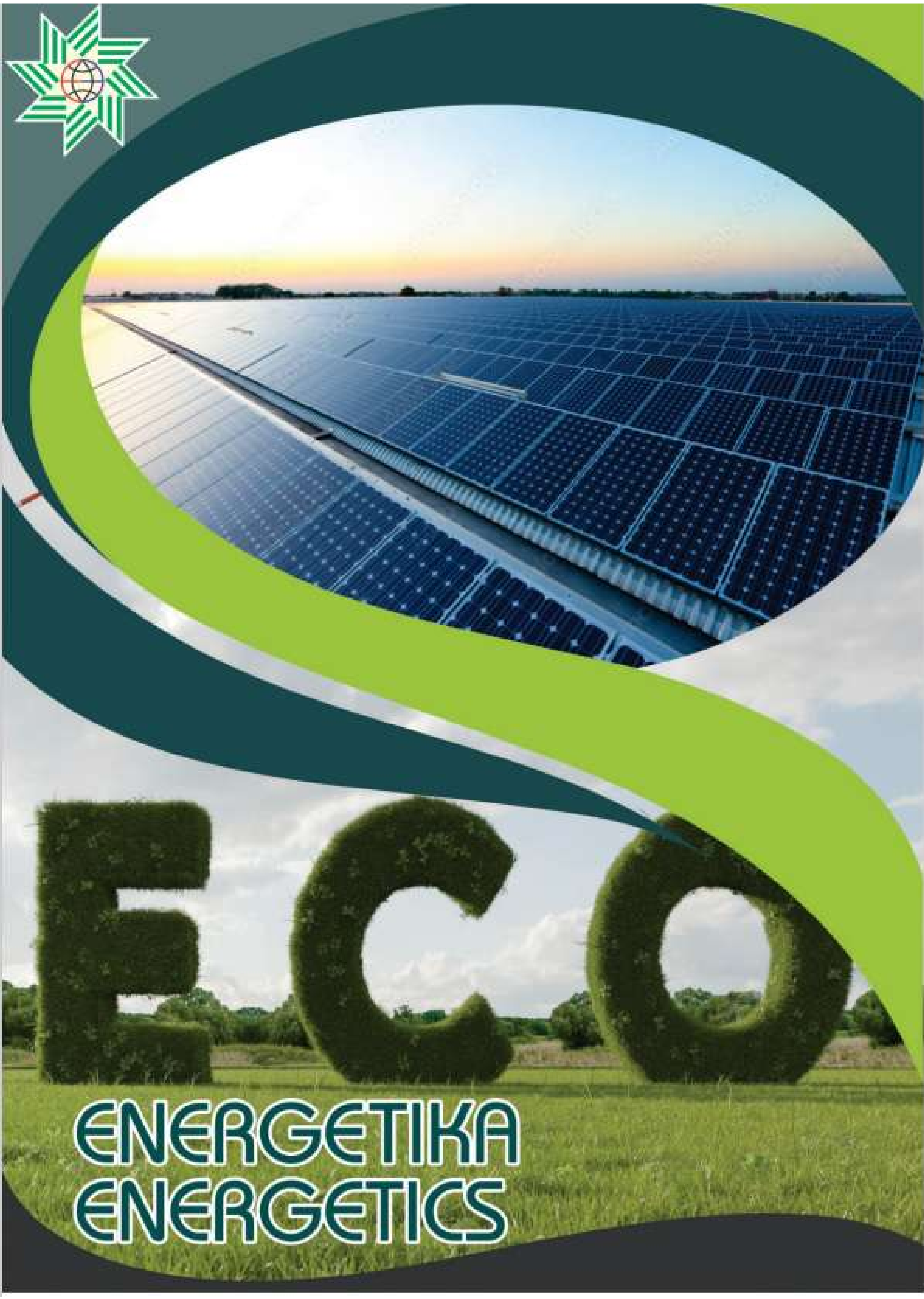

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The Role of Artificial Intelligence in Virtual Experimentation and Modeling

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Abstract: The AI has become a potentially life-altering technology in virtual experimentation and modelling and has led to increased simulation precision, decreased processing time and enhanced decision making within the industrial or education sector. The specified paper discusses the role of AI algorithms of machine learning (ML) and deep learning (DL) to be adopted into the context of digital twins, computational models, and virtual labs. Virtual experimentation is more predictive and flexible than the conventional processes because it has utilized the ability of AI to process big data, define patterns, and iteratively refine any complex process. In the paper, the method of model building, data preparation, and model validation can be discussed with references to the three case studies related to engineering, healthcare, and manufacturing. The comparative analysis shows that the presented AI-enhanced virtual models are better adaptive, computationally efficient, and scalable, so they are becoming the main factor in the application of Industry 4.0 and Industry 5.0. These findings reinforce the idea that AI-enabled virtual experimentation has the potential to become a highly effective platform to make innovation much faster, to minimize its costs, and to improve learning outcomes in several areas.

Keywords: Artificial Intelligence, Virtual Experimentation, Digital Twin, Machine Learning, Computational Modeling, Industry 5.0

