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THE SIGNIFICANCE OF VERNIER SENSORS IN ENHANCING THE EFFECTIVENESS OF PHYSICS LABORATORY EDUCATION

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Abstract. *This scholarly article meticulously examines the innovative methodologies associated with the integration of Vernier technologies aimed at significantly improving the overall effectiveness and educational value of physics laboratory sessions specifically within the context of Presidential schools. The strategic implementation of these advanced technologies during laboratory work not only facilitates considerable time-saving endeavors but also enhances the visualization of data, while concurrently simplifying the execution of intricate and complex experimental procedures that are often encountered in the physics curriculum. Furthermore, compelling evidence derived from the comprehensive study substantiates the assertion that the incorporation of Vernier technologies not only heightens students' interest and engagement in the subject matter but also effectively serves as a crucial bridge that connects theoretical knowledge acquired in the classroom with its practical application in real-world scenarios.*

Keywords: *vernier technologies, Vernier Graphical Analysis, Physics Education, Digital Transformation, Laboratory Experiments, Educational Technology.*

Introduction

In the contemporary world of rapid digital transformation within the educational sector, the strategic integration of classical instructional methods with innovative technological frameworks has become increasingly vital. Specifically, the organization of physics laboratory sessions through the utilization of advanced digital instrumentation – exemplified by Vernier sensors – plays a crucial role in reinforcing students' theoretical understanding while simultaneously nurturing their experimental and research capabilities. These digital sensors provide extensive functionalities for recording physical variables with high precision, allowing for immediate analysis and clear visualization through dynamic tables, graphs, and multidimensional diagrams. [1]

The Experimental Nature of Physics

Physics is fundamentally an experimental science, requiring the rigorous study of natural phenomena and physical laws through direct empirical research. Therefore, upgrading the educational infrastructure with interactive tools and innovative laboratory equipment is a key determinant in ensuring the excellence of the learning process. The application of Vernier sensors in physics laboratories does more than just modernize the classroom; it actively stimulates student engagement with current technological advancements and facilitates the development of essential competencies such as critical thinking, meticulous observation, and the synthesis of complex datasets.

Didactic Foundations and Learning Outcomes

This article provides an in-depth analysis of the didactic foundations and contemporary methodical strategies for incorporating Vernier sensors into the physics curriculum. It explores

how these innovative technologies not only elevate the quality of student outcomes but also foster a more positive and proactive attitude toward the subject matter. Research consistently demonstrates that sensor-integrated laboratory environments and computer-based experimentation significantly enhance the level of cognitive mastery among learners. [2]

The technology's capacity for automatic, real-time data acquisition redirects the student's cognitive load away from the tedious manual tasks of technical measurement and toward the conceptual essence of the physical processes being studied. This shift allows students to engage in higher-order thinking, significantly boosting the efficiency of the lesson and strengthening student motivation through immediate feedback loops.[3]

Practical Implementation and Software Requirements

Operating Vernier sensors effectively necessitates that students first install the specialized Vernier Graphical Analysis software on their computing devices and cultivate the technical proficiency required to navigate its features. This digital platform functions as the primary vehicle for visualizing experimental outcomes and formulating conclusions regarding physical laws. By providing a user-friendly interface for curve fitting, statistical analysis and data sharing, the software helps students bridge the gap between raw data and scientific theory. [4]

Below, we outline a practical example demonstrating the application of Vernier sensors within a standardized laboratory setting to illustrate these principles in action.

Investigation of the Law of Conservation of Momentum in Collisions

Student may have learned that a moving object possesses kinetic energy. Momentum is another property of an object, related to its mass and velocity, that is useful to describe its behavior. Momentum, p, is the product of the mass and velocity of an object, $p = m \bullet v$.

They may have learned an external force produces a change in the momentum of an object. If we consider as our system two carts that undergo a collision, then any forces they exert on one another are internal to the system. In this experiment student will examine the momentum of both carts before and after collisions to see what effect, if any, these forces have on the momentum of a system. [5]

The objective of this experiment is to study the law of conservation of momentum during collisions. The necessary equipment includes a measuring tape, carts, a scale, two data logging devices, a switch, light gate, a small hammer, a 1 kg mass, as well as various clamps and boss. (Figure 1)



Figure 1 (The necessary equipments for laboratory)

Regarding safety regulations, it is essential to follow specific precautions during the procedure. When performing the experiment on a special table, you must check that both ends of the track are secured with protective barriers to prevent the carts from falling and damaging the floor or causing personal injury. Additionally, you should be careful to protect your hands and fingers from being pinched or injured when a cart strikes a vertical barrier.

Experimental Procedure:

1. Measure a length of 1 m across the floor or a bench.

2. Measure the mass of two trolleys on the balance and record your results.

3. In the centre of the 1 m length, place the two trolleys back to back. Set up data loggers at either end of the 1 m space (0.5 m away from the back of each trolley, see Figure 2).

4. Set up the data logger to measure the velocity of each trolley as it passes through the light gate.

5. Hit the vertical release rod and record the velocity of each trolley as it passes through the light gate.

6. Repeat steps 2–5, adding different masses to one trolley.

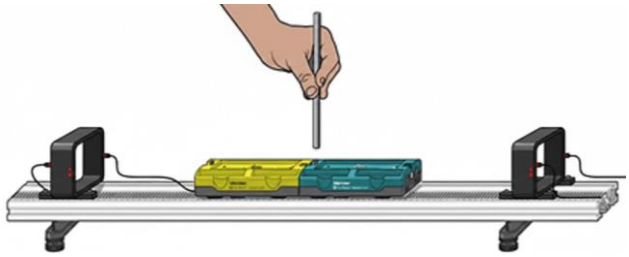


Figure 2 (Experimental set-up for investigating momentum in explosions)

How Velocity Measurement Works

Velocities are calculated by finding the time interval associated with the successive blocking of the two internal gates. This time interval is referred to as the pulse time. The ratio of the distance between the internal gates (2.0 cm) and the pulse time is reported as the magnitude of the object's velocity. An object that first blocks Gate 1 then blocks Gate 2 will report positive velocities. An object that first blocks Gate 2 then blocks Gate 1 will report negative velocities. Velocity measurements can be displayed with units of m/s (default), cm/s. [6]

The default data-collection mode for Object Velocity is Time-based. While collecting data, velocities and their associated time values are recorded. The reported time value, referred to as the velocity mid-time, is determined by averaging the times used for the pulse-time calculation. Student can make multiple velocity measurements in the same data set; however, it may be necessary to adjust the experiment duration in order to collect student desired data.

Recording results

These results were recorded in the laboratory lesson during the learning process.

Average Momentum of Trolley A: $p_A = 0.238\,kgm/s$

Mass of trolley A / kg	**Velocity of trolley A / m/s**	**Momentum of trolley A / kg m/s**	**Mass of trolley B / kg**	**Velocity of trolley B / m/s**	**Momentum of trolley B / kg m/s**
0.253	0.722	0.182	0.253	- 0.738	- 0.186
0.379	0.638	0.241	0.379	- 0.659	- 0.249
0.505	0.575	0.290	0.505	- 0.579	- 0.292

Average Momentum of Trolley A: $p_B = -0.242\,kgm/s$

The total initial momentum of the system was zero (both trolleys were at rest). The total final momentum ($p_A + p_B$) remains approximately zero for each trial. These results confirm the Law of Conservation of Momentum, which states that the total momentum of a closed system

remains constant. The slight differences between p_A and p_B are likely due to external factors such as friction on the track or air resistance.

Uncertainty Analysis: The uncertainty is calculated based on the deviation of the total final momentum from the ideal value of zero.

The total momentum p_{total} for the three trials are -0.004, -0.008, and $-0.002\ kgm/s$.

Range of deviations: $0.008 - 0.002 = 0.006$

Absolute Uncertainty: $\frac{Range}{2} = \pm 0.003\ kgm/s$

Percentage Uncertainty is calculated relative to the average magnitude of momentum measured ($\approx 0.240\ kgm/s$)

Percentage Uncertainty: $\left(\frac{0.003}{0.240}\right) \times 100\% = 1.25\%$

The calculated percentage uncertainty of 1.25% serves as strong evidence for the accuracy and reliability of this experiment. Such a low percentage indicates that the random errors associated with the light gate timing and the measurement of trolley velocities were kept to a minimum across all trials. Furthermore, this high level of precision demonstrates that the experimental setup effectively controlled for external variables, such as track friction and air resistance, during the measured interval. Because the total final momentum remains remarkably close to the initial value of zero with very little deviation, the data provides a high degree of confidence in validating the Law of Conservation of Momentum. Ultimately, this minimal uncertainty confirms that the results are not only consistent but also a true reflection of the underlying physical principles being tested.

Conclusion

Based on the laboratory activity described above, it is clear that organizing physics experiments with Vernier sensors makes the learning process more engaging and easier to understand by demonstrating physical phenomena through real-world devices. Students learn how to operate electronic equipment and navigate specialized software, which motivates them to test their knowledge through technical projects. Furthermore, by analyzing their results and identifying potential errors, students significantly develop their creativity and problem-solving skills. Thus, this set of experiments complements guided-inquiry and Modelling Instruction classrooms. [6][7]

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INFLUENCE OF AN ELECTROLYTE SOLUTION ON THE SEPARATION OF THE AQUEOUS PHASE FROM SOAPSTOCK-DERIVED SAPONIFIED MASS

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Abstract. *The three-stage technology for the production of fatty acids from a 50/50 mixture of cottonseed and sunflower soapstocks has been developed. The primary objective of the study presented in this article is to determine the optimal concentration, quantity, and duration of washing with an electrolyte—specifically, a sodium chloride solution—required for the effective separation of the aqueous and oily phases of the carbonate-saponified mass subsequently treated with a caustic soda solution.The research findings demonstrate that, for efficient separation of the soapstock mass from the aqueous phase, washing with a 20% sodium chloride solution at 50% of the total mass after both processing stages significantly enhances the intensity of accompanying substance removal, compared to the theoretically calculated electrolyte concentration of 5.83%.*
Keywords: *fatty acids, hydrolysis, saponification, soap, electrolyte.*

Introduction

In our previous research, we developed a technology for separating crude fatty acids through a three-stage processing of cottonseed and sunflower soap sludge. In this technology, a 50/50 mixture of cottonseed and sunflower soap sludge was prepared and, in the first stage, saponified with a 35% aqueous solution of soda ash at 90-95°C for 60 minutes.

During carbonate saponification (using soda ash), the triglycerides in the soap sludge are not completely saponified, and the saponification degree reaches 80%. The saponified mass was washed at this temperature with an intermediate product formed in the process—acidic soaps—a 20% concentrated solution of table salt (NaCl) with electrolyte properties, using up to 50% of the saponified mass. The aqueous phase was then allowed to settle for 1-4 hours. During leaching, the salt electrolyte transfers dyes, phospholipids, fatty acid degradation products, and various water-soluble gossypol compounds contained in the soap into the brine. After leaching, the aqueous phase, containing glycerin, associated substances, soda ash, carbonic acid, and table salt, is drained from the bottom of the reactor.

In the second stage, the primary saponified mass is completely saponified with a 42% caustic soda solution at 90-95°C for 180 minutes, then washed with a 20% sodium chloride solution (50% of the soap mass) and poured into the leaching aqueous phase. After leaching and settling for 4 hours, the alkaline soap solution is separated and fed to an acid digestion tank. The resulting alkaline soap solution is sent to separate the glycerin along with the water formed in the first stage, or to neutralize the water formed during acid digestion.

The yield of fatty acids obtained from processing the soap sludge from our own production and from industrial processing was 97.0% and 90.9%, respectively. The resulting oil phase contained 2.9% and 5.7% additives for each sample, respectively.

The subsequent studies examined the effect of the amount and concentration of the sodium chloride solution used in the carbonation and complete saponification processes on the physicochemical properties of the resulting oil and aqueous phases.

Literature Review

It can be seen that during the alkaline refining of vegetable oils, in addition to the neutralization of fatty acids to form soap salts, the presence of numerous oil-soluble by-products and the surface activity of the soap precipitate, due to its adsorption properties, results in the transfer of most of the oil-insoluble and unsaponifiable substances, as well as some of the neutral oil, to the precipitate. Specifically, during cottonseed oil refining, unlike other soap masses, a dark mass with a high content of non-fatty substances containing gossypol and its derivatives is separated [1]. While light-colored soap masses (soybean, safflower, rapeseed, etc.) are used in soap production, the fatty acids are separated from the cottonseed oil [2, 3]. The color of soap masses depends on the content of coloring agents and other accompanying substances in the refined oil and can vary greatly. In any case, the composition of soap masses can be divided into two groups: fatty substances – neutral oils in the form of mono-, di-, and triglycerides, fatty acid salts, free fatty acids, and waxy substances; and non-fatty substances – water-soluble organic acids and their salts, pigments, metal compounds, hydrocarbons, alcohols, ketones, and a number of other compounds.

