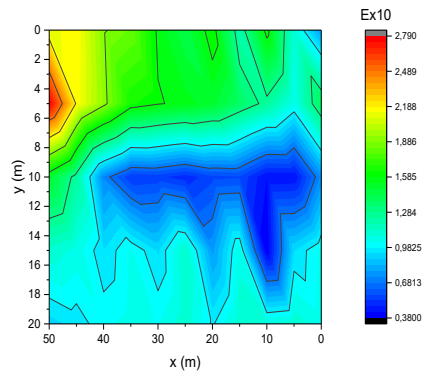
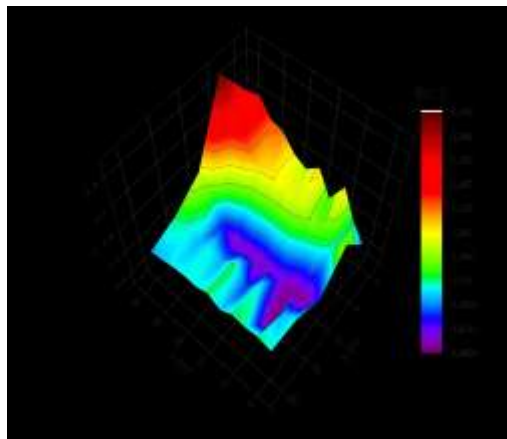
b)



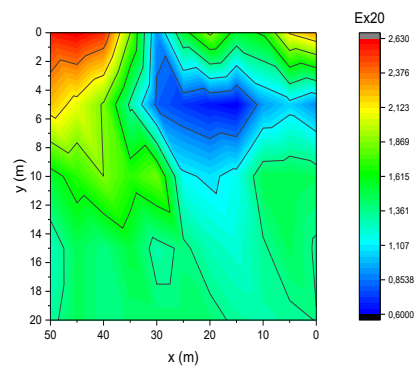
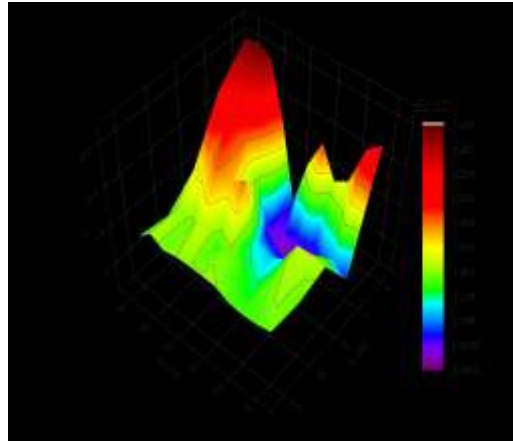


c)

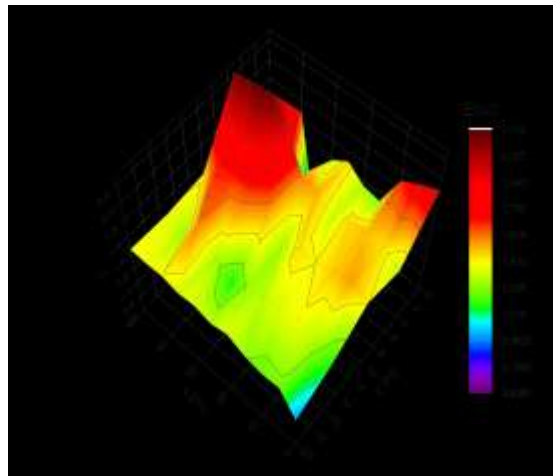
Figure 3. Graphical representation of the experimental data of parameter Hy for different depths 10 m (a), 20 m (b) 40 m (c)

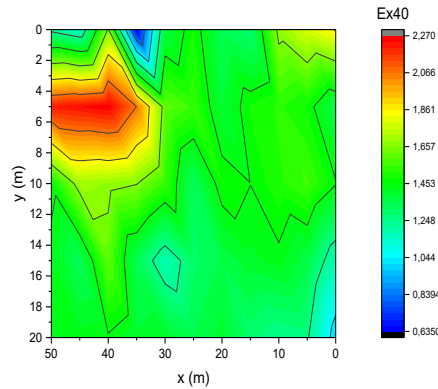


a)



b)





c)