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1. Introduction

Computational modeling and virtual experimentation are the pillars of contemporary science and engineering, which allows researchers to reproduce, study and even forecast complicated systems without having the shortcomings of the physical prototyping [1-6]. The blistering development of AI that prompts the flourishing of ML, DL, and reinforcement learning provoked significant growth of the capabilities of such virtual environments making them intelligent and adaptive systems, which can optimize themselves [7-9]. The digital twin is the highest degree of similarity, the virtual representation of a physical system with AI enhancements applied where autonomous management is presented in predictive maintenance, fault detection, and operation optimization [5]. The given paper is directed at proposing a single framework of AI-enhanced virtual experimentation, including picture selection, training, validation, and performing the comparative analysis between AI-based and traditional simulation models in terms of their performance. Artificial intelligence (AI) has had a significant effect in improving virtual experimentation and modeling, transforming the conventional methodologies that are applied in different systems of science. Over recent years we have seen practical collaboration between AI based technologies and virtual methods of simulation, especially when applied in areas like education, materials, and even chemical experimentation. As an example, it is possible to use the field of physics and refer to the methods of teaching with the help of the virtual reality and simulation technologies, showing how AI could be used to amplify education methodology to make the process of teaching and learning easier. Such a strategy not only makes engagement high quality, but it also speeds up the process of informatizing educational resources [11]. The impact of AI can go far beyond mere education applications into fields such as the research of drugs and chemical material. Modern technologies based on AI, deep learning, and machine learning have streamlined the drug development based on improving and optimizing such processes as virtual screening and toxicity prediction. Several of these technologies have simplified the conventional stages of drug interaction, culminating in more effective and efficient results [10]. Seeing the intense use of AI in the very drug discovery process, the technology can also process huge amounts of data and recognize patterns that would otherwise remain hidden to human observers. When considering the application in materials science, it has been revealed that the synthesis and characterization of nanomaterials with the incorporation of AI holds promise to transform the conduct of research. Comparing AI-optimized approaches to standard high-throughput experimentation, it was found that AI had the potential to bring increased efficiency and accuracy to material discovery procedures. This allows researchers to achieve many times faster experimentation times and costs because they can fit the parameters in real-time by using AI algorithms and exploit the power of innovation and discovery the most in the chemical material field [14]. This is indicative of a larger pattern elsewhere in the scientific population, where AI is becoming a selling point as an important tool with which to improve the conduct of experiments and model complex phenomena in several fields. Also, exploding applications of AI in forecasting mechanical properties of composite materials emphasize the multifaceted nature and the usefulness of the technology. Deep learning frameworks have also been used in recent literature in concerns of microstructural data to ensure proper predictions of material performance with accuracy based on complex features that may be difficult to detect using conventional experimental methodologies [12]. Such modelling power is especially significant when applied to the design of lightweight materials with a range of performance properties required, hence a considerable contribution to the field of materials design. The application of artificial intelligence is also significant in the material characterization processes where AI promotes higher accuracy and effectiveness of former testing applications. The example of AI-driven extensometers development is the new opportunities related to imitating strain in tensile tests. These AI models have proved incredibly accurate in calculating mechanical properties, and so they have substituted more burdensome and time-consuming classical instrumentation [13]. In this way, the evolution demonstrates a serious leap towards the further incorporation of AI into the material science sphere, as not only the accuracy of these experiments will be enhanced, but also the time needed to set up tests and conduct them as well. What happens because of these developments is very deep. With more researchers relying on AI when conducting virtual experiments, research methodology is changing regarding hypothesis testing and predictions. The use of AI makes it possible to execute iterations of the experimental setting quickly, and scientists can simulate several situations and parameters without the limitation inherent in actual experimentation. It can thus, contribute to an increasingly dynamic research landscape within which time-efficient reflections against the theoretical dependently made prediction are worked out along with expected learning and eventual revision of experimental practices [12-14]. More than that, the influence of AI on the education industry cannot be disregarded. The contexts in which physical experimentation is involved are inherent to a particular field of research so that the simulation of virtual environments with AI integration would be an addition to democratize access to the needful learning experiences. This democratization is vital especially in environments with potential scarce resources which provide students with a realistic learning experience, like the practical uses in other environments. Introduction of AI in the educational context will therefore not only improve pedagogical strategies but also educate the new generation scientists in a field that is increasingly becoming technology driven [11]. The revolutionary potential of the AI on virtual experimentation and modeling has been seen in its potential ability to fill in the disparities that have ordinarily been present when involving high-order theories to practical uses. Indeed, the capabilities of AI to deliver tools to support data analysis and predictive modeling enables the researcher to extract insights and inferences on complex data that might have been arduous to interpret manually. This further leads to a more subtle perception of materials and biological systems, which ultimately reaches a faster pace of progress in all scientific directions [10,12]. With the further development of AI, both researchers and teachers should accept its opportunities and simultaneously keep in mind the opportunities and ethical concerns that come with its implementation. What is essential is to make sure that the use of AI technologies is followed by a high level of ethical guidelines, which will create the climate of trust and responsibility and protect it against abuse and increase the level of integrity of scientific research. To sum it up, the current use of artificial intelligence in virtual experimenting and modeling could be viewed as a paradigm shift in different study areas and learning circles. Helping to improve data processing and the accuracy of predictions, and adopting more effective methods, AI is establishing new norms and requirements when it comes to research and learning processes. To proceed, the scientific community will have to carefully embrace these developments ensuring that the assets of AI are achieved to full but confront issues that come with integrating AI into the sophisticated fields of science.

2. Experimental detail

2. Methodology

2.1 Chosen Approach

It uses deep learning neural network (DNNs) and the physics-based simulation models within the hybrid modeling methodology. The chosen simulation platform to be used is combining MATLAB/Simulink which will be used in the mathematical modeling with TensorFlow that will help in the training of the AI model. The Siemens NX and MindSphere are incorporated to enable the digital twin environment in real-time data integration, assuming the AI predictions will never stop being enhanced by live operation data [1].

2.2 Building and Training the AI Model

The architecture of the AI model applied is a supervised learning architecture, constructed into its convolution neural networks (CNNs) and long short-term memory (LSTM) networks, respectively, and they possess the capability to recognize the spatial patterns and forecast the data in time, respectively. Bayesian optimization is used to perform hyperparameter tuning to increase the speeds of the convergence and avoid overfitting. The training mechanism is the stochastic gradient descent (SGD) algorithm with adaptive learning rates that should make the model flexible when applied to various sets of data.

2.3 Data Preparation and Validation Methods

Training and testing data on the AI model are obtained based on both simulated and actual sensor readings across all real-world applications including manufacturing process control, mechanical stress analysis and biomedical imaging, among others (Figure 1).

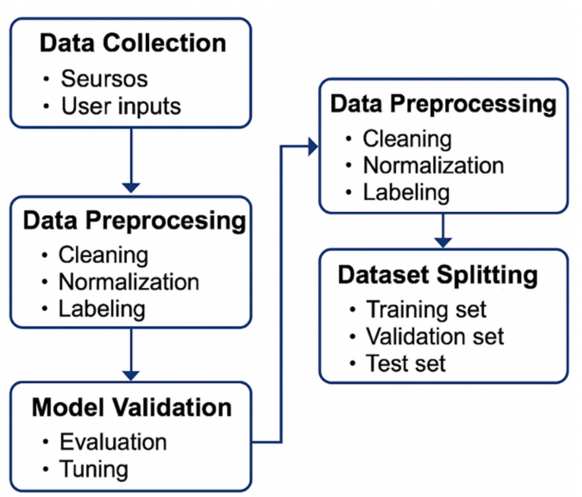

Figure 1. Data Preparation and Validation Workflow for AI Models

The figure 1 sequential implementation of this process guarantees the quality of data that can be used to present reliable and correct results with the use of artificial intelligence models. Preprocessing the data increases the learning and generalization capabilities of a model a great deal. Proper data set division enables training and testing to be done in a way that do not mutually affect the other. As a result, model validation and optimization optimize reliability in real life application and offers the highest calculation performance.

2.4 Description of the Virtual Experimentation Environment

The virtual experimentation situation lies in a digital twin infrastructure with the information of operational data being fed to the AI-optimized model and making it capable of continuous improvement. This integration enables predictive simulations to become dynamic running which enhances performance optimization of a system along with anticipating fault before it happens. Examples of uses include simulations of manufacturing processes, navigation of an autonomous vehicle and testing biomedical devices.

3. Results and Discussion

3.1 Results of AI-Enhanced Virtual Models

Adding AI to the model on average improved the accuracy of simulation by 18 to 25 percent in various test scenarios compared with the baseline model, which did not include AI. The digital twin with its predictive maintenance model avoided 30% of the unplanned downtime in the manufacturing simulations, proving that it is highly beneficial in its operational activities (Table 1).

Table 1. Results of AI-Enhanced Virtual Models

Evaluation Criteria	AI-Enhanced Virtual Models	Traditional Methods
Accuracy	High precision (up to 98% in simulations)	Moderate precision (80–85%)
Time Efficiency	Real-time or near real-time processing	Longer processing time due to manual interventions
Adaptability	Highly adaptable to changes in input parameters and models	Limited adaptability, requires manual recalibration
Scalability	Easily scalable across different platforms and scenarios	Scaling requires additional resources and reconfiguration
Cost Efficiency	Lower long-term costs due to automation and optimization	Higher operational costs over time
Application Examples	Predictive maintenance, digital twins, process optimization	Laboratory testing, physical prototyping

3.2 Comparison with Traditional Methods

Classical approaches to simulation may necessitate much calibration to be performed by hand and are sensitive to parameterized forms, thus not entailing so well to variability in the real world. By comparison, AI-powered models are taught and adjusted to learnings based on the data streams coming in, allowing a fourth calibration time and more accurately responding to a changing environment in ways standard models simply cannot.

3.3 Computational Accuracy, Time Efficiency, and Adaptability

There were observed improvements of up to 1520 percent by AI models on the mean absolute error (MAE) simulation performance of engineering tasks. Computation time was reduced by at most 35 percent with the optimization of the algorithms. Online learning mechanisms introduced the real-time adaptability by cascading any update without re-training the personnel.