The diverse and complex nature of the substances contained in the soap residue causes it to undergo rapid changes during storage and processing. Its fats and phospholipids are partially hydrolyzed during storage. Phospholipids also decompose under the influence of acids [4, 5]. The presence of polar and non-polar hydrocarbon radicals in phospholipids gives them strong emulsifying properties [6, 7]. During the decomposition of the soap residue, they remain in the emulsion layer between the oil and water phases, which slows the process. A method for the stepwise acidic decomposition of the fully saponified mass with the formation of acidic soaps has been proposed. In this case, the acidic soaps were salted using sodium sulfate formed during the acidic decomposition. The first stage was carried out at a pH of 4-5. As a result of salting, water-soluble acids (WSA) and their salts were formed, which precipitated. Complete decomposition was carried out at a pH of 1.5-3.0. Timely removal of the VRC accelerates the process and reduces sulfuric acid consumption by up to 4%.

Research Methods

Determination of the Color Index of Fatty Acids. The color index was determined using a Lovibond apparatus in accordance with ISO 15305:1998 [8]. This method is based on determining the color of oil or fatty acid mixtures in a single-layer mode, i.e., in cuvettes with a volume of 133.35 mm³ for light oils and 25.4 mm³ for dark oils. This method is used to determine the color of refined and unrefined cottonseed oil. This instrument makes color determination very simple: the sample cuvette size (25.4 or 133.35 mm³) is entered into the instrument's program, the "read" button is pressed, and within 15-20 seconds, three oil color values (red, yellow, and blue) are displayed on the instrument screen.

This method is based on determining the color of oil or fatty acid mixtures in single-layer mode, i.e., in cuvettes with a volume of 133.35 mm³ for light oils and 25.4 mm³ for dark oils. This method compares the oil color with the color of glass filters at a specified layer thickness. Lovibond PFX 880. The instrument has a lower and upper window. The upper window is used to illuminate the color filters. The cuvette containing the oil is placed in front of the lower window. The upper and lower windows direct the light beam to the eyepiece using plane mirrors and prisms.

Both halves of the field of view must be illuminated equally. This is achieved by correctly positioning the instrument in front of the illuminator.

The oil color is expressed in red units on the Kline scale, indicating the thickness of the cuvette and the number or sum of the numbers of yellow filters. For determining the color, the arithmetic mean of 3-5 measurements is taken. The difference between two parallel measurements should not exceed 1 unit in the range of 2-18 units. Determination of acid number by the salt method. The acid number of the soap solutions and fatty acids used was determined in accordance with ISO 660:2020 [9]. Equipment, reagents, and materials: Class 4 laboratory balance; 100 or 200 cm³ cylindrical special glass container; 25 cm³ burette with 0.1 cm³ divisions; 0.25 N or 0.1 N aqueous or alcoholic potassium hydroxide solution; 35-36% sodium chloride solution; Phenolphthalein.

It is acknowledged that place 20 g of soap solution in a 250 ml conical flask with a stopper. Add 50-60 ml of 15% neutral sodium chloride solution and 0.5 ml of phenolphthalein to the flask. Stopper the flask and shake it, then titrate with a 0.1 N mineral solution (for high acid numbers, a 0.25 N mineral solution can be used). During the titration, shake the liquid after each addition of 4-5 drops of alkali until the lower layer disappears in color. If the color gradually disappears after the next shaking, shake the flask after each addition of 1-2 drops of alkali. Continue titration until a transparent pink color appears in the lower layer of the liquid. The acid number is determined using the following formula (1):

$$Ks = \frac{5{,}611 \cdot a \cdot K}{m} \qquad (1)$$

Here: K_S 5.611 is the titration indicator for a 0.1 N neutral alkali solution, expressed in mg KOH; a is the volume of the 0.1 N solution used for titration, ml; m is the mass of the test sample, g; K is the titration correction.

When determining the amount of organic acid salts in the soap residue and fatty acids, compounds that react with sulfuric acid in the soap residue were taken into account: low-molecular and oxidized acid additives, amino compounds, derivatives of glycerophosphoric acid and gossypol, as well as other saponified substances. The analyses were carried out by potentiometric titration in an alcohol medium. A 0.5-1.0 g sample of soap residue was taken for the study and dissolved in alcohol. A 0.1 mol/dm³ alcohol solution of hydrochloric acid was used for titration. Based on the titration results, potentiometric titration curves were plotted to determine the equivalent volume of titrating agent. The amount of organic acid salts was determined using the following formula:

$$M_{ork.k.t} = \frac{C_{HCl} \cdot V_{HCl}}{m} \qquad (2)$$

Here: $M_{Org.k.t}$ – is the total content of organic acid salts, mol eq/kg; C_{HCl} is the concentration of the alcoholic HCl solution, mol/dm³; V_{HCl} is the volume corresponding to the equivalence point of the HCl solution, cm³; M is the mass of the extract, g.

The determination of the amount of soap and associated salts is based on the extraction of fatty acids from fully saponified soap residue with an organic solvent [30]. For this purpose, 5-10 g of fully saponified soap residue was taken at a temperature of 80-90°C and decomposed with sulfuric acid in a methyl orange medium with stirring. The separated fatty acids were extracted with petroleum ether, and the precipitate was separated by settling the mass. After removing the ether from the extract, it was dried and its mass was determined. The soap content was determined using three formulas:

$$M_{Soap} = \frac{1000 \cdot m_2}{m_1 \cdot M_e} \quad (3)$$

Here: M_{Soap} – soap content in the soap solution, mol eq/kg; m1 – mass of the solution, g; m2 – mass of the dry extract, g; Me – mass of fatty acids in the soap solution, averaging 280 g/mol eq.

The amount of salt impurities was determined using four formulas:

$$M_{if.miq} = M_{org.k.t} - M_{sovun} \quad (4)$$

Here: $M_{if.miq.}$ - amount of salt compounds, mol·eq/kg soapstock; MOrg.k.t – total content of salts of organic acids, mol·eq/kg; M_{Sovun} – soap content in soapstock, mol·eq/kg.

Results and Discussion

When washing saponified soap solution with an electrolyte solution of table salt, its concentration and quantity significantly affect the color of the resulting product and the additive content, as well as the consumption of the reagent used. The concentration of the electrolyte solution directly depends on the free separation of the saponified mass and alkaline water from the saponified mass, and the concentration that determines the complete separation of the oil phase from the aqueous phase is called the limiting concentration (Ch_k) [10]. This concentration was determined for individual fatty acids, and in our experiments, we determined it by calculating the concentration required to wash the saponified mass of cotton and sunflower soap solution in a 50/50 ratio in salt water. We used the following formula [10]:

$$Ch_k = \sum C_i \cdot K_i/100$$

Where: C_i – is the percentage of fatty acid relative to the total amount, and Ki is the limiting concentration for an individual fatty acid.

Since the limiting concentration is calculated relative to sodium hydroxide, when selecting different electrolytes, their amounts are determined based on their transfer coefficient relative to sodium hydroxide. The transfer coefficient for table salt is 1.15. Based on the fatty acid content of individual soap solutions and their mixtures, as well as the limiting concentrations, the calculated limiting concentration of table salt required to separate alkaline water under soap after saponification of the mixture used in the experiments is given in Table 1.

Table 1. Limiting concentration of table salt solution required to separate alkaline water under soap from a mixture of soap solutions

Type of fatty acids	Fatty acid content in soapstock, %			limit concentration, %	
	cotton	sunflower	mixed acids	counting to NaOH	counting to NaCl
Total fatty acids	50	50	100	5,07	5,83
Saturated fatty acids:	30	11	20,5	4,53	5,21
Stearin	2	4,5	3,25	2,9	3,34
Palmitin	25,7	6,2	15,95	4,6	5,29
Myristin	1,1	0	0,55	7,7	8,86
Araxin	1,2	0,3	0,75	7,9	9,09
Unsaturated fatty acids:	70	89	79,5	5,21	5,99
Olein	22,2	51,2	36,7	4,2	4,83

Palmitolein	2,5	0,2	1,35	3,9	4,49
Linoleum	41,9	33,3	37,6	6,6	7,59
Linolenic acid	0,14	0,3	0,22	8,3	9,55
Others	3,26	4	3,63	4,6	5,29

As can be seen from Table 1, in a 50/50 cottonseed/sunflower blend, unsaturated fatty acids account for 79.5% and saturated fatty acids account for 20.5%. In this case, the maximum concentration for unsaturated fatty acids is 5.99%, for saturated fatty acids 5.99%, and for total fatty acids 5.83%. It is important to note that the maximum concentration required for salting the saponified mass of short-chain fatty acids differs significantly from the maximum concentration of long-chain fatty acids.

The first change we made to the process of extracting fatty acids from soap sludge was to split the complete saponification step into two: in the first step, 50% of the lye in the solution was replaced with a 35% solution of sodium ash. After saponification at 90°C for 60 minutes, the solution was treated with a 20% sodium chloride solution as an electrolyte to separate the oil and water phases and leach water-soluble substances from the oil phase. In laboratory experiments, the amount of solution was added visually, depending on the free separation of the water and oil phases. However, for industrial applications, the concentration and amount of sodium chloride were studied, as it was necessary to determine in practice how much sodium chloride solution should be added during the process relative to the mass of fatty acids in the soap sludge. For this purpose, the optimal concentration of sodium chloride in the solution was analyzed in the studies. During the carbonate saponification of the soap residue, solutions of table salt with concentrations ranging from 5% to 25% were prepared. Upon completion of the process, the temperature was stopped and the mixture was treated with a table salt solution until the oil and water phases were clearly separated. The results are shown in Figure 1.

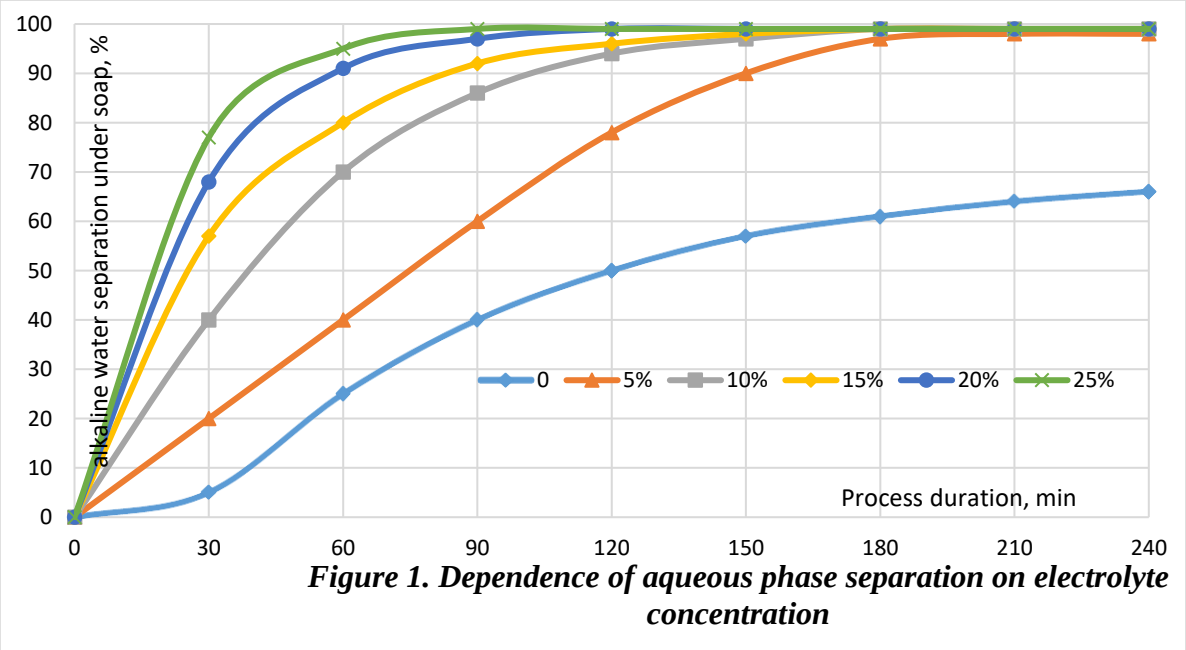


Figure 1. Dependence of aqueous phase separation on electrolyte concentration

As Figure 1 shows, in addition to the weak effect of electrolyte-free water, used as a control during washing of the carbonate soap solution, phase separation occurs very slowly due to emulsion formation. In practice, even after 240 minutes, the oil and aqueous phases do not separate completely.

