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Environmental aspects and statistical analysis of geological data of gas recovery in surface degassing wells

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Abstract. The article is devoted to the analysis of the environmental consequences of hydrocarbon production in Donbas, particularly the extraction of coalbed methane. During coal mining, significant amounts of methane accumulate in geological formations, which subsequently migrate to the surface, creating risks for public health and the environment. Since the share of methane emissions and other pollutants in coal-mining regions is significant, it is necessary to study the conditions of methane migration processes and possible ways to reduce its emissions into the Earth's atmosphere. One of the directions for solving this problem is to increase the efficiency of degassing systems, transportation and utilization of methane. It is known that the Donetsk basin has complex mining and geological conditions. For methane production through surface degassing wells, it is necessary to carry out methods of clogging and intensification of gas release. However, the implementation of these measures in the conditions of Donbas requires improvement. In the opinion of the authors, the solution to this issue is a statistical analysis of geological data of the rock's composition of wells working horizons and forecasting of methane accumulation areas. Effective monitoring and management of methane emissions is one of the aspects of ensuring a safe ecological state of the air. It was established that statistical analysis by the method of normality of distribution of experimental data according to the Kolmogorov-Smirnov and Shapiro-Wilk criteria generally corresponds to the methodology of research of geological data but does not allow to assess the regularities of the distribution of gas emissions. Therefore, based on obtained results, it is proposed to continue the analysis of wells' geological data for justification of wave impact parameters on rocks of the working horizon to restore or increase the methane production rate.

1. Introduction

Hydrocarbon deposits are one of the Earth's essential environmental components, providing crucial energy resources for various industries. When these deposits are developed, anthropogenic transformations and new formations arise in the geological strata due to the influence of geomechanical processes [1]. These processes can significantly alter the structure of the surrounding environment, leading to changes in soil, rock, and mineral compositions. For example, in a dynamic shear mould, the removal of emission-hazardous coal seams can trigger phase transitions of solid hydrocarbon compounds into a gaseous state [2]. This phenomenon primarily occurs in areas of



tension and compression, where the physical conditions foster such transformations [3]. As a result, the interaction between the geological strata and the extracted hydrocarbons can lead to complex environmental challenges, requiring careful management and monitoring.

Enormous volumes of methane remain in the stratification zones (between rock layers) and in sandstones, forming man-made deposits [1, 4]. This methane has been migrating to the earth's surface for decades and poses a threat to the life of the population. When a coal deposit is developed, a static shear mould is formed in the geological strata [2, 5]. According to surveyor observations, the subsidence of the earth's surface after the removal of a coal seam is up to 0.8 meters of its thickness. When several layers are removed, the subsidence reaches 22 meters [1, 6, 7].

The Donbas region of Ukraine is no exception. The coal seams currently being mined are located at depths ranging from 150 to 3000 meters. The seams being developed are between 0.5 and 2.6 meters thick. From a depth of 450 m, the coal is classified as hazardous, and from 600 m – as outburst hazardous.

When hydrocarbons are processed and used in technological processes, huge volumes of process fluid, fine dust and gas particles are released into the environment. All these factors, individually and in combination, create a complex environmental problem of natural resource management. As an example, Table 1 shows the total amount of air emissions based on the results of research in 2013 and 2018 [8].

Table 1. Total volumes of emissions into the atmosphere in coal-mining regions of Ukraine.

Name	2013		2018	
	tons per 1 km ²	kg per 1 person	tons per 1 km ²	kg per 1 person
In Ukraine as a whole	7.1 (1.0 <i>x</i>)	94.4 (1.0 <i>x</i>)	4.4 (1.0 <i>x</i>)	59.3 (1.0 <i>x</i>)
In Donetsk region	54.7 (7.7 <i>x</i>)	332.2 (3.5 <i>x</i>)	30.4 (6.9 <i>x</i>)	189.8 (3.2 <i>x</i>)
In Luhansk region	22.4 (3.2 <i>x</i>)	196.6 (2.1 <i>x</i>)	3.0 (0.7 <i>x</i>)	21.1 (0.4 <i>x</i>)
	2013		2018	
	·10 ³ tons	%	·10 ³ tons	%
In Ukraine as a whole	4265.1	100/100	2508.3	100/100
including – in the coal industry	817.2	19.5	274.0	10.9
including – methane	628.5	79.1	214.9	78.4
including – in energy and metallurgy	2687.2	63.0	1717.3	68.5
Total in 2 regions of Eastern Ukraine	1892.8	44.4/100	836.9	33.4/100.0
including – in the coal industry	578.8	30.6	164.4	19.6
including – in energy and metallurgy	1153.8	61.0	664.6	79.4
In Donetsk region	1448.6	34.0/100.0	790.2	31.5/100.0
including – in the coal industry	409.1	28.2	149.5	18.9
including – in energy and metallurgy	938.4	64.8	635.3	80.4
In Luhansk region	444.2	10.4/100	46.7	1.9/100
including – in the coal industry	169.7	38.2	14.9	31.9
including – in energy and metallurgy	215.4	48.5	29.3	62.7