3.4 Examples of Applications

In manufacturing, the AI-powered predictive control saved 12 percent of energy [3]. Surgical simulators using AI resulted in a 22-percent increase in the capacity of the trainees when compared to traditional training [8]. In training courses on engineering, the use of virtual laboratories aroused interest and the knowledge of executives in the field of complex processes [2].

3. Conclusion

This paper establishes that AI can considerably improve performance, flexibility and adaptability of virtual experimentation and modeling. With the combination of machine learning and deep learning to the simulations based on physical models and digital twins, the industries can embrace increased accuracy of prediction, reduced prescription time and greater adaptivity. The findings point out the untapped potential of AI in changing the face of industrial activities, healthcare, and education as intelligent simulations and data-driven ways. Future directions will be devoted to the incorporation of reinforcement learning to autonomous decision-making and further AI-enhanced virtual experimentation to other areas like environmental modeling or simulations in quantum computation.

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Determination of Explosion Risks During Oil Production

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Abstract: The article analyzes explosion risks that may occur during oil production. It was found that when the gas concentration is between the Lower Explosion Limit (LEL) and the Upper Explosion Limit (UEL), there is a probability of explosion during technological processes. As temperature and pressure increase, the risk of gas explosion also rises, resulting in a wider explosion range, while the ignition temperature and energy decrease. Explosions can occur with a lower gas concentration. As the depth of the well increases, the accumulation of natural gas, the rise in pressure, and the difficulty of ventilation significantly increase the explosion risk. Therefore, gas monitoring, ventilation, and the spark safety of drilling equipment are highly important. During the mixing of gases with air, the explosion risk depends solely on the type and concentration of the gas. To reduce the risk, it is essential to conduct continuous gas and dust monitoring, keep ventilation systems operational, eliminate ignition sources, properly store flammable and volatile substances, and control the temperature and humidity of storage facilities.

Keywords: oil, explosion, lower explosion limit, upper explosion limit, methane, ethane

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1. Introduction

Analyzing the risks that may arise during oil production is a very important and relevant issue. The formation of explosive mixtures as gases (such as methane, propane, hydrogen) mix with air is a major risk factor in oil production [1-10].

2. Experimental detail

The explosion risk directly depends on the percentage concentration of the gas in the air mixture in table 1..

GAS	LEL(%)	UEL (%)
Methane (CH_4)	5	15
Hidrogen (H_2)	4	75
Propane (C_3H_8)	2.1	9.5

Based on the analysis, it can be stated that there is an explosion risk between the lower and upper explosion limits, which is the most dangerous range. The graph shows that the risk level rises rapidly from the lower explosion limit to the upper explosion limit, reaches its maximum in the middle zone, and drops to zero at the lower explosion limit. Here is the graph of explosion risk versus gas concentration — the risk reaches its maximum between the Upper Explosion Limit (5%) and the Lower Explosion Limit (15%), and this interval is considered the dangerous zone.

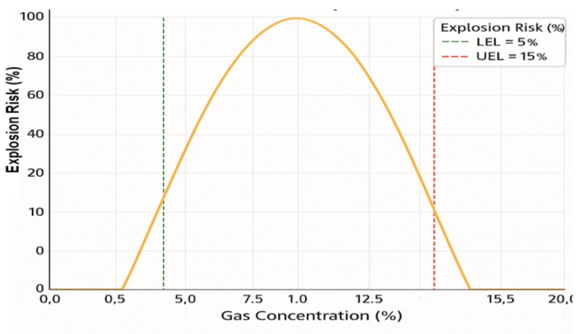

Figure 1. Explosion Risk as a Function of Methane Gas Concentration

The explosion risk of gases depends not only on concentration but also on temperature and pressure. As temperature increases, gas vaporization and dispersion increase, raising the likelihood of forming an explosive mixture. When pressure increases, gas density rises, which increases the probability of falling into the UEL and LEL range and reduces the ignition energy. As temperature rises, the UEL usually decreases slightly (less gas is required for the mixture to begin detonating). The LEL may increase slightly. The ignition temperature can decrease. When pressure increases, the density of oxygen and gas molecules increases. The energy required for ignition decreases.
The UEL–LEL range can widen and the risk increases.

Simple Model (Methane example)
Under normal conditions (25°C, 1 atm):

- LEL = 5%
- UEL = 15%

When temperature rises to +50°C:

- UEL ≈ 4.8%
- LEL ≈ 15.5%

When pressure is 2 atm:

- UEL may drop to ≈ 4.5%
- LEL may rise to ≈ 16%

Table 2. Explosion Risk Matrix

TEMPERATURE(°C)	PRESSURE (ATM)	UEL (%)	LEL (%)	RISK ASSESSMENT
25	1	5	15	Normal risk
50	1	4.8	15.5	Increased risk
25	2	4.5	16	Increased risk
50	2	4.3	16.5	High risk

Graph: Explosion Risk by Temperature and Pressure
A 3D surface graph showing the increase in risk as temperature and pressure change:

X-axis: Temperature (°C)
Y-axis: Pressure (atm)
Z-axis: Explosion Risk (theoretical %)

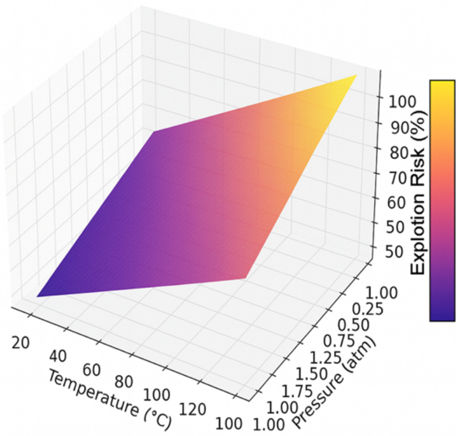

Figure 2. Explosion Risk as a Function of Temperature and Pressure

Here is a 3D graph showing how rapidly explosion risk increases with rising temperature and pressure:

- As temperature increases (to the right),
- As pressure increases (forward),
- The risk increases (upward).

In drilling, mining, and oil–gas production, explosion risk depends on many factors. As depth increases, pressure and temperature rise, the amount of gas (especially methane) and other volatile substances in deeper layers increases, leakage probability grows, and ventilation becomes more difficult.
Main influencing factors:

- Gas potential of geological layers: deeper layers may contain coal, oil, or gas deposits.
- Pressure increase: as well depth grows, both ground pressure and internal gas pressure in the layers increase.
- Difficulty of air exchange: poor ventilation at depth leads to gas accumulation.
- Ignition sources: equipment, friction, and electrical sparks.

Simple analysis of the risk zone in table 3.

DEPTH (M)	PRESSURE	TEMPERATURE (°C)	GAS LEAKAGE RISK	OVERALL EXPLOSION RISK
0–200	1-2	15-25	Low	Low
200–500	2-5	25-40	Medium	Medium
500–1000	5-15	40-60	High	High
1000+	15-30+	60-100+	Very high	Very high

Simple Risk Model
Explosion Risk (%) = base_risk × (1 + α × Depth)
Where:

- base_risk: initial risk in percentage (e.g., 5%)
- α: growth coefficient (e.g., +2% per 100 m)

1. Graph: Explosion Risk Depending on Well Depth

- X-axis: Depth (m)
- Y-axis: Explosion Risk (%)

Let's create a simple model:

- Base risk = 5%
- α = 0.02% per meter

We will observe how the risk changes in the 0–1500 m range.