As soon as the concentration of the sodium chloride solution exceeds 5%, rapid separation of the aqueous phase begins. Specifically, when treated with a 5% sodium chloride solution, 40% of the aqueous phase separates from the soap solution mass in 60 minutes, 78% in 120 minutes, and 96% in 180 minutes. Increasing the solution concentration by the next 10 and 15% accelerates the process and leads to separation of 96-97% of the aqueous phase within 150 minutes. Treatment of the soap mass with a 20-25% sodium chloride solution allows for complete separation of the aqueous phase within 90-120 minutes.

It can be supported from our experiments, separation of the aqueous phase from soap masses treated with 20% and 25% (saturated) sodium chloride solution yielded similar results, it is advisable to use a 20% sodium chloride solution for washing the mixture of cotton and sunflower soap residues after carbonate saponification in the first stage. During the course of our research, we learned that other authors had also reached a similar conclusion [11].

Therefore, there is a difference between the threshold concentration sufficient for separating alkaline water from the soap residue and the actual optimal amounts. It can be concluded that the main reason for this is related to the emulsifying properties of the accompanying substances in the soap mass. It is known that soap residue primarily contains three types of compounds:

1. Compounds that react with alkali to form soap. This type includes phosphatides (lecithin, cephalin, phosphatidic acid), oxidized fatty acids, and some gossypol derivatives. During cottonseed oil refining, almost all phosphorus-containing compounds are transferred to the soap residue. Since sunflower oil is first hydrated, their content in the soap residue is low. Phosphorus-containing substances have strong emulsifying properties, as they capture both polar and non-polar hydrocarbon radicals. As a result, they hinder aqueous phase separation. Depending on storage time and pre-processing conditions, the soap residue contains up to 1-10% oxidized fatty acids (hydroxy acids) [12]. Hydroxy acids are formed by the oxidation of unsaturated fatty acids and have a negative impact on the color of the separated fatty acids and phase separation.

2. Compounds that do not react with alkali, i.e., do not saponify. These compounds include ketones, aldehydes, tocopherols, some water-insoluble derivatives of gossypol, and aliphatic alcohols.

3. Pigments. Cottonseed oil contains significant amounts of gossypol, while sunflower oil contains chlorophylls and carotenoids. During the gossypol refining process, sodium combines with sodium, forming sodium gossypolate. However, this compound is unstable, and gossypol can easily be replaced by oxygen and combine with phosphatides, proteins, and their hydrolyzed derivatives, forming gossyproteins and gossyphosphatides.

The results obtained by adding a 20% solution of table salt to the soap mixture at a rate of 10-70% are presented in Table 2.

Table 2. Effect of electrolyte amount on phase separation of the saponified carbonate mass

Amount of solution, %	Cooling period, min				
	0	60	120	180	240
0	a	a	a	b	B
10	a	a	a	b	B
20	a	a	b	b	B
30	a	b	b	e	E
40	a	e	e	e	E

50	a	e	e	e	E
60	a	e	e	e	E
70	a	e	e	e	E

As can be seen from table 2, when the soap mass was allowed to settle for 4 hours (240 min) without adding electrolyte, the aqueous phase did not separate clearly. Similar results were obtained when treating the soap mass with a 10-20% solution of table salt. When adding more than 30% of the required process, a clear separation of alkaline water from the soap occurred within 60-240 min. Clear separation of the aqueous phase, a minimum amount of water remaining in the soap phase, and the best results in terms of color were obtained using a 30% solution in the range of 180-240 min, a 40% solution in the range of 60-180 min, and a 50% solution in the range of 60-120 min. Subsequent treatment of the soap mass with a 60-70% electrolyte solution also led to similar results. Based on this, a conclusion was drawn on the advisability of washing the carbonate soap mass with an electrolyte solution with a concentration of up to 50%.

According to our proposed method, the washed (salted) mass, containing 50% carbonate soap mass and 20% concentrated sodium chloride solution relative to the soap mass, is completely saponified in a second step with a 42% caustic soda solution at 90°C for 180 minutes.

In conventional technology, the fully saponified mass is treated with a sodium chloride solution and then held for 4 hours. However, in our process, it is necessary to accelerate the separation of the soap and water phases, as well as the saponification process itself. Furthermore, by washing the saponified carbonate mass with an optimal (50%) amount of salt solution, most of the associated substances are transferred to the alkaline water of the soap base and removed, after which caustic saponification occurs. A sharp reduction in the content of directly emulsifying, water-insoluble, and unsaponifiable substances in the soap mass reduces the consumption of caustic soda and electrolyte for separating soapy water before complete soap formation, or, accordingly, increases its efficiency.

For testing our assumptions in practice, in the second stage, we studied the optimal amount and duration of the process by washing the caustic soap mass with a solution of 10-70% by weight, based on a predetermined 20% concentration of table salt. The results obtained in the experimental studies are presented in Figure 2.

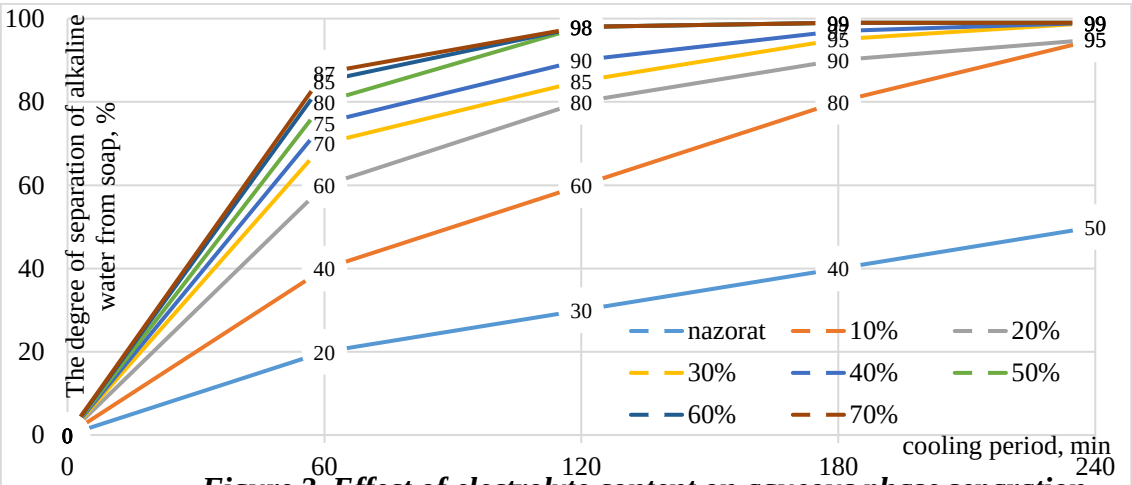


Figure 2. Effect of electrolyte content on aqueous phase separation from caustic fully saponified mass

As can be seen, the separation of the aqueous phase from the carbonate saponified mass using a salt electrolyte accelerates the caustic complete saponification process and the subsequent separation of the aqueous phase, due to the fact that most of the accompanying substances are

removed in the previous stage. As can be seen from Figure 2, in the industrial method (control), the process of washing the completely saponified mass with caustic soda in one stage with a salt solution and settling it, due to the large number of accompanying substances in its composition, including emulsifiers that prevent phase separation, the settling decreases by 50% within 4 hours (240 min). The process takes 6-8 hours to complete. Two-stage saponification and washing the soap mass with salt water at each stage facilitates the separation of accompanying substances from the completely saponified mass. In particular, the use of salt water in the amount of 10-50% relative to the saponified mass accelerates the sedimentation process, leading to the separation of 40% to 98% of the aqueous phase within 60-120 min. Subsequent salting with a solution of 60-70% does not significantly affect the process speed. Therefore, it is advisable to wash the caustic finished saponified mass in the second stage using 50% of a 20% solution of table salt. Thus, the composition of the saponified mass obtained as a result of two-stage complete saponification is given in Table 3.

Table 3. Indicators of two-stage complete saponified mass

Samples	Color	Saponified fatty acids, %	Triglycerides, %	Gossypol and its derivatives, %	Phospholipids, %	Others, %
A blend of cotton and sunflower soapstone						
Experience -3*	dark brown	27,8	18,85	4,53	13,4	2,45
Experience -4**	light brown	35,85	19,1	0,92	2,2	2,25
After washing with carbonated soap and salt water						
Experience -3	light brown	40,2	5,75	0,96	2,9	0,83
Experience -4	light brown	47,07	7,1	0,14	1,2	0,67
After washing the caustic soaped mass in salt water						
Experience -3	Yellowish brown	45,33	0,31	0,36	0,98	0,79
Experience -4	Dark yellow color	53,27	0,43	0,11	0,65	0,57

*-50/50 blend of cotton/sunflower soapsacks obtained from emulsion-refined oil;

**-50/50 blend of cotton/sunflower soapsacks obtained from emulsion-refined oil treated with MEA.

As shown in table 3, after the second stage of complete saponification with alkali, the saponification rate of the soap residue relative to the total fat fraction was 45.33 (94.9%) in Experiment 3 samples and 53.27 (95.8%) in Experiment 4 samples, while the unsaponifiable triglyceride content was 0.31% and 0.43%, respectively. It is also evident that the amount of gossypol derivatives, phospholipids, and other substances, including color additives, in the oil phase significantly decreased after the first and second stages of saponification and washing with an electrolyte solution.

Conclusion. In the 50/50 cottonseed/sunflower soap residue mixture, the unsaturated fatty acid content was 79.5%, and the saturated fatty acid content was 20.5%. In this case, the maximum

concentration for unsaturated fatty acids is 5.99%, for saturated fatty acids 5.99%, and for the total concentration 5.83%. However, in practice, this value is significantly higher. It is important to note that the maximum concentration required to salt the saponified mass of short-chain fatty acids differs significantly from the maximum concentration of long-chain fatty acids.

By washing the saponified carbonate mass with a 35% solution of soda ash and an optimal amount of 50% of a 20% concentrated salt solution, the majority of the associated substances are transferred to the alkaline water of the soap base in the first stage and removed. The resulting mass is then completely saponified with a 42% caustic soda solution at 90°C for 180 minutes, and then washed with another 50% of a 20% concentrated salt solution at the end of the second stage. This significantly reduces the amount of gossypol, phospholipids, and other additives, including coloring agents, in the oil phase.

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ANALYSIS OF MUDFLOW DISCHARGE COEFFICIENTS AND OPTIMIZATION OF FLEXIBLE BARRIER DESIGNS UNDER CLIMATE CHANGE

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Abstract. *The increasing frequency of extreme hydrological events in Uzbekistan, driven by climate change and accelerated glacial melting, necessitates the implementation of advanced flood mitigation structures. This study analyzes the efficiency of flexible (elastic) debris flow barriers and proposes their adaptation for the specific orographic conditions of the Tashkent region, particularly the Bostanlyk district. By evaluating the relationship between the probability of exceedance (P) and the discharge coefficient (A), the research demonstrates that traditional rigid dams often fail to dissipate the dynamic energy of flash floods. The paper provides scientific recommendations for improving flexible barrier designs by integrating triangular prism deflectors and an elastic cable network. These enhancements are aimed at creating a "launch-ramp" effect to redistribute impact forces. The findings offer a technical basis for modernizing Uzbekistan's flood management infrastructure, emphasizing material durability (B25 concrete, W8 waterproofing) and structural elasticity as key factors for regional hydrological security.*

Keywords: *Mudflow flow, climate change, elastic barrier systems, hydrodynamics, structural improvement, energy dissipation, point foundation, filtration mechanism, engineering protection.*

INTRODUCTION

In recent years, a significant increase has been observed worldwide in the occurrence of large-scale natural and man-made emergency situations with severe consequences. This trend has led to a growing number of people being left without shelter, an increase in premature mortality, and substantial economic losses. Consequently, there is a pressing need to ensure effective protection of the population and territories during such emergencies, as well as efficient management of the forces and resources involved in response operations. Special importance is attached to the advance training of managerial and operational personnel of governing bodies responsible for emergency protection, mitigation of consequences, and provision of essential living conditions for the affected population. In recent years, emergency situations occurring within the territory of the republic have consisted of 58.9% man-made and 41.1% natural events. Given their scale and level of damage, man-made emergencies demonstrate higher impact indicators, necessitating the implementation of targeted risk reduction measures. In this context, particular attention is paid to improving the effectiveness of the state emergency prevention and response system, including the management bodies, forces, and resources involved in mitigating the consequences of local and regional emergency situations.