The table shows relative indicators – the number of emissions per 1 person and the density of emissions per 1 km². It should be noted that for every ton of emissions, generated by coal mining in Ukraine as a whole, 3.2 tonnes of pollutants were released into the air during the use of coal in energy and metallurgical sectors. The coal industry accounts for about 34% of total air pollution in Ukraine. At the same time, in Donetsk region it is about 30%, and in Luhansk region – 45%. Therefore, studying the processes of methane emissions from coal mines and the volume of air emissions from other sources in Donbas is one of the most pressing environmental issues.

In terms of improving the ecological state of the environment, Ukrainian scientists are conducting research in many scientific areas. In [9] examine the potential for producing green hydrogen from coal mine water, emphasizing its role in promoting a circular economy. The study underscores the ecological benefits of utilizing waste resources while providing a statistical framework to evaluate production costs. Thus, demonstrating the feasibility of integrating environmental sustainability into traditional mining practices. This approach not only addresses energy production but also contributes to reducing the environmental footprint associated with coal mining operations. In [10] analyze the operational effectiveness of gas distribution companies, highlighting the importance of efficient gas management for environmental protection and economic stability. The statistical analysis presented offers insights into operational performance, allowing for targeted improvements in gas distribution systems. The works by Nikolsky et al. [11, 12] on the hydrodynamics of gas flow in vortex heat generators and thermodynamics in liquid heating processes provide a deeper understanding of energy transfer mechanisms, which are crucial for optimizing gas recovery and minimizing emissions in mining operations. All together, these studies contribute to a holistic understanding of gas management, integrating ecological considerations with statistical methodologies to enhance both environmental and economic outcomes in the mining sector [13-14].)

Researches [13–21] consider directions for methods and schemes for preventing of gas-dynamic phenomena, degassing, methane extracting and transporting. The processes of gas drainage in the massif, the influence of geomechanical factors on the parameters of coal seam displacement and its gas-dynamic state are considered in [1–5, 21–23].

The efficiency of hydrocarbon production and reduction of methane emissions into the air are significantly affected by the processes of stress redistribution during the intensification of technological processes and methods of clogging in the zone around the well [24–28]. For example, papers [24, 25] consider the regularities of the influence of geomechanical factors and rock deformation on methane filtration in the rock. Papers [26–28] describe the electrical characteristics and modes of electric discharge action on the bottomhole zone of a coal seam. Innovative approaches to the use of the coal gasification method and the prediction of its parameters are discussed in [29, 30].

Research about hydrocarbons processing and utilization is of great importance from the ecological point of view [31, 32]. For example, the functional schemes for automatic control and the parameters optimization of coal preparing to achieve complete combustion of coal and reduce gas emissions into the air [31].

At the same time, the use of methods of analysis, modelling and forecasting for improving and implementing the above-mentioned processes requires a more detailed study. In many areas of knowledge, the laws of geomatics and probability distribution play a significant role [33–35]. Their application is useful when it is necessary to select a few indicators and parameters from many that have the maximum impact on the process intensity.

So, the purpose of this study is to analyze statistical geological data to predict gas release from the coal-rock mass into surface degassing wells and reduce methane emissions into the air.

2. Methods

In our research, we consider geological data according to analysis of the surface wells on a coal-rock mass. The most likely reason for the anomaly in the distribution of geological characteristics is the failure to meet the requirements of the central limit theorem, i.e., the uniform smallness and independence of the factors generating the random variable studied. This type of distribution is the most common in comparison with other types of distribution. Most statistical methods for solving geological problems are based on the use of the properties of certain distribution laws. However, it is usually not possible to know in advance what properties will be obtained because of the study of a sample population. Therefore, the solution of specific problems is preceded by the stage of comparing empirical distributions with known theoretical ones.