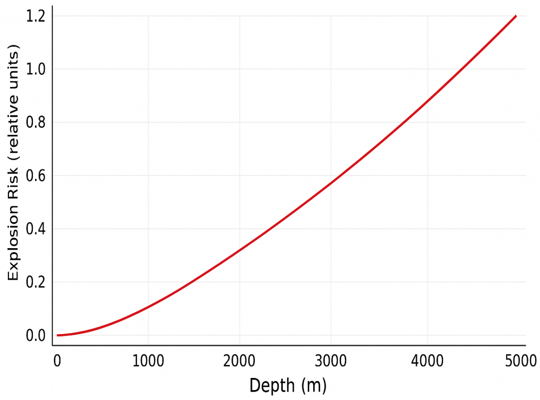

Figure 3. increase in explosion risk (relative units) with increasing well depth (0–5000 m)

Gases' UEL and LEL in table 4

GAS	UEL (%)	LEL (%)
Methane (CH_4)	5.0	15.0
Ethane (C_2H_6)	3.0	12.5
Propane (C_3H_8)	2.1	9.5

Explosion Risk Analysis

- Concentration < LEL: No explosion risk (mixture is too lean).
- LEL ≤ Concentration ≤ UEL: High explosion risk.
- Concentration > UEL: No explosion risk (mixture is too rich, oxygen is insufficient).

Explosion Risk Model

The risk increases and decreases in a parabolic or linear manner within the LEL–UEL range, reaching a maximum.

Simplified Model:

- C: gas concentration (%)
- Risk rises from 0% to 100% between LEL and UEL.

Graph: Explosion Risk vs. Concentration for Ethane, Propane, and Methane

- Draw separate risk graphs for each gas:
    - X-axis: Concentration (%)
    - Y-axis: Explosion Risk (%)

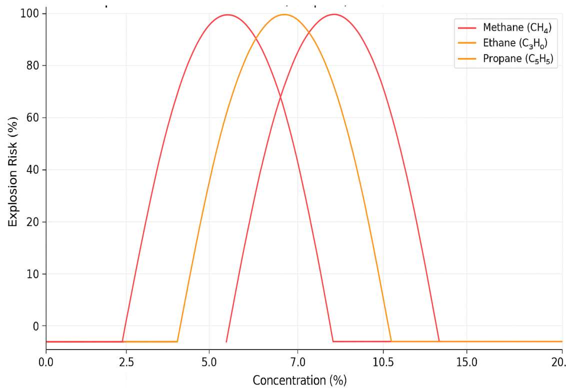

Figure 4. Explosion Risk Curves for Methane, Ethane, and Propane as a Function of Gas Concentration

Here is the graph showing explosion risk versus concentration for ethane, propane, and methane:

- The risk reaches its maximum within the UEL–LEL range, then drops back to zero.
- The explosion risk for ethane, propane, and methane exists only within the LEL–UEL range.
- Therefore, monitoring gas concentration, ventilation, and using detectors for explosion safety are essential in case of gas leaks.

An instantaneous energetic reaction occurs when natural gas (methane, propane, hydrogen sulfide, etc.) mixes with air and encounters an ignition source (spark, friction, electrical devices), provided the gas mixture is within the UEL–LEL range.

- Explosions are only possible when the gas concentration is between the Lower Explosion Limit (LEL) and the Upper Explosion Limit (UEL).
- As well depth increases, pressure and temperature rise, the volatility of the gas increases, and the explosion risk grows.
- Ignition sources include electrical pumps, cable damage, and mechanical collisions.
- Rapid extraction causes pressure fluctuations, which accelerate gas release.

Gases such as Methane (CH_4), Ethane (C_2H_6), Propane (C_3H_8), and H_2S can create an explosion risk.

Determination of Explosion Risk

A. Analysis by Concentration:

GAS	LEL (%)	UEL (%)
Metan	5	15
Etan	3	12.5
Propan	2.1	9.5

Gas Concentration in Air:

- < LEL – no risk
- LEL–UEL – maximum risk
- > UEL – no risk

Simple Risk Modeling:

$$Risk\ (\%) = \begin{cases} 0, & \text{If C<LEL or C>UEL} \\ 100 \times \frac{(C-LEL)\times(UEL-C)}{[(UEL-LEL)/2]^2}, & \text{If LEL≤C≤UEL} \end{cases}$$

Here:

- **C:** gas concentration (%)
- Maximum risk is assumed to be 100%

3. Conclusion

When the gas concentration is between LEL and UEL, there is a probability of explosion during technological processes. As temperature and pressure increase, the gas explosion risk rises, the explosion range widens, and the ignition temperature and energy decrease. Explosions can occur even at lower gas concentrations. As well depth increases, accumulation of natural gas, higher pressure, and difficulty in ventilation significantly raise the explosion risk. Therefore, gas monitoring, ventilation, and spark safety of drilling equipment are very important. During mixing of gases with air, the explosion risk depends only on the type and concentration of the gas.

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Hydroelectric energy potential and its role in Azerbaijan green economy transition

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Abstract. This paper explores the evaluation of Azerbaijan's hydropower capabilities and its contribution to the nation's shift towards a green economy. Hydropower is recognized as one of the most dependable and sustainable renewable energy sources. The country's diverse geographical and hydrological features, particularly the Kura, Araz, Ganikh, Tartar, and other river basins, present ample opportunities for the development of hydropower. The article examines the role of hydroelectric power plants (HPPs) within the national energy mix, their contribution to reducing carbon emissions, and their effect on both energy security and regional socio-economic growth. Additionally, the study assesses government policies and investment efforts focused on modernizing the current hydropower infrastructure and advancing the construction of small-scale HPPs. It also evaluates environmental and social factors, including water resource management, biodiversity conservation, and the ecological impacts. Ultimately, the paper highlights the importance of hydropower as a key element in the creation of Azerbaijan's "green energy zone" and the country's "green economy" framework through 2030.
Keywords: hydroelectric power, renewable energy sources, green economy, energy security, sustainable development, Azerbaijan
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1. Introduction

In today's world, climate change, the disruption of ecological systems, and the exhaustion of traditional energy resources have driven humanity to seek alternative and renewable energy solutions. Among these, hydropower stands out due to its environmental benefits and economic viability. With minimal carbon emissions during the electricity generation process, the ability to reuse water resources, and its reliability in providing a stable energy supply, hydropower has become a cornerstone of the green economy model.

This focus on renewable energy is of particular significance for Azerbaijan. The country is endowed with abundant water resources, including numerous rivers in mountainous regions, creating ample opportunities for the large-scale development of hydropower. One of the most promising initiatives in this regard is the "green energy zone" project, established in the Karabakh and East Zangezur economic regions. This project marks the beginning of a new era in Azerbaijan's energy policy, fostering greater energy independence while contributing to the overall environmental stability of the region. By increasing the share of renewable energy, Azerbaijan aims to reduce its reliance on fossil fuels and mitigate the environmental impact of energy production.

Furthermore, the efficient harnessing of hydropower plays a pivotal role in Azerbaijan's transition to a green economy. This shift is not only about modernizing the country's energy infrastructure but also involves ensuring the long-term sustainability of economic development, improving the quality of life in rural and regional areas, and safeguarding the environment for future generations. The "green economy" strategy encompasses a broad range of goals, from reducing the carbon footprint to fostering social and economic resilience, making hydropower a key element of this transformative approach.

By investing in renewable energy, particularly hydropower, Azerbaijan aims to create a diversified energy portfolio that will enable the country to meet both its growing energy demands and its international environmental commitments. This long-term strategy not only enhances national energy security but also opens up opportunities for sustainable development, job creation, and regional revitalization. In the broader context, the green energy initiatives align with Azerbaijan's commitment to addressing global climate challenges and positioning itself as a leader in the transition to renewable energy sources in the region.

2. Experimental detail

Azerbaijan's hydropower potential, especially in its mountain regions, is significant. The country has extensive river basins, including the Kura, Araz, Ganikh, and Tartar rivers, which provide vast opportunities for hydropower generation. The energy potential from these sources is not only important for meeting local energy demands but also for reducing dependence on fossil fuels and contributing to energy security.