In accordance with the fundamental principles of emergency protection in the republic-namely humanitarianism, the priority of human life and health, and the effective organization and implementation of emergency protection measures-systematic actions aligned with the administrative reforms of the "New Uzbekistan" framework are being implemented. Within this context, the state system for emergency prevention and response places emphasis on conducting scientific research aimed at enhancing and developing the competencies, skills, and managerial capacities of leaders of governing bodies responsible for the management of forces and resources during emergency situations. To address these objectives, particular importance is attached to the development of protection algorithms and models based on the identification of potential emergency hazards and contributing factors. This approach is intended to improve the operational effectiveness of existing emergency management authorities, ensure the protection of the population and territories during emergency situations, and optimize the balance between forces and resources involved in emergency prevention, response, and consequence mitigation.

EXPERIMENTAL RESEARCH

The Resolution of the President of the Republic of Uzbekistan No. PQ-311 dated October 20, 2025, *"On Measures for the Digitalization of the Emergency Protection Sector and the Development of Scientific and Innovative Activities,"* together with Presidential Decree No. PF-60 dated January 28, 2022, which approved the *"Development Strategy of New Uzbekistan for 2022–2026,"* defines the strengthening of national security and defense capacity as a key priority. In particular, within Goal 92-focused on enhancing national security and implementing an open, pragmatic, and proactive foreign policy-the establishment of an effective system for the prevention and mitigation of emergency situations is identified as a priority direction with clearly defined objectives and tasks. Ensuring the protection of the population and territories of the Republic of Uzbekistan from flood and mudflow hazards, as well as from emergency situations that may arise in reservoirs due to such events, is of critical importance for safeguarding human life and preventing the escalation of emergency impacts. Achieving these objectives requires a scientifically grounded assessment and analysis of hydro meteorological observations to identify areas exposed to mudflow and flood risks, to reveal existing challenges, and to implement an effective system for preventing flood-related emergency situations that may result from potential failures of hydraulic structures and reservoirs.

Regions with High Mudflow Risk Across the Republic

Table 1

Region	**Number of Mudflow Sites**	**Main Hazard Types**	**Historical Peak (Recent Years)**
Namangan	124 ta	Flash mudflows, Kosonsoy basin	July 2021 (Kosonsoy disaster)
Surxondaryo	108 ta	Mudstone-laden mudflows	Spring 2022 (Sherobod, Boysun)
Tashkent Region	95 ta	Glacial and mixed mudflows	March 2023 (Rivers of Chirchiq basin)
Jizzakh	82 ta	Floods resulting from flash flows	April 2022 (Egizbuloq disaster)

Statistical data from countries worldwide indicate a continuous increase in both the frequency and magnitude of natural disasters. Similar trends are also observed within the territory

of the republic, where natural hazards occur with increasing regularity. Analytical assessments reveal that there are 409 rivers and streams across the republic that are exposed to mudflow hazards, with the highest concentration located in specific regions, as presented in Table 1.

On June 9, 2015, in the Beshko‘bi village of Zomin district, Jizzakh region, intense rainfall caused a mudflow that swept away a VAZ-2106 vehicle. Of the five individuals in the vehicle, two lost their lives. On May 15, 2016, in Pop district of Namangan region, a mudflow triggered by heavy rainfall inundated 58 houses in the Kalqurbon mahalla. On May 16 of the same year, subsequent mudflows in the same mahalla resulted in the complete collapse of one house, claiming the lives of three out of four family members residing there. On May 16, 2018, in Chiroqchi district, Qashqadaryo region, intense rainfall caused a mudflow in the Mirzato‘q mahalla, Sariqqamish village, resulting in five fatalities. On May 1, 2020, the breach of six piers of the Sardoba reservoir dam in Sirdaryo region led to the flooding of the Qorqontepa settlement in Sardoba district. In total, 22 settlements across 10 mahallas were affected, damaging 5,388 residential and non-residential structures.

Among these, 1,691 were individual houses;

2,038 were concrete-panel residential buildings;

1,014 were multi-storey apartments;

147 were standard-design houses;

455 were incomplete houses or vacant plots.

Fully destroyed houses numbered 1,640, while 3,003 required major repairs. Furthermore, 108 farms and agricultural enterprises suffered damage to 16,525 hectares of land, including 9,704 hectares of cotton, 6,821 hectares of grain, 231 hectares of vegetables, 1,095 hectares of melons, 14 hectares of potatoes, 154 hectares of orchards, and 83 hectares of vegetable plots within orchards. In addition, 66 km of gas pipelines, 47 gas distribution facilities, and 7,550 household gas cylinders were damaged across 11 settlements in Sardoba, Oqoltin, and Mirzaobod districts. Significant damage also occurred to irrigation infrastructure, including 8.5 km of the “Central Network” canal, 4.5 km of the “Right Network” canal, and 3 km of the “Left Network” canal. These events underscore the increasing hazards in the geotechnosphere and highlight the necessity of constructing additional protective engineering structures to safeguard human settlements and critical infrastructure.

On March 15, 2022, in Baxt settlement of Sirdaryo district, a flood completely rendered two multi-storey residential buildings uninhabitable. On May 4, 2022, in the mountainous areas of Zomin district, Jizzakh region, heavy rainfall caused mudflow events along streams passing through the Peshag‘or, Achchi, Qang‘li, and Shorcha villages. According to the regional Department of Internal Affairs, two individuals stranded by the mudflow were successfully rescued. In response to the flood, 140 rescuers and 8 specialized vehicles from the regional Emergency Situations Department, along with 83 personnel and 25 specialized vehicles from subordinate organizations of the state emergency prevention and response system, were deployed. Teams conducted assessments in streets and residential areas affected by the floodwaters and cleared debris, while accumulated water from courtyards and basements was removed using specialized equipment.

On May 5, 2022, at 23:00, in Uzun district of Surxondaryo region, intense rainfall in mountainous and hilly areas caused the “Orta Ariq” canal, which passes through the “Toshtepa” area of the “22nd Anniversary of Independence” MFY, to overflow. This flooding affected nearly 40 residential houses, gardens, and 15 household plots in the Dehqon mahalla. To ensure the safety

of residents, over 230 individuals from the 40 affected households in Toshtepa village were temporarily relocated to School No. 19 in the district under the coordination of the regional Emergency Situations Department, in cooperation with rescuers, the Ministry of Internal Affairs, the National Guard, and responsible officials from the regional administration. Uzbekistan can thus be considered among countries facing frequent flood risks. Rapid development of mountainous areas has disrupted natural conditions, contributing to the emergence of numerous mudflows. As a result of ecological imbalance, mudflows now occur in locations previously unaffected. Considering existing and potential hazards, alongside a comprehensive approach to planning and design, allows for scientifically justified measures to protect against mudflows. Between 2015 and 2022, a total of 507 mudflow events were recorded across the territory of the republic. The distribution of these events by year is presented as follows.

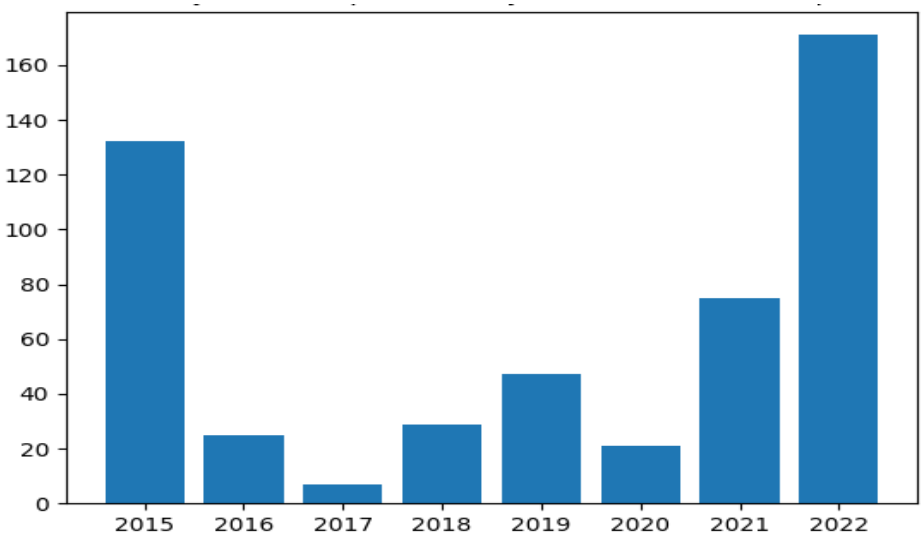


FIGURE 1. Number of flash floods and floods in the Republic from 2015 to 2022 years

The climate of the Republic of Uzbekistan is situated within one of the regions most significantly affected by global warming. According to data from the Agency for Hydrometeorological Services of the Republic of Uzbekistan (Hydromet), the average air temperature in the country has increased by 1.5°C since 1900, which notably exceeds the global average increase of 1.1°C. This warming trend is particularly accelerated in mountainous regions compared to lowlands, reflecting a shift in the vertical temperature gradient. This process leads to an increase in the moisture-holding capacity of the atmosphere. In accordance with the Clausius-Clapeyron equation, for every 1°C increase in temperature, the water vapor holding capacity of the air rises by approximately 7%. Consequently, the immense energy accumulated in the atmosphere manifests as short-duration yet extreme convective rainfall events. An analysis of mudflow and flood occurrences across the republic's territories during the period of 2016–2022 is presented in Figure 2.

The highest incidence of these events was recorded in the Fergana region, accounting for 23.4% of the total cases. This high frequency is attributed to the region's foothill and mountainous relief, the frequent occurrence of short-term intensive precipitation, and the high density of the river and stream network. The Namangan region ranks second, with a 20.0% share of mudflow and flood events. Key risk-amplifying factors in this area include the high concentration of settlements located in the foothills and the rapid rise in water discharge levels. The third-largest share belongs to the Surkhandarya region at 18.9%. The topography of this region is characterized by sharply fragmented relief, where mudflow events are primarily driven by rapid snowmelt and

heavy rainfall during the spring months. In the Tashkent and Kashkadarya regions, these figures stood at 11.8% and 10.8%, respectively. The hazard levels in these regions are further exacerbated by the proximity of flood risks to industrial and infrastructure facilities. Although relatively lower indicators were observed in Jizzakh (6.6%), Navoi (4.74%), and Samarkand (2.63%) regions, mudflow events in these areas can still result in severe damage under specific meteorological conditions.

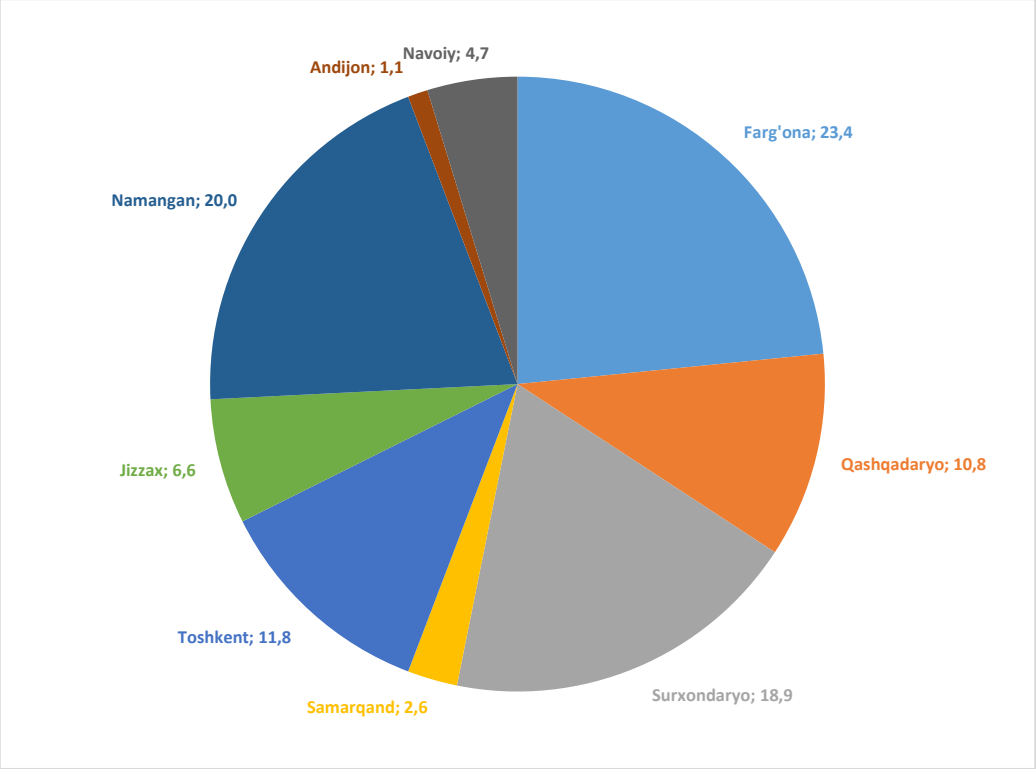


Figure 2. Regional distribution of mudflows and flood events.