In most cases, when solving real-world problems, the distribution law and its parameters are unknown. At the same time, statistical methods are used, which often require a certain distribution law

as a background [35, 36].

The most visual definition of a normal distribution is a graph of the Gaussian curve (Figure 1). It is symmetrical with respect to the average value of x_{av} . The placement of values in the variation series is characterized by certain regularities of the normal curve and the deviation of the arithmetic mean, which practically cover six σ (3 to the left and 3 to the right side). Provided that the vertices of the histogram columns are described by the theoretical normal Gaussian curve, the distribution is considered normal.

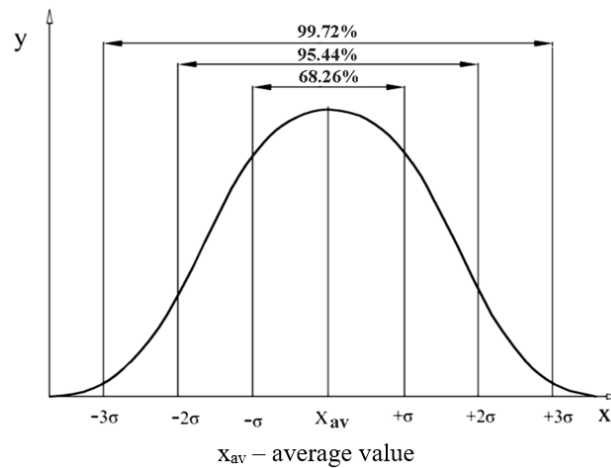


Figure 1. Theoretical normal Gaussian curve.

There are various methods for determining the normality of data distribution. In our research, we consider three methods: indirect, graphical, and calculated. If the hypothesis of normality is rejected by one of the indirect tests, the data is interpreted as non-normally distributed. Indirect methods for assessing the normality of a distribution include the asymmetric coefficient and kurtosis.

Let's start with the coefficient of asymmetry, which characterizes the degree of asymmetry in the data distribution. If it is zero ($\gamma = 0$), the normality hypothesis is not rejected, and the actual data is a parabola. The asymmetry coefficient is positive ($\gamma > 0$) if the right tail of the distribution is longer than the left tail and vice versa. The asymmetry coefficient is negative ($\gamma < 0$) if the right tail of the distribution is shorter than the left tail (Figure 2a).

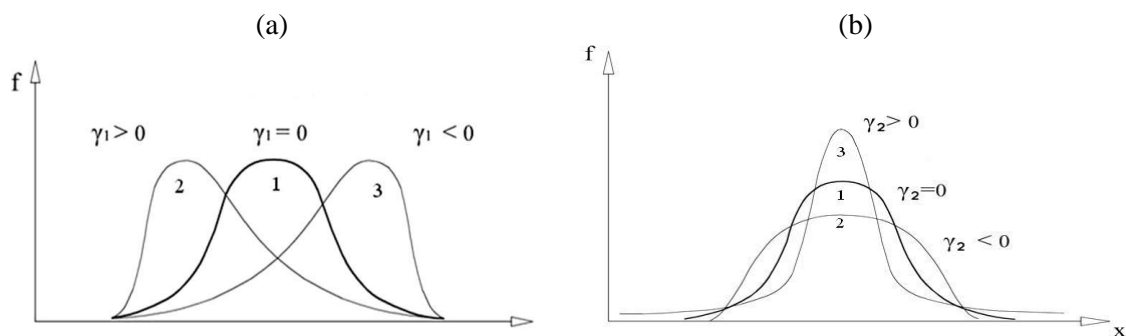


Figure 2. Types of asymmetries: (a) types of kurtosis; (b) sample kurtosis.

The standard value of the sample kurtosis is assumed to be zero ($\gamma = 0$). If the sampling distribution corresponds to a negative kurtosis ($\gamma < 0$), the corresponding polygon has a flatter peak compared to the normal distribution. In the case of a positive kurtosis ($\gamma > 0$), the polygon is steeper than the normal distribution (Figure 2b).

Graphical methods for assessing the normality of a distribution include frequency histograms, normal probability plots, box plots (Figure 3).