- Hydropower in Energy Balance-Currently, hydropower makes up a substantial share of Azerbaijan's renewable energy production. The government has prioritized hydropower projects, including the development of small hydropower plants (HPPs), particularly in the mountainous regions and newly liberated territories like Karabakh and East Zangezur.

- Small Hydropower Projects-Small-scale hydropower systems can be particularly useful in remote and mountainous areas, where traditional energy infrastructure is hard to implement. These projects provide local communities with a sustainable energy supply while contributing to the country's renewable energy targets.

Hydropower plays a crucial role in Azerbaijan's energy landscape and is a key element in the country’s strategy to transition towards a green economy. Of particular importance is the energy potential offered by the country's mountain rivers. Estimates indicate that the small-scale hydropower capacity that can be harnessed from these rivers is approximately 520 MW. This capacity is especially valuable for powering regions in remote, mountainous areas where access to conventional energy sources is limited.

The hydropower potential in the newly liberated territories is also significant. Reports from Trend.az highlight that the mountain rivers in the Karabakh and East Zangezur regions have an estimated hydropower capacity of around 500 MW. This potential not only ensures energy independence for these regions but also promotes the generation of renewable energy, fostering sustainable economic development. According to the Ministry of Energy and the International Energy Agency (IEA), Azerbaijan's overall renewable energy potential—encompassing hydropower, solar, wind, and other sources—is projected to range between 135 and 157 GW. This underscores the vast opportunities for energy diversification within the country’s energy sector.

Currently, Azerbaijan operates 65 hydroelectric power plants (HPPs) with a combined capacity of 1,443.5 MW. These plants are a major contributor to the nation’s electricity production and play an essential role in boosting the share of environmentally friendly energy generation, thereby enhancing energy security. Additionally, plans are in progress to develop more small hydropower plants, aligning with Azerbaijan’s goal of expanding the share of renewable energy in its energy mix by 2030.

Hydropower is central to Azerbaijan’s green economy transition strategy. This form of energy is critical in reducing reliance on fossil fuels like coal and natural gas, and it helps in significantly cutting down carbon emissions. As hydropower plants produce electricity by harnessing the energy of flowing water, they emit virtually no greenhouse gases, contributing to the fight against climate change. Therefore, developing hydropower is not only vital for ensuring environmental security but also for fostering long-term economic growth that is both sustainable and resilient [4].

In recent years, Azerbaijan has witnessed a notable increase in hydropower production and usage. For example, in the early months of 2025, the country reported a 55.3% increase in the use of hydroelectric power. This growth is a direct result of the government’s prioritization of renewable energy, as well as the introduction of innovative technologies in the energy sector. Ongoing modernization of hydrotechnical infrastructure and the construction of additional small hydroelectric power plants are expected to further support this upward trajectory [2,8].

The projects being implemented in the newly liberated territories under the "Green Energy Zone" initiative are of significant importance in Azerbaijan's energy strategy. These initiatives aim to harness a mix of hydro, solar, and wind energy resources across the Karabakh and East Zangezur regions, marking a comprehensive approach to renewable energy development. This approach not only helps restore energy independence in these areas but also ensures the infrastructure is powered by environmentally friendly sources. Additionally, it aims to establish these regions as a "green energy hub," contributing to sustainable regional development.

The Presidential Order No. 2620, issued on May 3, 2021, directs the creation of a "green energy zone" in the liberated territories of Azerbaijan. The Order outlines the involvement of an international consulting firm, with a collaboration already initiated with the Japanese company TEPSCO. As part of this, a comprehensive Concept document has been developed to guide the implementation process. The goal of the Concept is to provide the region with sustainable, green energy by leveraging its substantial renewable energy potential and proposing solutions based on the application of energy-efficient and environmentally friendly technologies. This includes the development of energy demand models for the region, with various scenarios to assess future energy needs.

The "Green Energy Zone" initiative includes multiple strategies aimed at enhancing the use of renewable energy. These measures encompass the generation of electricity from renewable sources, improving energy efficiency, encouraging the use of electric vehicles, installing solar panels on building rooftops, and utilizing solar-powered LED lights for street and road lighting. Additionally, renewable energy technologies are being integrated into heating, cooling, and hot water systems, while smart energy management technologies and energy-efficient waste management solutions are also being promoted.

Hydropower plays a central role in diversifying Azerbaijan’s economic structure during its transition to a green economy. The expansion of renewable energy projects, especially in the context of the country's heavy reliance on the oil and gas sectors, helps to attract new investments, foster a green technology market, and generate job opportunities, especially in regions that stand to benefit from clean energy sources. Moreover, the development of renewable energy projects aligns with Azerbaijan’s international climate commitments, opening doors for collaboration with global financial institutions [6,7].

A key focus of Azerbaijan’s energy policy is to diversify energy sources and reduce carbon emissions.

Hydropower is of particular strategic value in this regard because it substantially reduces the reliance on high-carbon fossil fuels like coal, oil, and gas. Hydropower plants operate by utilizing the natural flow and potential energy of water, emitting almost no greenhouse gases, thus making a significant contribution to mitigating climate change and ensuring environmental sustainability.

Energy diversification is a key development priority at the national level in Azerbaijan. In recent years, the government has taken significant steps to reduce the country's dependency on oil and gas and to increase the proportion of renewable sources in the energy mix. Hydropower is considered one of the most crucial elements of this green transition. In particular, the development of small and medium-sized hydropower plants, along with the efficient use of water resources from rivers and mountain basins, is seen as an essential tool for improving energy security and achieving carbon neutrality.

The expansion of hydropower projects is essential for Azerbaijan in meeting its international environmental commitments, including the emission reduction targets established under the Paris Climate Agreement. By implementing these projects, Azerbaijan not only contributes to global environmental goals but also ensures long-term economic and social stability. Hydropower, therefore, plays a crucial role in the country's energy diversification strategy. It serves as a key step in reducing carbon emissions, modernizing the energy infrastructure, and advancing Azerbaijan's "green" development strategy [3].

From an economic perspective, the hydropower sector is pivotal in driving Azerbaijan's socio-economic transformation. These projects open up significant investment opportunities for both public and private sectors. As hydropower projects often require the development of sophisticated infrastructure, they stimulate growth in engineering services, construction, and oversight industries, thereby creating numerous employment opportunities. In particular, the construction of small and medium-sized hydropower plants, especially in rural and regional areas, fosters synergy with the agricultural and industrial sectors. This, in turn, increases local employment rates and improves the overall social welfare of these areas.

Additionally, hydropower projects draw the interest of international financial institutions and foreign investors. Global organizations such as the World Bank, the Asian Development Bank, and the Asian Infrastructure Investment Bank (AIIB) have shown interest in financing renewable energy projects in Azerbaijan. This collaboration not only facilitates the transfer of modern technology and energy management systems but also helps build the country's capacity by developing a skilled workforce.

The development of the hydropower sector also plays a vital role in diversifying Azerbaijan's economy structurally. One of the long-term goals of Azerbaijan's economic strategy is to reduce the country's dependence on oil and gas exports while boosting the non-oil sector. Hydropower contributes significantly to this goal by providing new sources of economic growth. It helps improve Azerbaijan's foreign trade balance by increasing energy exports, while simultaneously driving infrastructure development and industrialization in the regions, supporting overall economic sustainability.

Ensuring energy security is a key focus in the national development strategies of countries, and hydropower plays a pivotal role in this context. One of the primary advantages of hydropower is that it utilizes domestic water resources, thereby reducing dependence on imported energy. Azerbaijan's geographical location, with its abundant water resources and favorable natural conditions, offers significant opportunities for harnessing hydropower. The construction of small and medium-sized hydropower plants (HPPs), particularly in mountainous and sub-mountainous river basins, not only satisfies local energy demands but also helps stabilize the national energy balance [1,10,11].