The lowest percentage was recorded in the Andijan region, at only 1.05%, where the relatively flat terrain leads to a lower frequency of flood hazards. Extreme rainfall events lead to a sharp increase in water levels, exceeding the capacity of rivers and lakes, subsequently flooding agricultural lands, residential areas, and transport infrastructure. Such disasters result in substantial economic losses, fatalities, and the disruption of vital life-support systems.

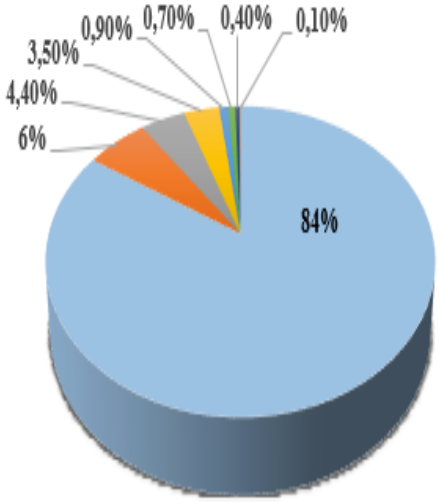
The primary causes of flood occurrences are systematically categorized in Figure 3.

Dynamics of Precipitation and Runoff Patterns

- **Increased Intensity:** Over the past 15 years, the frequency of days with daily precipitation exceeding 30 mm has increased by 15–20%.
- **Seasonal Shifts:** The peak period for mudflow activity, which historically occurred in April and May, has shifted toward late February and March. This phenomenon is driven by the convergence of rapid snowmelt and intensive rainfall, leading to the formation of "mixed-fed mudflows."
- **Localization:** Flood events are increasingly characterized by their extreme speed (flash floods) within small mountain river basins (soys) with catchment areas of up to 50–100 km².

Glacial Degradation and its Hydrological Consequences Uzbekistan's hydrological security is fundamentally linked to the glaciers of the Pskem, Chatkal, Gissar, and Turkestan ranges.

- **Glacial Reserves:** Central Asian glaciers have lost approximately one-third of their total volume over the last 50 years.



Heavy rainfall / Intense precipitation	**84%**
Rapid snowmelt	**6%**
Rain accompanied by hail	**4.40%**
Rain-on-snow events (Combined snowmelt)	**3.50%**
Dam or embankment breach	**0.90%**
Hailfall	**0.70%**
Glacial lake outburst floods (GLOF)	**0.40%**
Other miscellaneous factors	**0.10%**

Figure 3. Causative factors of flood occurrences

- **Hydrological Impact:** Accelerated glacial melting has increased the base flow of mountain rivers. However, this has compromised the static stability of riverbeds, resulting in a 1.2 to 1.4-fold increase in the concentration of solid sediments (stone, sand, and silt) within mudflow mixtures.

Glacial Lake Outburst Floods (GLOFs) Out of more than 800 high-altitude lakes threatening the territory of Uzbekistan, 124 are classified as breakout-prone (moraine-dammed lakes). A breach in these natural dams could trigger the instantaneous release of tens of millions of cubic meters of water-silt mixture, descending to lower altitudes within minutes.

Socio-Economic Impact and Risk Management Approximately 12% of the Republic's territory is situated within high-risk flood zones. These disasters annually inflict severe damage on economic sectors and infrastructure, including agricultural lands, residential settlements, industrial facilities, and irrigation systems. Most tragically, these events result in human fatalities.

- **Vulnerable Populations:** Currently, 4,149 households and 21,426 individuals reside in flood-prone areas, with the highest population density recorded in the Fergana region.
- **Monitoring and Infrastructure:** Within the state system for emergency prevention and response, over 300 observation posts are operational. There are 29 primary mudflow basins identified in Uzbekistan, primarily concentrated in the mountainous provinces of Namangan, Fergana, Surkhandarya, Tashkent, Kashkadarya, and Samarkand.

At present, there are several sites within the study area where peak discharge erosive flows occur multiple times annually. This phenomenon serves as a primary indicator of spatial differentiation in hazard levels. Based on the results of our field scientific research conducted in the mudflow and flood basins of the Bostanlyk district, Tashkent region, we have derived an equation to calculate the slope erosion coefficient as a function of time.

$$E = [0.58 + 1.40(F_1/F_0) \cdot (t/T)0.21], \quad (1)$$

The calculation of the slope erosion coefficient is based on the relationship between the eroded surfaces and the total catchment area over a specific timeframe. The variables are defined as follows:

F_1 – the eroded area within the river basin (km^2);

F_0 – the total surface area of the river basin (km^2);

t – the specific time interval (year);

T – the total duration of the observation period.

Furthermore, the peak discharge value of mudflows from various sources of origin is calculated using the following analytical expression:

$$Q_{\max} = A(34 + 400i)F_0^{0.61} \text{m}^3/\text{s}, \quad (2)$$

The variables within the aforementioned formula are defined as follows:

A – the mudflow discharge coefficient, the values of which vary depending on the probability of exceedance (P%) as detailed in Table 2.

Relationship between the mudflow discharge coefficient (A) and the probability of exceedance (P,%)

Table 2.

The probability of exceedance P (%)	0.1	1	3	5	10	25
Mudflow discharge coefficient A	2.4	1.0	0.7	0.6	0.5	0.3

Using the relationships (1) and (2), we calculated the erosion-washout coefficient for active tributaries of the erosion-destructive flow type within the river catchment area of the Bostanlyk district. Additionally, the maximum peak discharge values for destructive flows with a 1% probability of exceedance were determined.

RESEARCH RESULTS

Innovative Design of an Elastic Debris Flow Regulatory Barrier. Natural anomalies, particularly debris flows, necessitate specialized engineering solutions for effective mitigation. As debris flows are among the most destructive natural phenomena, regulation measures must be directly aligned with their genesis and dynamics. Conventional rigid barriers often fail to redistribute dynamic forces or alter the flow regime on the impact surface. To address these limitations, a collaborative research effort has resulted in the development of an innovative elastic debris flow regulatory dam.

1. Structural Design and Geometry. The barrier is composed of multiple sections featuring triangular prisms of uniform height integrated into the bed of the flow channel. These prisms are positioned with their lateral sides in close proximity. The base height of the prisms increases progressively along the direction of the debris flow, effectively creating a "trampoline" (kick-jump) effect.

2. Functional Elements and Elasticity. The upper segment of the structure is oriented against the flow direction. It incorporates elastic cables stretched between the upper edges of the prisms, which are interconnected to form a unified network. The lateral cables are configured to create "pockets" between the edges, specifically designed to capture and decelerate the debris mass.

3. Technical Novelty. Unlike traditional barbed-wire or rigid structures, the novelty of this elastic barrier lies in its constructive configuration. By utilizing triangular prisms combined with uniform vertical stems placed within the debris flow layer, the structure ensures a smooth, non-linear reception of the impact. This allows for the gradual dissipation of kinetic energy and the redistribution of dynamic pressure, significantly increasing the structural resilience of the dam.

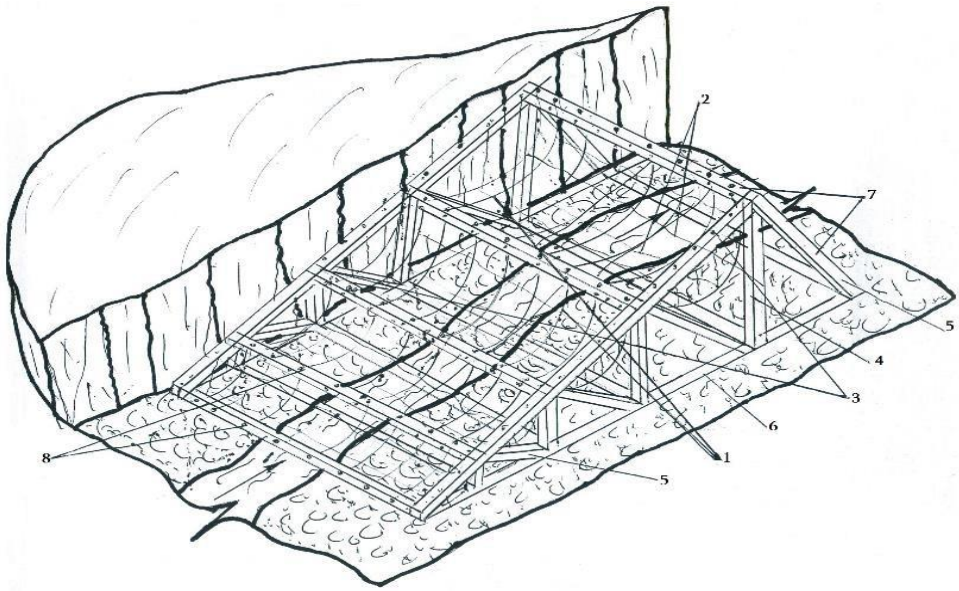


Figure 3. Flexible debris flow barriers

The proposed structure is designed in segmented sections to optimize force distribution. The impact-receiving surface is composed of high-tension cables, forming a curvilinear elastic mesh. Along the flow direction, the height of the prism supports increases progressively, functioning as a launch ramp (kick-jump) to dissipate kinetic energy. The cross-sectional dimensions and the overall length of the structure are determined based on the rheological properties, density, and impact force of the debris flow.

Figure 3. Legend and Component Description

The structural arrangement illustrated in Figure 3 consists of the following components:

1) *Longitudinal elastic cables:* Suspension elements that absorb tension along the flow axis.

2) *Transverse elastic cables:* Lateral cables that maintain structural integrity and form the mesh grid.

3) *Triangular prisms:* Primary deflectors that alter the flow trajectory.

4) *Triangular prism bases:* The foundational support for the deflectors.

5) *Prism base height:* Variable height segments that create the ramp effect.

6) *Prism anchors/grips:* Fixation points for the structural network.

7) *Attachment orifices:* Specialized openings for securing the mesh or secondary cables.

Mathematical Modeling of Dynamic Impact

The dynamic influence of the debris flow on the innovative regulatory structure is calculated using the following functional relationship:

$$P_1 = \frac{\gamma \omega V^2}{g} \sin\psi \, f(m) \text{ N/m}^2, \quad (3)$$

The dynamic impact of the debris flow on the innovative elastic structure is determined based on the following physical and rheological parameters:

γ – the volumetric weight (unit weight) of the debris flow mixture (N/m^3);

ω – the effective cross-sectional area of the flow (m^2);

V– the velocity of the flow (m/s);

φ– the internal friction angle of the debris material;

α – the gradient angle of the structure relative to its base (^{0});

f – the coefficient of internal friction, which is defined as follows:

$$\psi = tg^2(45^0 - \frac{\varphi}{2}), \quad (4)$$

Parameters of Flow Rheology and Interaction

h_0 – equivalent bonding depth (m)

H – flow depth (m)

a – a dimensionless coefficient defined by the relationship $(1 - h_0)\ \psi$;

f_m – a coefficient representing the rheological properties of the debris flow mixture.

$$f'_m = \frac{16 - \left(\alpha^3 + 4\alpha\sqrt{\alpha}\right)\left(2 + \sqrt{\alpha}\right)^2}{\left(\alpha^3 + 4\alpha\sqrt{\alpha}\right)\left(2 + \sqrt{\alpha}\right)^2} \quad (5)$$

The proposed structural advancement for debris flow mitigation is engineered as a high-strength steel-integrated spatial framework. To ensure localized stability under extreme hydrodynamic pressures, a system of isolated (point) foundations was strategically implemented. These foundations utilize B25 grade impermeable concrete (W8) formulated with Portland cement to withstand constant moisture exposure. Furthermore, advanced hydro-insulating coatings protect all structural surfaces in direct contact with the soil and fluvial seepage. The support architecture functions as a unified spatial system, specifically calibrated to absorb and redistribute both static dead loads and transient impulse forces generated by high-velocity mudflow events.