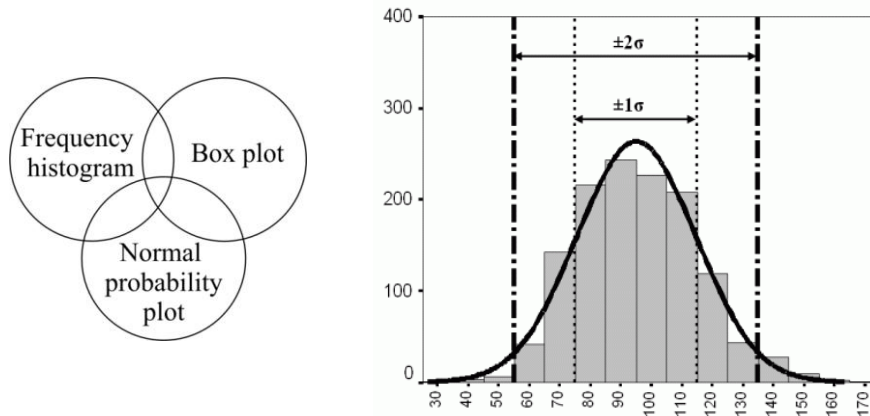


Figure 3. Graphical methods of distribution normality and the histogram.

Frequency histograms are used to check how well the actual data fits a theoretical normal curve. If the theoretical normal curve describes the columns of the actual data well, the hypothesis of normality of the distribution is not rejected. The main sign of non-normality is the asymmetry of the histogram.

A box plot is defined by calculating the median. The median is the value in a sorted sample that divides it into two equal parts. You can also determine the median for random variables, in which case it divides the distribution in half. The median of a random variable is a number such that the probability of getting the value of the random variable to its right is equal to the probability of getting the value to its left and they are equal (Figure 4a) [37]. Based on these statistics, a box plot is constructed. It is used to evaluate the sample in terms of quartile range, gross errors, median and distribution of data (Figure 4b) [37].

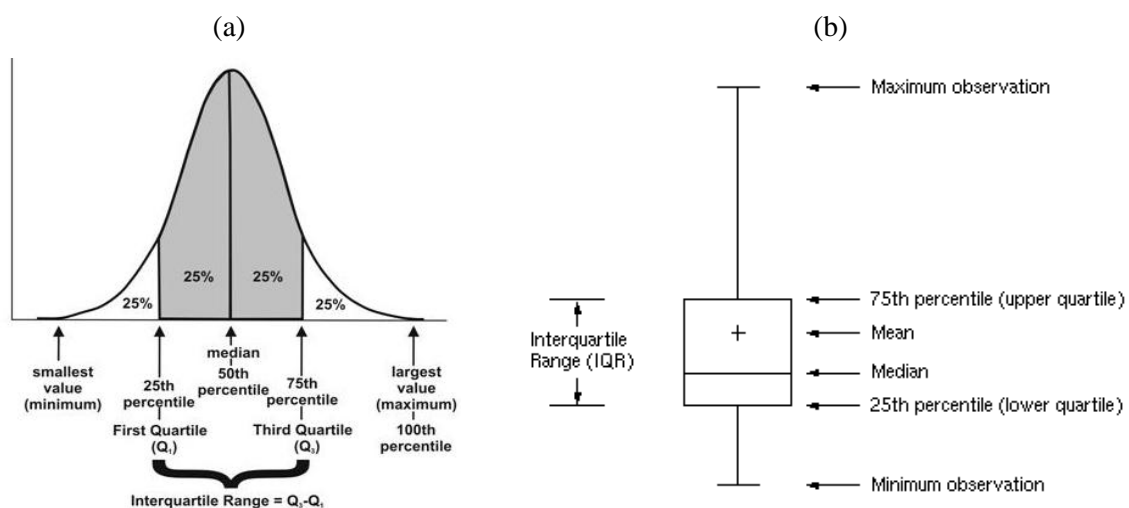


Figure 4. Median in a sorted sample and box plot: (a) median; (b) box plot.

A box plot is analyzed by the location of the median, symmetry of quartiles and outliers. Normal probability plots are analyzed by the closeness of the actual data to the theoretical normal curve (Figure 5). If there are no systematic deviations from the theoretical straight line, the hypothesis of a normal distribution is not rejected.