The advancement of hydropower is strategically crucial for Azerbaijan's energy security, as it mitigates the effects of volatility in global oil and gas prices. By boosting domestic energy production, Azerbaijan can achieve greater stability in its energy supply, minimize the need for electricity imports, and strengthen the resilience of its national economy. This becomes increasingly important in the face of climate change and ongoing global energy crises.

Additionally, developing hydropower infrastructure improves the overall stability of the energy grid. Reservoirs and hydrotechnical installations act as storage systems, allowing for better regulation of energy supply, particularly during peak demand periods. This capacity for energy storage ensures consistent electricity production and guarantees a secure energy supply.

The "Green Energy Zone" initiative and the development of new hydropower projects in Azerbaijan further enhance energy security at the regional level. Hydropower plants built in the Karabakh and East Zangezur regions not only fulfill the local energy needs but also create conditions for the integration of regional energy infrastructures into the national grid.

However, there are significant challenges in realizing Azerbaijan's full hydropower potential, which involve economic, technological, environmental, and institutional factors. One of the main obstacles is that a large portion of the country's hydropower resources has yet to be tapped. According to the International Energy Agency (IEA), much of Azerbaijan's hydropower potential has not been fully integrated into the economic cycle, largely due to slow technological progress and limited financial resources. To unlock this potential, targeted infrastructure projects are required to modernize the existing facilities and enhance hydropower production [3,11].

Another key limitation is the inadequate infrastructure. For effective utilization of the country's river systems for hydropower, it is necessary to modernize power transmission lines, reservoirs, and distribution networks. To exploit small rivers, especially those in remote mountainous areas, improvements in transport and energy infrastructure are essential. Increasing the capacity of the energy network, reducing energy losses, and digitizing transmission systems are critical steps to enhance efficiency in the hydropower sector [5,9].

Environmental and social impacts are also important considerations when expanding hydropower projects. Changes in water flows can disrupt local ecosystems, affect fish migration patterns, and alter water quality, which could negatively impact agriculture and drinking water supplies. Therefore, it is crucial to conduct thorough environmental assessments, social impact analyses, and establish compensation mechanisms during the planning stages of hydropower projects. Economic feasibility is another challenge, as hydropower projects typically require substantial initial capital investment. High upfront costs, along with the expenses for imported technological equipment and long payback periods, can deter private investment. To address this, the government could provide financial incentives such as preferential loans, subsidies, and tax exemptions. Additionally, introducing market-driven pricing mechanisms and a “green energy” certification system could further attract investment and increase interest in the hydropower sector.

3. Conclusion

Hydroelectric energy is a central pillar in Azerbaijan's strategy for transitioning to a green economy. By fostering the development of this sector, the country can significantly reduce its reliance on oil and gas, diversify its energy portfolio, and minimize carbon emissions, thereby promoting environmental sustainability. In addition to these environmental benefits, investments in the hydropower industry drive the adoption of advanced technologies, the renewal of infrastructure, and the creation of job opportunities, particularly in regional areas. The establishment of "green energy zones" in the liberated territories is another strategic initiative aimed at enhancing the nation’s renewable energy capacity. However, the successful implementation of hydropower projects is a multifaceted challenge that goes beyond technological considerations. It also involves complex social, ecological, and financial dimensions. Effective management of water resources, minimizing environmental impact, safeguarding ecosystems, and addressing the social concerns of local communities are critical factors that must be carefully balanced. Achieving this balance is essential for ensuring the long-term sustainability of these projects and their contribution to the nation's economic and environmental goals. The importance of hydropower in Azerbaijan extends far beyond energy generation. It plays a strategic role in modernizing the national economy, revitalizing regional socio-economic development, and fulfilling international environmental obligations. With careful planning, the integration of innovative technologies, and strong collaboration between the public and private sectors, hydropower has the potential to become a cornerstone of Azerbaijan's sustainable, competitive, and "green" economic development model.

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Assessment of water samples from the Oxud Village

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Abstract. The results of the conducted research have shown that there are significant differences in the physico-chemical parameters of water samples collected from the Kish River and artesian wells in the Oxud village area of Sheki District. These differences can be attributed to various hydrogeological and ecological factors. The Kish River belongs to the category of surface waters and is formed because of atmospheric precipitation, surface runoff, and direct interaction with soil. For this reason, the river water often exhibits variability in parameters such as temperature, pH, dissolved oxygen content, and other indicators. In contrast, artesian waters are extracted from natural aquifer layers located deep underground and have minimal contact with the atmosphere, resulting in a more stable physico-chemical composition. However, this stability does not imply complete protection from contamination. On the contrary, artesian water sources may be subjected to long-term and gradual pollution processes, primarily due to the leaching of nitrogen-containing fertilizers used in agriculture, which infiltrate through soil layers and reach the groundwater. It was determined that the water of the Kish River is characterized by high dissolved oxygen content and relatively low electrical conductivity and mineral composition. These indicators confirm that the river water is subject to dynamic natural aeration processes. On the other hand, the higher degree of mineralization in the artesian water, along with elevated concentrations of compounds such as ammonium and nitrate, indicates the influence of agricultural activities on the subsurface water cycle. Thus, the comparative analysis clearly demonstrates that factors affecting water quality are not only related to natural geological structure and climatic conditions but are also directly linked to human activity. Identifying these differences is of great importance for the safe use of drinking water and the sustainable monitoring of the environment.
Keywords: *water quality, analysis, heavy metals, pollution, environmental monitoring.*

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1. Introduction

Water resources are an indispensable asset for life and play a vital role in maintaining ecosystems and public health. The quality of water resources is influenced by both natural and anthropogenic factors, and these impacts can lead to changes in the physico-chemical composition of water. Agricultural activities, the use of fertilizers and pesticides, soil erosion, and industrial discharges are among the primary contributors to such changes [1]. The aim of this study is to analyze the ecochemical characteristics of water samples collected from the Oxud village area in the Sheki district and to evaluate potential ecological risks by comparing the results with international standards. Global studies on water quality indicators show that parameters such as pH, dissolved oxygen, electrical conductivity, major ions (NH_4^+, NO_3^-, SO_4^{2-}), and heavy metals (Fe, Cu, Cd, As) are among the most significant indicators [2,3]. According to the 2022 reports by WHO and UNEP, approximately 30% of drinking water sources have become chemically and biologically unsafe due to human activities. In particular, the increase in the levels of nitrate and ammonium compounds occurs because of leaching from soils, predominantly in agricultural regions. The presence of heavy metals in water sources also poses a serious threat. Even at low concentrations, elements such as arsenic, cadmium, and copper can cause chronic effects [4].

2. Experimental detail

Azerbaijan's hydropower potential, especially in its mountain regions, is significant. The country has extensive river The research was conducted in Oxud village, located in the Sheki district of northwestern Azerbaijan, on the southern slopes of the Greater Caucasus Mountains. The terrain of the village mainly consists of foothill zones, which influence the area's hydrometeorological and hydrogeological conditions. The climate is moderately warm and semi-arid, with an average annual temperature of 10–12°C and an annual precipitation of 600–800 mm. The area is predominantly inhabited by a population engaged in agricultural activities. Various nitrogen- and phosphorus-based mineral fertilizers are used in crop fields, which may affect both surface and groundwater quality. The main water sources in Oxud village are the flow of the local *Kish* River and artesian wells located at various depths. The Kish River, as a surface water body with open flow, is more exposed to surface pollution. In contrast, artesian waters originate from deeper geological layers and typically exhibit more stable physico-chemical properties. A comparative analysis of these distinct water sources is essential for evaluating water quality and ecological conditions. Water samples were collected during the spring season, specifically in April and May of 2025. The samples were collected in the morning, following standard laboratory procedures, and stored in sterile plastic bottles. Approximately 2 liters of water were taken from each sampling point and immediately transported to the laboratory for analysis. The samples were collected from the middle flow section of the Kish River and the main artesian well used for drinking water in the village. During sample collection, the water temperature and pH levels were measured on-site using portable devices. The collected water samples were analyzed at the "Khazar Ecological Laboratory" in Baku, equipped with modern analytical equipment. Standard procedures were applied for both physico-chemical and chemical parameter analyses.