CONCLUSION

Based on the comprehensive analysis of debris flow dynamics and structural engineering solutions, the following conclusions were reached:

1. *Hydrological Vulnerability:* The 15-20% increase in daily precipitation intensity in Uzbekistan significantly raises the risk of "mixed-fed" mudflows, requiring a shift from rigid to flexible protection methodologies.
2. *Model Reliability:* The calculated discharge coefficients (ranging from 0.3 to 2.4 for P=25% to 0.1%) provide a calibrated baseline for engineering designs in the Bostanlyk district, ensuring that structures are resilient to 10-year and 100-year return period events.
3. *Structural Adaptation:* It is recommended to enhance flexible barrier designs by adopting a spatial system of triangular prisms with varying base heights. This modification creates a trampoline effect that redirects flow energy away from the foundation, thereby increasing structural longevity.
4. *Material Integrity:* For the implementation of these barriers in Uzbekistan’s river basins, the use of point foundations with B25 grade concrete and W8 waterproofing is essential to withstand high filtration pressures and corrosive soil environments.
5. *Practical Application:* The proposed improvements to the elastic barrier design offer a cost-effective and structurally superior alternative to traditional concrete dams, providing a sustainable pathway for protecting the country's population and infrastructure.

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PROBLEMS RELATED TO PROTECTIVE EQUIPMENT OF WORKERS WORKING AT THE NAVOI-URAN STATE ENTERPRISE

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Abstract. *This article analyzes the problems associated with personal protective equipment of workers operating at the Navoi-uran State Enterprise. The state of protective equipment, the practice of their use, and existing shortcomings in the conditions of chemical and physical hazards inherent in the processes of uranium mining and sulfuric acid production were studied. As a result of the study, it was revealed that some protective equipment does not fully meet the requirements of modern labor protection, and there is a need to improve the mechanisms for their selection and control. The article provides scientific and practical proposals aimed at increasing industrial safety and protecting the health of workers. Article 37 of the Constitution of the Republic of Uzbekistan establishes the right of every citizen to work and guarantees of work in safe working conditions. This constitutional right is the foundation of all labor legislation. Every enterprise, organization and entrepreneur is legally obliged to create a safe and healthy working environment. Compliance with modern safety standards Provision of protective equipment Implementation of a system of constant monitoring and control Training and advanced training of employees depends on a number of factors. In the modern labor market, the quality of working conditions affects not only the health and well-being of employees, but also the efficiency of the entire economy. In this article, we will deeply analyze the most important aspects of creating a labor protection system, safety standards and a healthy working environment in Uzbekistan.*

Keywords: *labor protection, personal protective equipment, industrial safety, chemical hazard factors, uranium mining, sulfuric acid production, navoi-uran state enterprise.*

I. INTRODUCTION

Nowadays, the complexity of production processes and the increase in technological capacity at industrial enterprises are further increasing the requirements for the labor protection system. Especially in enterprises where chemicals, high-temperature, pressure equipment, and harmful production factors are present, protecting the health of workers is one of the urgent issues. In such conditions, the correct selection of personal protective equipment, its rational use, and constant monitoring are considered important factors in ensuring production safety. Navoiyuran State Enterprise is one of the largest strategic industrial entities in the Republic of Uzbekistan engaged in the extraction and processing of natural uranium. The enterprise carries out technological processes such as uranium mining, underground alkalization methods, and sulfuric acid production. These processes require workers to work under the influence of chemical, physical, and technological risk factors [1].

Practical observations show that insufficiently effective use of personal protective equipment in production processes or failure to update them in accordance with modern requirements can have a negative impact on the health of workers. Therefore, it is important to

assess the condition of existing protective equipment at the enterprise, identify problems in their use, and develop scientific and practical proposals aimed at eliminating them. This article analyzes the problems associated with personal protective equipment of workers operating at the Navoiyuran State Enterprise, and provides conclusions aimed at increasing production safety and improving the labor protection system [2].

II. METHODS

This article is aimed at assessing the state of personal protective equipment for workers engaged in uranium mining and sulfuric acid production processes at the Navoiyuran State Enterprise. The article studies the practice of using protective equipment in conditions of chemical, physical and technological risk factors inherent in the production environment. A set of analytical and practical methods was used in the preparation of the article. In particular, the current regulatory and legal documents on labor protection, internal instructions of the enterprise and production regulations were analyzed. Based on observations conducted at workplaces, the technical condition of personal protective equipment, their compliance with production hazards and the level of use were assessed.

Also, harmful factors encountered during the activities of workers were classified, taking into account the technological characteristics of production processes. The information obtained within the framework of the article was processed using comparison and generalization methods, and scientific and practical conclusions were formed aimed at identifying existing problems and eliminating them.

III. RESULTS

This article assesses the current state of personal protective equipment used in the uranium mining and sulfuric acid production processes of the Navoiyuran State Enterprise. The results show that there are certain inconsistencies between the risk factors present in the production environment and the level of use of protective equipment.

Table 1. Main risk factors identified in production processes

Production direction	**Type of risk factor**	**Risk level**
Sulfuric acid production	Chemical (H_2SO_4 vapors, SO_2)	High
Uranium mining	Chemical (solutions, aerosols)	Medium–high
Technological equipment	Physics (temperature, noise)	Average
Pump and piping systems	Mechanical (under pressure)	Average

It was found that the highest level of risk is observed in sulfuric acid production workshops, which further increases the demand for protective equipment. Below, the level of provision of workers engaged in production processes with personal protective equipment was analyzed. These indicators allow us to assess the compliance of existing protective equipment with real risk factors in production and identify shortcomings in their use. The results are presented in Table 2.

Table 2. Status of provision of personal protective equipment

Type of protective device	**Coverage rate (%)**	**Current status**

Special work clothes	100	Partially obsolete
Protective gloves	92	Fast food
Protective masks (respirators)	78	Not enough
Goggles and face mask	81	Partially compatible
Chemical protective suit	65	There is a shortage.

It can be seen from the table data that, respiratory and chemical protection equipment The level of provision is relatively low, which poses a risk to the health of workers.

The main problems identified in the use of personal protective equipment are summarized below. These problems can directly affect the effectiveness of protective equipment and reduce the level of production safety. The identified shortcomings are presented in Table 3 as a percentage.

Table 3. Main problems in the use of personal protective equipment

Problem type	**Detection rate (%)**
Obsolescence of tools	47
Incompatibility with modern standards	39
Insufficient control over proper use	34
Not being replaced regularly	29

According to the results, the effectiveness of the use of personal protective equipment is significantly affected not only by the supply, but also by the control and monitoring system. In general, the results show that although the Navoiyuran State Enterprise has personal protective equipment, some types of it do not fully correspond to the level of production hazards. This situation indicates the need to further improve the labor protection system.

IV. DISCUSSION

The results presented in the article showed that there are significant discrepancies between the risk factors associated with production processes and the level of use of personal protective equipment at the Navoiyurgan State Enterprise. In particular, despite the high level of chemical risk factors in the sulfuric acid production processes, as shown in Table 1, the results of Table 2 showed that the provision of respiratory and chemical protective equipment is insufficient. The results obtained show that the level of provision of respirators and chemical protective suits is 78% and 65%, respectively, which does not fully correspond to the existing level of risk. This situation increases the risk of workers being exposed to harmful gases and aggressive chemical environments.

The issue of respiratory protection is especially important in production conditions associated with sulfuric acid vapors and sulfur compounds. The results presented in the article showed that there are significant discrepancies between the risk factors associated with production processes and the level of use of personal protective equipment at the Navoiyurgan State Enterprise. In particular, despite the high level of chemical risk factors in the sulfuric acid production processes, as shown in Table 1, the results of Table 2 showed that the provision of

respiratory and chemical protective equipment is insufficient. The results obtained show that the level of provision of respirators and chemical protective suits is 78% and 65%, respectively, which does not fully correspond to the existing level of risk. This situation increases the risk of workers being exposed to harmful gases and aggressive chemical environments. The issue of respiratory protection is especially important in production conditions associated with sulfuric acid vapors and sulfur compounds.

V. CONCLUSION

This article analyzes the situation of workers working at the Navoiyuran State Enterprise with regard to personal protective equipment. The results obtained showed that the level of provision and use of some protective equipment is insufficient in relation to chemical and physical hazards present in production processes. In particular, the low level of provision of respiratory and chemical protective equipment was identified as a risk factor for the health of workers. According to the results of the article, the main reasons for reducing production safety are the obsolescence of personal protective equipment, its incomplete compliance with modern labor protection requirements, and insufficient control over their use. These circumstances increase the likelihood of occupational diseases and adverse effects associated with production. In conclusion, it can be said that it is necessary to improve the labor protection system at the Navoiyuran State Enterprise, carry out the selection and renewal of personal protective equipment in accordance with the level of production risks, as well as strengthen constant monitoring and control over their use. These measures serve to increase production safety and protect the health of workers.

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ARTIFICIAL INTELLIGENCE AND ITS NECESSITY IN MODERN MEDICAL MANAGEMENT

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Abstract. *This article examines the essence of artificial intelligence (AI), its entry into the healthcare sector via digital technologies, its significance in modern medicine, and the necessity of its application today.*

Keywords: *modern medicine, artificial intelligence, digital technologies, healthcare, algorithms, automation.*

Introduction

AI technologies are revolutionizing the medical field. Modern healthcare requires processing large volumes of data, accurate diagnostics, early disease detection, and optimized management processes. Integrating AI into medical management is therefore urgent and strategically important. Currently, AI automates diagnostic processes, individualizes treatment plans, reduces human errors, and optimizes the use of medical resources. AI algorithms also play a crucial role in analyzing medical images, deepening genetic research, patient monitoring, and forecasting epidemics. In the ongoing digital transformation, AI provides innovative approaches, precision, and rapid decision-making capabilities in healthcare management, making it an essential direction in modern medicine.

Objective: The aim of the research is to conduct a thorough scientific analysis of the role, place, and effectiveness of artificial intelligence (AI) technologies in managing modern healthcare systems, and to explore the necessity of integrating these technologies into medical practice and administration.

The study focuses on investigating the role, capabilities, and efficiency of AI technologies in contemporary healthcare management, as well as developing scientific and practical foundations for their implementation in the health sector. Through this research, the following approaches are undertaken: a scientific analysis of the core principles of AI, its operational mechanisms, and areas of application in medicine; examination of AI's potential in early disease diagnosis, automation of treatment processes, health monitoring, and epidemic forecasting; justification of the importance of big data, machine learning, and neural networks in managing and analyzing medical information; and identification of opportunities to optimize healthcare institution management, reduce human error, and accelerate decision-making through AI tools.

Additionally, the study aims to develop a conceptual model that ensures the sustainable development of AI technologies in the digital transformation processes within the medical field. Overall, the research seeks to determine ways to enhance healthcare service quality, preserve human life, and efficiently manage medical processes through the application of AI in healthcare system management based on digital transformation.

Materials and Methods: The main material of the study consisted of artificial intelligence (AI) systems applied in the medical field, software platforms, digital databases, algorithms for analyzing medical imaging, healthcare management programs, and relevant scientific literature. Additionally, opinions and experiences regarding the use of AI technologies in global and Uzbek medical practice were examined. The article employed the following scientific-methodological approaches and methods:

Theoretical analysis – studying the scientific foundations, operating principles, and areas of application of artificial intelligence in medicine.

Comparative method – comparing the effectiveness of traditional management systems with AI-based management models.

Systemic approach – analyzing the interconnection and integration of AI across all levels of healthcare management.

Empirical (practical) methods – studying the practical outcomes of existing AI platforms, such as diagnostic software and data analysis systems.

Statistical analysis – analyzing and summarizing performance indicators related to the implementation of AI in medicine. Using these methods, the study focused on a detailed examination of the practical capabilities of AI technologies in medicine, their impact on management efficiency, and their role in reducing human error.

Research Results: Artificial intelligence (AI), as the term implies, refers to technology that simulates human thinking, learning, and decision-making processes through computers and software. AI algorithms rely on large datasets, have the capacity to learn independently (machine learning), and often provide results faster and more accurately than humans. “Artificial intelligence is a distinct branch of computer science, which deals with creating computer systems capable of performing tasks typically associated with human cognition: understanding language, learning, reasoning, problem-solving, translation, and similar abilities. AI allows computers to learn from experience, adapt to given parameters, and perform tasks that were previously possible only for humans” [1]. Thus, at present, AI consists of algorithms and software systems designed to perform a variety of functions, successfully executing tasks that humans are capable of.