Computational methods for analyzing the normality of data distribution include the Kolmogorov-Smirnov normality criterion and the Shapiro-Wilk normality criterion. The parameters of the distribution are usually mathematical expectation and the variance. Sometimes the root of the variance, i.e. the standard deviation, is considered instead. To test the hypothesis, it is proposed to use one of two criteria: Kolmogorov-Smirnov (with the Lilliefors correction) if more than 60 observations are analyzed, and Shapiro-Wilk if less than 60 observations are analyzed [38].

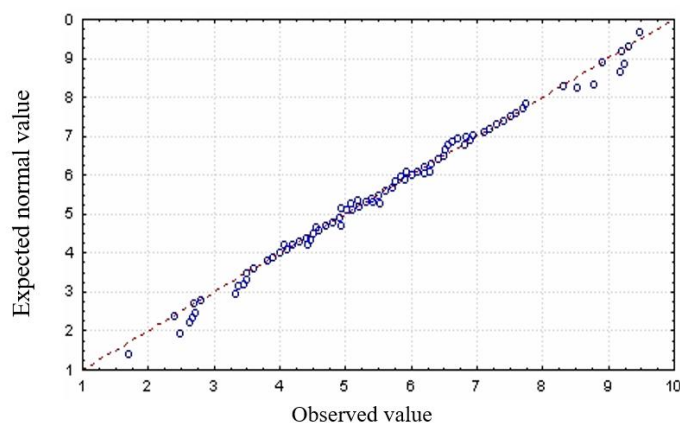


Figure 5. Normal probability plot for a normal curve.

As a result of calculating each of these criteria, their significance level p is determined. The norm of the Kolmogorov-Smirnov criterion is $p > 0.2$. If $p < 0.2$, the hypothesis of normal distribution is rejected. For the Shapiro-Wilk criterion, $p > 0.05$. If $p < 0.05$, the hypothesis of normality of the data distribution is rejected.

Thus, it has been established that the method of normal distribution of experimental data corresponds to the methodology of studying geological data through surface degassing wells on a coal-rock mass. Therefore, for the completeness of the research results, we will apply a comprehensive assessment by using all the above-mentioned methods of analysis.

3. Results and discussion

Based on the conclusion about the analysis of experimental data, let us consider the results of studies of the distribution of geological data on the methane emission by analyzing the normality of data distribution. The investigation was carried out on eight surface degassing wells (SDW) drilled in a mine field in Donbas.

The geological data is presented in Table 2, where the first four wells are wells with no gas flow and the second four wells have specific values for the volume of gas that flowed from them.

The following conclusions can be drawn from Table 2:

- the number of layers crossed by the perforation zone of the SDW MT-340 is 37. Most of them are sandstones. The asymmetry, kurtosis and their errors are within the normal distribution. The average layer thickness is 7.2 m and the median (i.e. the frequency of occurrence of the same phenomena) is 5.8 m, while the asymmetry, kurtosis and their errors are not within the normal distribution;
- the number of layers crossed by the perforation zone of the SDW ZD-2 is 48. Most of them are siltstones. The asymmetry, kurtosis and their errors are within the normal distribution. The average layer thickness is 6.2 m, and the median is 3.5 m, while the asymmetry, kurtosis and their errors are not within the normal distribution;
- the number of layers crossed by the perforation zone of the SDW ZD-3 is 55. Most of them are siltstones. The asymmetry and error are within the normal distribution, which is not the case with the kurtosis and its error. The average thickness of the layer is 6.3 m, and the median is 4 m, while the asymmetry, kurtosis and their errors are not within the normal distribution;

- the number of layers crossed by the perforation zone of the SDW D-5 is 103. Most of them are siltstones. The asymmetry and error are within the normal distribution, which is not the case with the kurtosis and its error. The average thickness of the layer is 4.2 m, and the median is 2.5 m, while the asymmetry, kurtosis and their errors are not within the normal distribution;
- the number of layers crossed by the perforation zone of the SDW ZD-4 is 53. Most of them are siltstones. The asymmetry and standard error are not within the normal distribution, which is not the case with the kurtosis and its errors. The average thickness of the layer is 6.2 m, and the median is 4.5 m, while the asymmetry, kurtosis and their errors are not within the normal distribution;
- the number of layers crossed by the perforation zone of the SDW ZD-5 is 71. Most of them are siltstones. The asymmetry and standard error are not within the normal distribution, which is not the case with the kurtosis and its errors. The average thickness of the layer is 5.4 m, and the median are 3 m, while the asymmetry, kurtosis and their errors are not within the normal distribution;
- the number of layers crossed by the perforation zone of the SDW 1185-D is 115. Most of them are siltstones. The asymmetry, kurtosis and their errors are within the normal distribution. The average layer thickness is 5.1 m, and the median is 2 m, while the asymmetry, kurtosis and their errors are not within the normal distribution;
- the number of layers crossed by the perforation zone of the SDW MS-598 is 68. Most of them are siltstones. The asymmetry, kurtosis and their errors are within the normal distribution. The average layer thickness is 4.7 m, and the median is 2.9 m, while the asymmetry, kurtosis and their errors are not within the normal distribution.