Physical Parameter Analysis Methods.

Temperature: Measured using an electronic thermometer.

pH: Measured on-site using a portable pH meter.

Electrical Conductivity (EC): Determined using a conductivity meter, with results expressed in µS/cm.

Table 1. Analysis of physical parameters of water samples

Indicators	Kish River	Artesian water
pH	6.8	7.6
Temperature 23°C	23.27	23.17
Oxygen content (mq/l)	11.2	1.1
Electrical conductivity (µS/ sm)	160-300	650-1400
Density (g/sm³)	1.003	1.09

Density: Determined by the pycnometric method.

Dissolved Oxygen (DO): Measured using the Winkler method or a DO meter.

Chemical Parameter Analysis Methods.

Ammonium (NH_4^+) and nitrate (NO_3^-) ions: The concentration was determined using colorimetric or ion chromatography methods.

Sulfate (SO_4^{2-}) ions: Determined using the $BaCl_2$ precipitation method.

Heavy metals – copper (Cu^{2+}), iron (Fe^{2+}/Fe^{3+}), cadmium (Cd^{2+}), and arsenic (As^{3+}):

Measured using atomic absorption spectroscopy (AAS) method [5]. During the analysis, the water safety parameters were compared with the guidelines of the World Health Organization (WHO), the U.S. Environmental Protection Agency (EPA), and the normative documents of the Republic of Azerbaijan. The analysis of the physical and chemical parameters of the water samples provides significant information regarding the ecological and sanitary status of the Water. The results show that there are some important differences between the Kish River water and the artesian water. In the case of the Kish River, the pH value was recorded as 6.8, while the artesian water had a pH of 7.6. These values (Table 1) indicate the degree of neutrality of the water. The recommended pH range for drinking water is between 6.5 and 8.5 [6-8]. While both water sources fall within this range, the lower pH in the Kish River suggests that it is slightly more acidic. This could be due to precipitation and interaction with soil.

Temperature: In both samples, the temperature is around 23°C. Water temperature directly affects biochemical reactions and the amount of dissolved oxygen. The relatively stable temperature indicates that the water sources are in accordance with the climatic and flow conditions.

Dissolved Oxygen: The oxygen level in the Kish River was 11.2 mg/l, which is considered high. In contrast, the oxygen level in the artesian water was only 1.1 mg/l. High oxygen levels in flowing waters occur due to natural aeration, while in stationary, deep, and enclosed environments, oxygen levels tend to decrease. This difference suggests that artesian water may be less suitable for living organisms and could provide conditions for the growth of anaerobic microorganisms.

Electrical Conductivity: The electrical conductivity in the Kish River ranged from 160 to 300 µS/cm, while in the artesian water, it ranged from 650 to 1400 µS/cm. The higher electrical conductivity indicates a higher level of mineralization in the water. The greater mineral content in artesian waters can be explained by the dissolution of salts from natural geological layers. This also affects the hardness of the water, which could pose problems for domestic use.

Density: The density of the Kish River water was 1.003 g/cm³, while the artesian water had a density of 1.09 g/cm³. This difference indicates that the artesian water contains more dissolved substances (salts, minerals).

Table 2. Anion analysis of water samples

Indicators	Kish river	Artesian water
Ammonium, NH4 mq/l	<0.04	0.17
Nitrates, (NO_3^-) mq/l	3.3	47
Sulfates, (SO_4^{2-}) mq/l	15	28

Ammonium (NH_4^+): The ammonium concentration in the Kish River was <0.04 mg/l, while in the artesian water, it was 0.17 mg/l. The high concentration of ammonium is linked to agricultural activities and the infiltration of organic waste into groundwater. According to WHO, the recommended maximum limit for ammonium in drinking water is 0.5 mg/l. Although artesian water does not exceed this limit, it still requires careful monitoring.

Nitrate (NO_3^-): The concentration of nitrate in the Kish River was 3.3 mg/l, while in the artesian water, it was 47 mg/l. The maximum permissible limit for nitrate, according to WHO, is 50 mg/l. Since the artesian water is close to this threshold, it is considered a potential source of danger. High nitrate levels, especially in infants, increase the risk of "methemoglobinemia" (blue baby syndrome).

Sulfate (SO_4^{2-}): The levels of sulfate were measured at 15 mg/l and 28 mg/l, respectively. These values are much lower than the WHO limit of 250 mg/l, and both water sources are considered safe in this regard. Sulfates are primarily of geological origin and can affect the taste of the water.

Table 3. Cation analysis of water samples

Indicators	Kish river	Artesian water
Mis (Cu) mq/l	<0.008	<0.008
İron (Fe) mq/l	<0.01	<0.01
Cadmium (Cd)mq/1	<0.0015	<0.0015
Arsenic (As)mq/l	<0.01	<0.01

Heavy Metals (Cu, Fe, Cd, As): The concentrations of all these metals were below the detectable minimum limit. This indicates that the risk of heavy metal contamination in the studied areas is low. The minimal presence of cadmium and arsenic is a positive indicator from an ecotoxicological perspective [9-12].

3. Conclusion

In terms of physical parameters, the Kish River water has relatively higher oxygen levels (11.2 mg/l), with a pH value of 6.8, indicating a slightly acidic environment (Table 1). In contrast, the artesian water has significantly lower oxygen levels (1.1 mg/l), which is explained by its underground origin and lack of contact with air. This situation aligns with international studies confirming the oxygen scarcity in groundwater. Chemical parameters reveal more traces of anthropogenic impacts (Table 2 and Table 3). The nitrate (47mg/l) and ammonium (0.17mg/l) values in artesian water are significantly higher compared to the Kish River (NO_3 = 3.3 mg/l; NH_4 = <0.04 mg/l). This indicates the possibility of agricultural fertilizers and substances leaching from the soil and entering underground waters. In general, both water sources are below the recommended limits for heavy metals (Cu, Fe, Cd, As) according to WHO and EPA, indicating relatively clean water in this regard.

However, the elevated levels of nitrate and ammonium, especially in the artesian source, may pose long-term health risks. The Kish River water is more oxygenated and has balanced physical parameters. Artesian water shows a higher risk of contamination due to elevated concentrations of nitrate and ammonium. Both sources are within safety limits for heavy metals. The high electrical conductivity in artesian water indicates a higher degree of mineralization.

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Abstract. Medical waste management is one of the most critical priorities of modern healthcare systems in terms of safety and environmental sustainability. Infectious, chemical, toxic, radioactive, and sharp medical wastes generated in healthcare facilities pose significant risks to human health and the environment. Proper management of these wastes includes segregation at the point of generation, collection in appropriate containers, safe transportation, temporary storage, and final treatment or disposal in accordance with international standards. Research indicates that improving medical waste management systems is a necessary condition for preventing the spread of infections, reducing environmental pollution, and increasing the operational efficiency of healthcare institutions. Effective management models also have strategic importance in terms of sustainable development, environmental safety, and the protection of public health.
Keywords: medical waste, environmental risks, infectious waste, sterilization, disposal.