In modern medicine, AI development and data analysis enable highly effective diagnosis and treatment. AI algorithms assist in processing clinical information, making diagnoses, and planning treatment. Today, digital technologies and innovations such as AI have become an integral part of human life. The use of AI and digital technologies across various fields plays a critical role in fostering innovation, simplifying human life, and improving efficiency. One of the most relevant contemporary directions in medicine is the development and application of intelligent systems for disease diagnosis and prognosis. These systems are based on various mathematical models and algorithms. AI systems grounded in mathematical apparatuses are particularly effective in solving problems related to medical diagnosis and prediction [2].

Consequently, AI performs routine tasks with high accuracy. For example, it can detect foreign objects or pathological changes on X-rays and identify cancer cells in cytological samples. AI has already demonstrated excellent results in analyzing various medical data — for instance, accuracy in detecting pathologies through ultrasound and MRI exceeds 90%. The research results indicate that integrating AI technologies into healthcare management significantly improves the quality, speed, and accuracy of health services.

Based on the reviewed literature and practical experiences, the following findings were obtained: AI-based diagnostic systems enable early disease detection and reduce human errors in

diagnosis by 30–40%. Algorithms for analyzing medical data allow rapid processing of large volumes of clinical information (Big Data) and the formulation of individualized treatment strategies. AI-based management systems have shown high effectiveness in optimizing the use of resources in medical institutions, distributing medications, and controlling patient flow.

Telemedicine and digital consultation platforms have expanded opportunities for remote patient communication, real-time health monitoring, and timely decision-making. The use of AI tools by medical personnel has improved work efficiency, saved time, and reduced professional errors. The findings confirm the strategic necessity of AI utilization in medicine, demonstrating that it is elevating healthcare management to an intelligent level.

Discussion: According to the scientific literature [3], today AI is one of the most "trending" topics. The 21st century is the age of technology, and technology represents the future. Consequently, revolutionary changes bring up several questions:

- **Will AI take jobs away from humans?** This question is very relevant. AI itself does not replace human jobs; however, people who can effectively use AI may gain a competitive advantage. Therefore, there is no need to fear AI itself, but rather to study and understand it thoroughly.
- **Which fields are most impacted by AI?** AI has rapidly entered the media sector, particularly in image processing, editing, and similar tasks. Abroad, AI avatars have been developed to replace television presenters, conducting programs in some cases.
- **What are the negative aspects of AI?** Like any tool, AI can have negative consequences depending on its use. Just as a knife can be used in the kitchen or as a weapon, AI can be beneficial or harmful depending on the purpose and the user. For example, in late 2022 and early 2023, numerous fake images circulated, generating false news. On the positive side, this has highlighted the need for fact-checking and verification.

Conclusion and Recommendations: Analysis of the research results indicates that, although AI use in healthcare is still relatively new, studies on its application across various medical sub-disciplines and related fields are ongoing. Implementing AI technologies in healthcare is one of the most important directions for modernizing the sector. With AI, healthcare processes — including diagnosis, treatment, prevention, surgery, medical data management, and healthcare organization — can be conducted accurately, quickly, and efficiently. AI enables medical personnel to save human resources, reduce errors, continuously monitor patient health, and optimize decision-making in healthcare management. Furthermore, AI serves as an important tool for automating medical institutions' operations, ensuring fair distribution of medications and healthcare services, and reducing corruption in healthcare management.

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WAYS TO ENSURING FINANCIAL SUSTAINABILITY OF ELECTRICITY NETWORK ENTERPRISES

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Abstract. *This research work is devoted to assessing the financial stability of power grid enterprises using the example of JSC "Regional Electric Grids". In the conditions of increasing demand for electricity as a result of economic growth, accelerated urbanization processes and population growth, the dynamics of the enterprise's assets, liabilities, profitability indicators and capital structure were analyzed. The results of the study showed a sharp increase in the share of debt funds, the transition of net assets to a negative state and the instability of profitability indicators. Factors affecting financial stability were divided into internal and external groups, and the cost structure, debt burden and cash flow stability were identified as important internal factors. At the same time, tariff policy, insufficient development of market mechanisms and state regulation were assessed as external factors. According to the conclusions of the study, restructuring the debt portfolio, increasing operational efficiency and strengthening financial management are important areas for ensuring the long-term financial stability of power grid enterprises.*
Keywords: *financial stability, electric power companies, state-owned enterprises, financial analysis, debt burden.*

Introduction. The electricity sector is one of the most important sectors of the energy sector, and global electricity consumption is expected to increase dramatically in the coming decades. According to forecasts, electricity demand will increase to 31,000–36,000 TWh by 2030 and to 52,000–71,000 TWh by 2050. Much of this growth is expected to come from developing economies. In particular, almost 85% of the additional global electricity demand by 2026 is expected to occur outside developed economies. These trends indicate that ensuring the financial sustainability of energy companies is not only an economic issue at the firm level, but also a strategic issue closely linked to macroeconomic stability and national energy security.

Reforming state-owned enterprises in Uzbekistan and adapting them to market mechanisms has also become a priority policy direction. By Resolution No. 166 of the Cabinet of Ministers of the Republic of Uzbekistan dated March 29, 2021, the Strategy for the Management and Reform of State-Owned Enterprises for 2021–2025 was approved. The Strategy provides for a gradual reduction in state participation, expansion of financial opportunities, and the introduction of mechanisms for the sale of shares through the IPO and SPO markets.

On this basis, the aim is to assess the financial stability of state-owned enterprises in the energy sector and identify the main factors that enhance such stability. In particular, the research work systematizes financial stability indicators, analyzes internal and external determinants of stability, and develops practical recommendations for increasing financial stability in the context of participation in the capital market. The results will serve to make decisions aimed at strengthening financial management, investment policy, and corporate governance in energy sector enterprises.

Literature review. In modern economic relations, the concept of financial stability of an enterprise is widely used from the micro to the macro level. Although financial stability is often equated with solvency, in theoretical sources it is highlighted as a broader category that determines the overall stability and long-term development potential of the enterprise (Glossaries and Encyclopaedias on Academician, 2011).

The identification of financial stability with "solvency" is found in practice, but solvency is a narrow criterion expressing the ability to fulfill debt obligations on time and is only one part of corporate financial stability (Lozovsky et al., 2007). Therefore, the structure and stability of cash flows are also of particular importance in assessing financial stability. In corporate finance management, the choice of the ratio of equity and debt capital, i.e., the optimization of the capital structure, is indicated as an important direction that directly affects stability. Bocharov (2001) emphasizes the issue of optimizing the capital structure as one of the most complex problems in corporate financial management. Blank (2011) highlights the relationship between the ratio of capital sources and efficiency in the context of financial resource management.

Assessing financial stability only through accounting profit may not be sufficient; because an enterprise, even if profitable, faces liquidity problems under the pressure of investment and debt repayment. In this regard, the sum of the operating, investment and financial cash flows of the enterprise provides a general picture of the free cash flow for owners (Cernavskis, 2012). It is also advisable to analyze the factors and risks affecting it in ensuring the financial stability of these enterprises and develop measures to eliminate them. In this case, the enterprise should assess the impact of specific target areas, the state's economic, social and environmental policies and foreign policies on its economic and financial activities.

Especially against the background of the rapid development of information technology and the increase in financial risks, financial regulation is steadily increasing, as a result of which the regulatory environment has an increasingly significant impact on the activities of enterprises. Strict financial and environmental regulation not only ensures market transparency, stability and fairness, but also encourages enterprises to accelerate the introduction of digital technologies to improve operational efficiency and meet compliance requirements in the face of complex regulatory requirements (Wu et al., 2024).

Methodology. This scientific article analyzes the financial stability of the state-owned "Regional Electric Networks" joint-stock companies based on their financial and economic indicators, and attempts to group the dynamic changes in these indicators by analysis to draw scientific conclusions. The following methodological approaches and methods were used in the research process, namely, comparative and statistical methods.

Analysis and results. In accordance with the Resolution of the President of the Republic of Uzbekistan No. PQ-4249 dated March 27, 2019 "On the Strategy for Further Development and Reform of the Electric Power Network in the Republic of Uzbekistan", the "Regional Electric Networks" joint-stock company was established, which manages the enterprises of regional electric networks that distribute and sell electricity to end consumers. As of January 1, 2024, the total number of electricity consumers in the Republic of Uzbekistan was 8,089,339, including 433,217 legal consumers and 7,656,307 household consumers (population). In addition, the stable economic growth rate in Uzbekistan and the rapidly growing urbanization process can increase the demand for electricity and the number of consumers. In addition, the main electricity generators in terms of electricity supply are thermal and hydroelectric power plants, and although wind and

solar power plants have a share, production shows a significant increase compared to previous years.

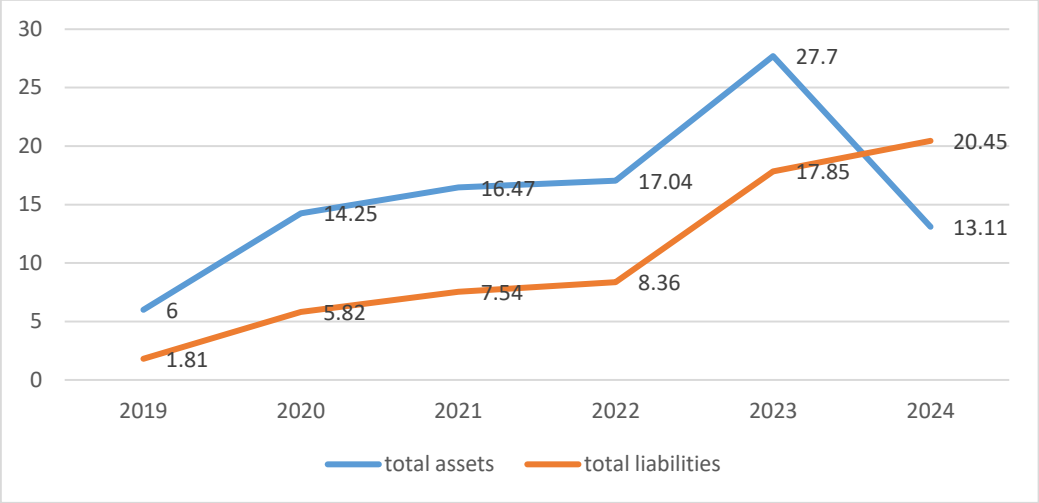


Figure 1. Dynamic changes in assets and equity of JSC "Regional Electric Networks". (trln.sum)

The total assets of the Regional Electric Networks JSC amounted to approximately 6 trillion sums in 2019, 14.25 trillion sums in 2020, and 16.47 trillion sums in 2021. Although this indicator reached 27.7 trillion sums in 2023, this value decreased to 13.11 trillion sums in 2024. Similarly, the dynamics of the joint-stock company's liabilities in 2020 increased by 222% compared to 2019 and amounted to 5.82 trillion sums, indicating a rapid growth in creditors. In 2023, liabilities increased from 8.36 trillion sums to 17.85 trillion sums compared to 2022. In this case, the conclusion is drawn that the financing of the JSC's activities was carried out mainly through debt. And in 2024, the amount of liabilities reached 20.45 trillion sums, and sharply exceeded total assets. Also, based on this data, the debt share, i.e. the liability/asset ratio, was 30.2 percent in 2019, while in 2024 it was 156 percent, and this percentage can be noted as a dangerous point. At the same time, the analysis of the amount of net assets, i.e. the difference between Assets - Liabilities, showed a positive difference of 4.19 trillion sums from assets and liabilities in 2019, while in 2024 it ended with a negative difference of −7.34 billion sums. This indicator may pose a risk of technical insolvency of the joint-stock company.