Table 2. Descriptive statistics of wells based on indirect methods of normal distribution.

Well name	Observation number	Mean	Median	Asymmetry	Standard asymmetry error	Kurtosis	Standard kurtosis error
MT-340	37	102.76	Sandstone	0.39	0.39	-0.80	0.76
Layers	37	7.16	5.8	1.85	0.39	3.11	0.76
ZD-2	48	102.5	Siltstone	0.22	0.34	-0.76	0.67
Layers	48	6.2	3.5	1.58	0.34	2.44	0.67
ZD-3	55	102.77	Siltstone	0.04	0.32	-1.01	0.63
Layers	55	6.38	4.0	1.99	0.32	3.33	0.63
D-5	103	102.89	Siltstone	-0.03	0.24	-0.69	0.47
Layers	103	4.17	2.5	1.81	0.24	3.24	0.47
ZD-4	53	103.04	Siltstone	-0.02	0.33	-0.72	0.64
Layers	53	6.19	4.5	2.33	0.33	6.57	0.64
ZD-5	71	102.80	Siltstone	-0.09	0.29	0.46	0.56
Layers	71	5.43	3.0	2.84	0.29	9.24	0.56
1185-D	115	103	Siltstone	-0.19	0.26	-0.80	0.45
Layers	115	5.18	2.0	3.73	0.23	17.10	0.45
MS-598	68	103.09	Siltstone	-0.29	0.29	-0.25	0.57
Layers	68	4.67	2.9	2.22	0.29	6.97	0.57

From the above, it follows that the thickness of a single rock layer (coal, sandstone, mudstone, siltstone, limestone) and their quantity do not directly affect the gas release from a well.

For example, the calculated results of geological data conformity to the normal distribution are shown in Figure 6.