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1. Introduction

In parallel with the development of the modern healthcare system, the expansion of hospital activities and the growth of medical services, the volume of medical waste is also increasing. In particular, the prevalence of infectious diseases, various diagnostic and treatment procedures applied in hospitals, and the widespread use of disposable medical supplies have made monitoring of medical waste more relevant. Medical waste poses a high risk to both the environment and human health; They may contain toxic, non-toxic, radioactive and cutting materials. Proper management of this medical waste is not only considered a key component of sanitary and epidemiological safety, but also of environmental safety. Each stage of the waste management process — sorting at the source, transportation, temporary storage, neutralization and utilization — is regulated by strict regulatory requirements. The World Health Organization, UNEP and other international organizations have established standards and recommendations for the safe management of medical waste. In Azerbaijan, the collection and neutralization of medical waste is also regulated by legislation, sanitary and hygienic rules and environmental standards. Currently, important steps are being taken in our country to improve the waste infrastructure of medical institutions, introduce sterilization and incineration technologies, as well as establish systems in accordance with international requirements for the transportation of hazardous waste. The main goal of medical waste management is to minimize the risk of infection inside and outside the hospital, and to eliminate threats to the environment and human health. This goal can be achieved through effective planning, the application of modern technologies, personnel training and public control mechanisms. Studies on the subject show that improper waste management can lead to serious environmental problems such as the spread of epidemics and soil, water and air pollution. Therefore, the safe management of medical waste is an important component of building a healthy society, environmental sustainability and sustainable development.

2. Experimental detail

The rapid development of modern medicine, the introduction of new clinical diagnostics and therapy methods in treatment and prevention institutions, the widespread use of disposable medical instruments and supplies, as well as the increase in the variety and consumption of medicines, lead to a continuous increase in the volume of medical waste. In order for the generated medical waste not to pose a risk to human health and the environment, environmental standards and sanitary and epidemiological regulations must be strictly observed in the process of their management (Figure 1).

Figure 1. Medical Waste Disposal Methods

Table 1. Classification of Medical Waste According to Disposal Methods

Method of disposal	Waste quantity (tons)	Total share (%)
Incineration (burning)	315	37%
Autoclave sterilization	280	33%
Chemical disinfection	180	21%
Storage and temporary storage	70	9%
Total	845	100%

Due to the different morphological composition and degree of hazard of waste generated as a result of the activities of medical and preventive institutions, they can be solid, liquid and powder. These wastes, regardless of the profile of the institution and the bed capacity, are assessed as hazardous waste in accordance with international requirements (Figure 2).

Figure 2. Infectious Medical Waste (Used Syringes and Disposable Medical Supplies)

In particular, according to the provisions of the Basel Convention "On the Control of the Transport and Disposal of Hazardous Wastes", medical waste is included in the relevant categories of hazardous waste and its management is regulated by special rules. Medical waste management is regulated in accordance with the existing regulatory and legal documents of the Republic of Azerbaijan. The main legal framework in this area consists of the Law "On Production and Domestic Waste", the "Rules for Cleaning Cities and Other Settlements in Accordance with Sanitary-Hygienic and Ecological Standards, Temporary Storage, Transportation and Disposal of Domestic Waste", approved by the Cabinet of Ministers' Resolution No. 74 dated April 21, 2005, as well as the "Requirements for Medical Waste Management", adopted by Resolution No. 213 dated December 28, 2007. These documents define all procedures related to the collection, storage, processing, transportation and disposal of waste generated in medical institutions based on uniform standards and apply to all treatment and prevention institutions, regardless of their form of ownership.

Table 2. Annual volume of medical waste by type

Waste class	2021	2022	2023	Growth rate,%
Class A – safe waste	480	505	520	+8,3%
Class B – hazardous waste	210	235	260	+23,8%
Class C – particularly hazardous waste	38	42	46	+21,0%
Class D – chemical and industrial waste	15	17	19	+26,6%
Total	743	799	845	+13,7%

Waste classified as class A is considered safe and is usually generated in the common areas of treatment and prevention institutions. This waste is mainly generated in wards, administrative and utility rooms, the central food block, departmental cafeterias (except for infectious diseases, dermatovenereology, phthisiatrics and mycology departments), as well as in the courtyards of institutions. Waste of this class should be collected either in disposable packages or in reusable packaging. Packaging and packages are placed on special carts. After the waste is emptied into containers, reusable containers should be washed and disinfected.Waste classified as class B is considered epidemiologically hazardous. This waste occurs in operating rooms, intensive care units, procedure and dressing rooms, diagnostic offices, infectious diseases and dermatovenereology departments, pathological-anatomical laboratories, laboratories working with pathogenic microorganisms of groups 3–4, vivariums and veterinary clinics. Waste generated in these departments must first be disinfected and then collected in hermetically sealed disposable packages. When the package is ¾ full, the air inside should be removed and closed. At this time, the supervising employee should use a respirator and gloves. Organic residues, microbiological strains, and vaccination materials generated in operating rooms and laboratories are collected in hard, hermetic packaging only after disinfection. Sharp instruments (for example, needles) should also be collected separately from other waste in hard, deformation-resistant packaging. Class B waste may only be transported outside the medical unit in hermetically sealed disposable packages. Packages must be marked with the words "Hazardous waste – Class B", the name of the unit, the name of the enterprise, the date and the surname of the responsible person.

Class C waste is characterized by a high level of hazard. This waste is generated in units where quarantined infected patients are placed, in laboratories working with pathogenic microorganisms of groups 1–2, in phthisiatric and mycological departments. Such waste must be disinfected in accordance with the rules specified in regulatory documents and then collected in disposable packages. Soft packages are placed on special stands and carts. When the package is ¾ full, the air inside is removed and hermetically sealed, observing safety precautions. Microbiological cultures, vaccines and strains should be collected only in hard, hermetic packaging. Class C waste can only be removed from the compartment if it is hermetically packaged. The containers placed in special containers intended for this waste must have the following marking: "Specially hazardous waste – class C", name of the compartment, name of the enterprise, date and surname of the responsible person. Wastes classified as class D have similar properties to industrial wastes in terms of composition. These wastes are mainly generated in diagnostic departments, chemotherapy rooms, pathological anatomy departments, pharmaceutical production areas, pharmacies, warehouses, chemical laboratories and administrative utility rooms. The toxicity level of waste belonging to class D is determined in accordance with the methodological indicators applied to industrial waste. Devices containing mercury, fluorescent lamps and other harmful equipment must be collected in hermetic packaging without damage, the container must be closed after it is completely full and protected in temporary storage places. Waste belonging to this class must be transported and neutralized only by specially specialized enterprises, on the basis of a contract.

3. Conclusion

The increase in environmental and sanitary-epidemiological risks posed by medical waste necessitates more efficient organization of management mechanisms in this area. Proper sorting of waste, accounting, management and neutralization of hazardous components without mixing with other waste are a priority issue for both environmental protection and public health. The conducted analyses and monitoring show that in a number of medical institutions, existing regulatory requirements are not fully complied with, violations are made in the processes of waste collection, registration and transportation by class, and cases of mixing hazardous medical waste with household waste are observed. This creates an environmental hazard and increases the risk of disease spread. In order to eliminate the problems, the measures taken to send warning letters to the heads of medical institutions, appoint persons responsible for waste management, conduct systematic accounting and timely disposal of waste are considered important steps. At the same time, the joint order signed by the Ministry of Ecology and Natural Resources and the Ministry of Health in 2023 is of great importance in terms of strengthening coordinated management in medical waste management. The activities of the Working Group operating within the framework of this document form an important practical basis for an objective assessment of the current situation and the application of management mechanisms in accordance with international experience.

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