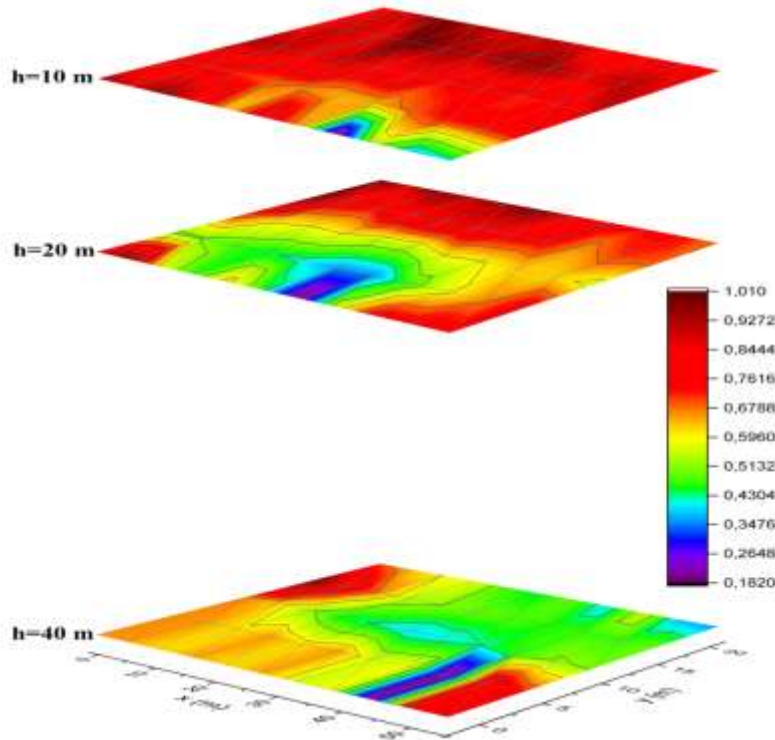
**Figure 4. Graphical representation of the experimental data of parameter Ex for different depths 10 m (a), 20 m (b) 40 m (c)**

The distribution of signals received by the measuring detector from different measurement points is different, which is associated with a heterogeneous underground structure.

As we see from the data in Figure 3, the experimental data show for a given geological object significantly different values of the magnetic component in the reflected electromagnetic wave. Thus, measuring the response of only the magnetic component makes it possible to detect anomalous regions containing materials with high magnetic permeability and significantly affecting the intensity of the reflected radio wave.

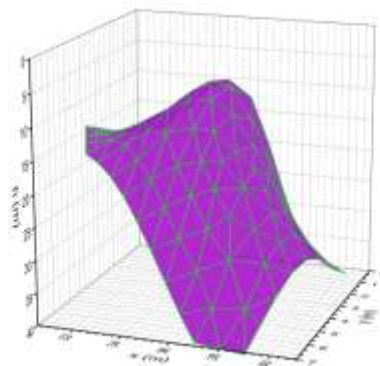
Similarly, as can be seen from the data in Fig. 4, the experimental data show for a given geological object significantly different values of the electrical component in the reflected electromagnetic wave. Thus, measuring the response of only the electrical component makes it possible to detect anomalous regions containing materials with a high dielectric constant and significantly affecting the intensity of the reflected radio wave. Measuring the response of only the electrical component makes it possible to identify areas containing water, since water has a dielectric constant that is much higher than that of terrestrial rocks. The domain with a high dielectric index is located at a depth of 10 to 20 meters and is practically absent at depths of 40 meters (Figure 4).

Figure 5 shows the intensity distributions of parameter S of the reflected electromagnetic beam at different depths. The minimum intensity is recorded in small areas and is marked in blue. These domains of underground space maximally absorb electromagnetic radiation. If the values of the matrixes with the minimum level of reflection as coordinate data and construct a new matrix, in which the scanning depth will be as the coordinate z, then the resulting matrix displays the three-dimensional topology of the underground domain and its geometric dimensions can be measured.



**Figure 5. Graphical representation of the experimental data of parameter S for different depths 10 m, 20 m and 40 m**

Three-dimensional graph for the parameter S with minimum signal values for the underground relief of the study area is shown on Figure 6. The data smoothing method in the OriginLab program was used. In our experiment, the step was 5 meters, which is not quite enough for an accurate measurement. At the same time, the proposed method for finding the geometric dimensions of underground domains with high absorption of radio waves can be effectively used. For more accurate measurements, it is necessary to reduce the measurement step and use a larger set of depths. This requires the development of automation of the proposed GPR measurement methods, since manual measurements are very laborious.



**Figure 6. Three-dimensional graph using the data smoothing method in the Origin Lab program for the parameter S with minimum signal values for the underground relief of the study area**

Similarly, three-dimensional graphs of the parameters of the electric and magnetic components of the reflected electromagnetic wave with minimum signal values for the studied underground relief can be constructed. Such data of three-dimensional 3D topography will be informative for the search for dielectric (content of water molecules) and magnetic (iron atoms) anomalies in the form of domains in the underground structure.

### Conclusions:-

The use of computer processing of experimental GPR data made it possible to obtain a three-dimensional image of the anomalous area, from which the reflected electromagnetic signal comes much weaker than from neighboring areas. This region may contain high values of the dielectric and magnetic constants, which lead to strong absorption of electromagnetic waves. Measuring the response of only the electrical component makes it possible to identify areas containing water, since water has a dielectric constant that is much higher than that of terrestrial rocks. Measuring the response of only the magnetic component makes it possible to detect anomalous regions containing materials with high magnetic permeability and significantly affecting the intensity of the reflected radio wave.

The accuracy of determining the geometric dimensions is limited by the measurement step (in our case, 5 m) and sounding depths (in our case, 10, 20 and 40 m). The information content of 3D graphs and the accuracy of measurements of geometric parameters can be significantly increased. However, this requires automation of measurement processes, which may be the subject of further research.

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