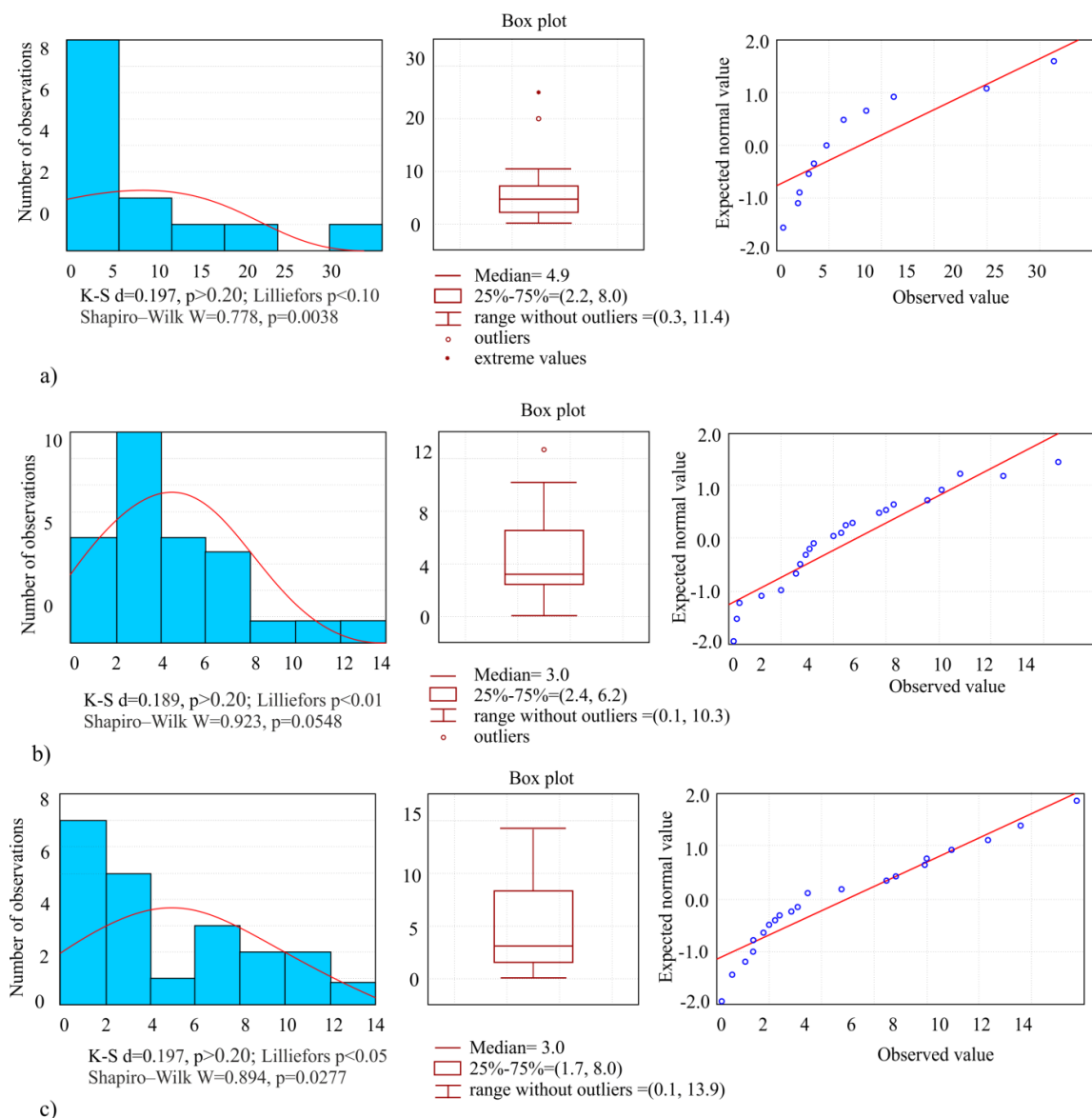


Figure 6. Graphical distribution of normality by rock layers of SDW MS-598.

The analysis of Figure 6 shows the following results:

a) For sandstone: the analysis of the graphs shows that according to the Kolmogorov-Smirnov criterion, the hypothesis of normality does not deviate from the normal distribution, according to the Shapiro-Wilk criterion, it does, the histogram is asymmetric and not described by the normal curve, the box plot is asymmetric and outliers are present, the normal probability plot shows the deviation of the actual data from the theoretical line, i.e., a non-normal distribution of data is observed.

b) For siltstone: analysis of the graphs shows that according to the Kolmogorov-Smirnov criterion, the hypothesis of normality does not deviate from the normal distribution, according to the Shapiro-Wilk criterion, it does, the histogram is asymmetric and not described by the normal curve, the box plot is asymmetric and outliers are present, the normal probability plot shows the deviation of actual data from the theoretical line, i.e., a non-normal distribution of data is observed.

c) For mudstone: analysis of the graph shows that the Kolmogorov-Smirnov criterion does not deviate from the normal distribution, the Shapiro-Wilk criterion does, the histogram is asymmetric and not described by a normal curve, the box plot is asymmetric and outliers are not present, the normal

probability plot does not show deviations of the actual data from the theoretical line, i.e. a non-normal distribution of data is observed.

4. Conclusions

Hydrocarbon mining in Donbas has a significant impact on the region's environment due to methane migration and accumulation. Methane accumulating in rocks drains to the surface and creates serious environmental and social risks. The study confirmed the relevance of controlling this process, especially in conditions where there is a high threat of air pollution and increased risks to public health.

Effective monitoring and control of methane emissions is one of the aspects of ensuring a safe ecological state. It has been established that statistical analysis by the method of distribution normality of experimental data according to the Kolmogorov-Smirnov and Shapiro-Wilk criteria generally corresponds to the methodology of geological data research but does not allow to assess the regularities of gas emissions distribution. Therefore, based on the obtained results, it is proposed to analyze the geological data of wells and to substantiate the parameters of the wave method of loading rocks in working horizon to recover or increase methane production in the following areas:

1. Determination of the geological parameters of rock layers and their relation to the perforation zone of the wells working horizon, where gas production is recovered or increased.
2. Investigation of the number of rock layers and their sequence that form the working horizon of the well for the ability to recover gas production.

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