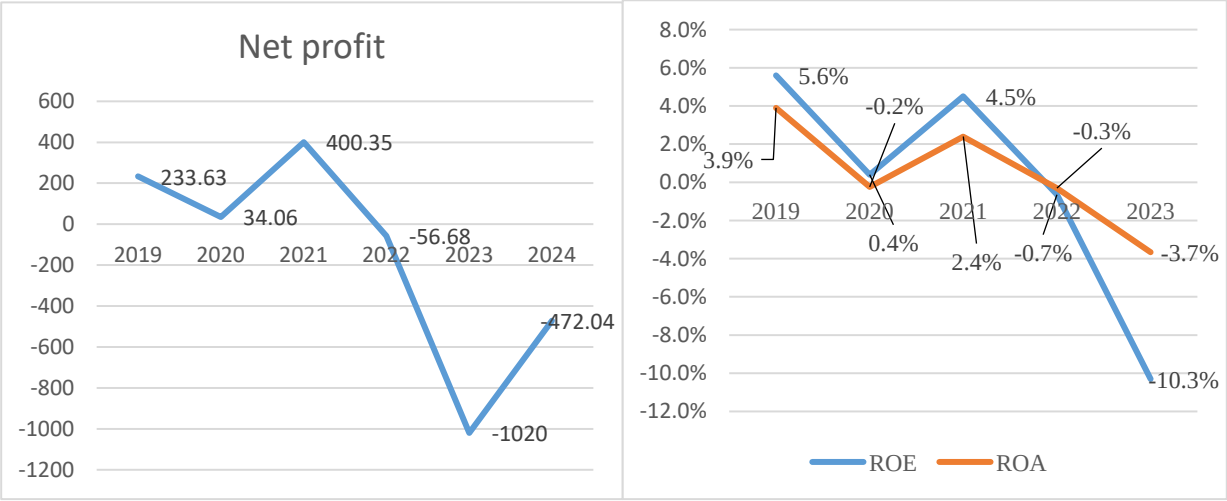


Figure 2. Dynamic changes in profitability indicators of the Regional Electric Networks Joint Stock Company. (bln.sum and percent)

The dynamics of net profit of Regional Electric Networks JSC from 2019 to 2024 was in a state of sharp fluctuations. In 2019, net profit amounted to 233.63 billion sums, and in 2020 it decreased to 34.06 billion sums. In 2021, this indicator recovered and reached its peak, amounting to 400.35 billion sums. However, in 2022, net profit became negative and amounted to -56.68 billion sums, which indicates the beginning of a significant deterioration in the income-expense ratio. In 2023, net profit decreased to -1020 billion sums, which is a decrease of -963.32 billion sums compared to 2022. In this regard, it can be noted that the company's expenses related to financial activities have increased sharply. Although the situation improved somewhat in 2024, this indicator reached -472.04 billion sums. However, the amount of net profit remains negative.

The return on equity of JSC "Territorial Electric Networks", that is, the share of net profit per unit of capital, was 5.58 percent in 2019, while in 2020 this amount was 0.4 percent. In 2021, this amount was 4.48 percent. Also, in 2022, this profitability indicator decreased by -0.65 percent, while in 2023 this amount was -10.3 percent. That is, there are 10 percent losses for every 1 capital. Similarly, the return on assets, which was 3.9 percent in 2019, was -0.24 percent in 2020. In 2021, it increased to 2.43 percent, while in 2022 it was -0.33 percent and in 2023 it was -3.66 percent. The relative indicators of the financial and economic results of the joint-stock company are in an unstable state, and a systematic analysis of the financial condition of joint-stock companies also suggests that there are financial problems.

Conclusion. Against the background of the growth of assets of “Regional Electric Networks” JSC in 2019–2023, liabilities also grew rapidly, which indicates an increase in financial leverage, i.e. debt bondage. In 2024, as a result of a sharp decrease in assets and an increase in liabilities, we can see that liabilities had a high share in relation to assets, and net assets turned into a negative value. This situation characterizes the possibility of the financial stability of the enterprise being exposed to financial and economic risks. The analysis of the debt and equity ratios in the financial activities of the joint-stock company showed an increase in the share of debt. At the same time, maintaining debts at effective and marginal levels, in turn, serves the stability of the enterprise. For this reason, it is necessary to take measures to restructure the debt portfolio, strengthen capital, strengthen cash flows, i.e. revise the tariff system, and improve operational efficiency.

The high level of electricity prices set by the authorities of the JSC "Regional Electric Networks" and the existence of prices classified by price, in turn, negatively affect the low level of income and profitability indicators cited as relative indicators. Also, the lack of a developed electricity market, the growth of production in the economy, the rapid growth of the urbanization process, and the population growth trends are also increasing the demand for electricity and similar utilities. Since the price level does not have a tendency to increase due to the mismatch of supply and demand in the market, the financial and economic indicators of these enterprises show negative results. These circumstances may require significant expenses from the state budget, i.e. additional funds, and may entail fiscal risks. These circumstances may require significant expenses from the state budget, i.e. additional funds, and may entail fiscal risks. For this reason, the reports on macrofiscal risks of the Ministry of Economy and Finance of the Republic of Uzbekistan include a comprehensive analysis of the financial and economic indicators of state-owned enterprises.

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CONCEPTUALIZING SEA-BASED WATER SPORTS TOURISM AS A COASTAL TOURIST ATTRACTION: EMPIRICAL EVIDENCE FROM AMPARA DISTRICT, SRI LANKA

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Abstract. *Sea-based water sports tourism has emerged as a significant niche within coastal tourism, offering opportunities for economic development, recreational engagement, and sustainable use of marine resources. This study conceptualizes sea-based water sports tourism as a coastal tourist attraction in Ampara District, Sri Lanka, using a mixed-methods approach. Quantitative surveys of 200 domestic and international tourists, combined with qualitative interviews with 15 local stakeholders, identified the key factors influencing tourist participation, satisfaction, and destination attractiveness. Factor analysis revealed that natural coastal resources, accessibility and infrastructure, safety management, and promotional activities are critical determinants for developing sea-based water sports tourism. Stakeholder insights emphasized the importance of regulatory frameworks, community involvement, and eco-friendly practices to ensure sustainable growth. Based on these findings, a conceptual framework is proposed linking tourist demand, destination attributes, and sustainable management strategies. This study contributes to the understanding of niche coastal tourism development and provides practical guidance for policymakers, tourism operators, and local communities aiming to enhance sea-based water sports tourism in emerging destinations.*

Keywords: *sea-based Water Sports Tourism, Coastal Tourism, Tourist Attraction, Ampara District, Sri Lanka.*

1. Introduction

Tourism plays a pivotal role in the Sri Lankan economy, serving as one of the country's major sources of foreign exchange, employment, and regional development (Rathnayaka & Fernando, 2020). As an island nation with an extensive coastline of approximately 1,600 km, Sri Lanka's coastal and marine environments are central to its tourism appeal, offering a variety of natural attractions ranging from beaches and coral reefs to marine biodiversity (Sri Lanka Embassy, 2024). Within the broader tourism industry, coastal tourism has been widely recognized as a significant contributor to both national and local economies, supporting activities such as beach recreation, cultural experiences, and sea-based water sports.

Sea-based water sports including surfing, snorkeling, scuba diving, jet skiing, and kayaking represent a growing niche within coastal tourism that appeals to adventure seekers and contributes to lengthening tourist stays and increasing expenditure (Nugawela & Perera, 2023). In Sri Lanka, well-known water sports destinations such as Arugam Bay in the Eastern Province have attracted international surf tourism, illustrating the potential of sport-related coastal tourism products to diversify tourist offerings and enhance destination competitiveness (Wikipedia: Surfing in Sri Lanka, 2025). However, there is limited empirical research on how such activities function as attractions in emerging coastal destinations especially in relatively underdeveloped regions such as the Ampara District.

Ampara District, located on Sri Lanka's east coast, boasts pristine beaches, coral reefs, and favorable sea conditions, yet it remains underutilized in terms of organized sea-based water sports tourism and lacks comprehensive infrastructure and promotional strategies to fully leverage its potential. Existing studies on Sri Lankan tourism have largely focused on beach tourism broadly or on environmental sustainability criteria such as coastal ecosystem management (Thirukeswaran & Jayawardena, 2024), while limited research addresses niche segments such as water sports tourism and their role as coastal attractions. Moreover, research on related sport tourism in Sri Lanka suggests that water sports are influential in shaping tourist motivation and revisit intentions, highlighting the relevance of sport-specific experiences in the tourism value chain (Rathnayaka & Fernando, 2020).

This study seeks to fill these gaps by conceptualizing sea-based water sports tourism as a coastal tourist attraction in Ampara District using empirical evidence gathered through mixed methods. Specifically, it investigates (1) the key factors influencing tourist participation in sea-based water sports, (2) how destination attributes such as natural resources, infrastructure, and safety measures affect attractiveness, and (3) a framework for sustainable development of water sports tourism in emerging coastal destinations. By doing so, the research contributes to both academic discourse on niche tourism products and practical strategies for destination planning and sustainable tourism development.

2. Literature Review

2.1 Coastal Tourism and Sea-Based Water Sports

Coastal tourism has been widely recognized as a major contributor to regional economic growth, recreational experiences, and community development due to its ability to attract diverse tourist markets (Duan & et al. 2022). Within this broader tourism sector, sea-based water sports tourism often termed marine sports tourism focuses on activities conducted in marine environments such as surfing, snorkeling, scuba diving, jet skiing, sailing, and kayaking. Recent bibliometric research highlights that marine sports tourism is an emerging niche within tourism studies, integrating economic, environmental, and social components (Duan & et al. 2022; El Silisna & Susanti, 2020). These activities offer unique opportunities for diversifying coastal tourism products and catering to adventure and experience-seeking tourists, thereby enhancing destination competitiveness and extending tourist stays.

For instance, El Silisna & Susanti, (2020) emphasizes that marine and coastal sports tourism enrich waterfront experiences and can significantly contribute to local economies by attracting both participants and spectators of diverse water-based activities. This underscores the potential of sea-based sports not only as leisure pursuits but also as major coastal tourist attractions (El Silisna & Susanti, 2020). Moreover, the diversity of water sports from casual snorkeling to competitive surfing demonstrates the multifaceted nature of coastal sport tourism offerings, aligning with broader trends in experiential and adventure tourism.

2.2 Determinants of Tourist Attraction

Research on determinants of tourist attraction to coastal destinations consistently identifies natural resources and scenic beauty as foundational elements that draw visitors (Duan & et al. 2022; El Silisna & Susanti, 2020). High-quality beaches, coral ecosystems, and marine biodiversity create inherent value that attracts tourists, particularly for water-based activities. In addition to natural assets, infrastructure and service quality including ease of access, accommodation options, availability of equipment rentals, and professional guidance significantly influence tourist satisfaction and participation in sea-based water sports.

Further, managerial and safety measures play a crucial role. Studies suggest that proper risk management, safety protocols, and clear regulatory standards are essential for encouraging wider participation in water sports, especially among international tourists who may have higher expectations of safety and service quality (Wang & et al. 2020). These determinants interrelate with promotional activities, where effective marketing and visibility through digital platforms and travel media enhance destination appeal and raise awareness of sea-based water sports offerings (Duan & et al.2022).

2.3 Sustainable Development of Water Sports Tourism

Sustainability has become a central concern in tourism development, particularly in coastal and marine environments where ecosystems are fragile and prone to degradation. Unregulated sea-based water sports tourism can exert negative environmental impacts such as reef damage, marine pollution, and disturbance to wildlife, undermining long-term destination viability (Duan & et al. 2022). To counteract these effects, tourism scholars advocate for sustainable coastal management practices that balance tourist satisfaction, economic benefits, and ecological conservation.

This includes enforcing environmental standards, monitoring carrying capacity, and implementing eco-certification schemes like the Blue Flag program, which promotes environmental education, water quality, and safety standards in coastal tourism settings (Thirukeswaran & Jayawardena, 2024). Integrating sustainability reinforces the idea that water sports tourism must align with broader coastal conservation goals to ensure the longevity of both the tourism industry and the natural attractions that draw visitors.

2.4 Conceptual Gap

While global research underscores the importance of marine sports tourism, there is a notable research gap in context-specific studies, especially in emerging destinations such as the Eastern Province of Sri Lanka. Existing literature on Sri Lanka's coastal tourism primarily focuses on general beach tourism, ecosystem management, and visitor satisfaction in established destinations such as Nilaveli and southern beaches (Jassintha & Karunarathne, 2019; Thirukeswaran & Jayawardena, 2024). However, empirical studies that explicitly conceptualize sea-based water sports tourism as a coastal tourist attraction considering factors such as destination attractiveness, infrastructure determinants, sustainability considerations, and stakeholder perspectives in lesser-studied regions like Ampara remain sparse.

This gap highlights the need for research that not only assesses the potential of water sports as a niche tourism product but also examines how destination attributes and management frameworks can be tailored to specific local contexts. The current study responds to this gap by offering empirical insights from Ampara District, thereby contributing to both academic discourse and practical tourism planning for developing sustainable sea-based water sports attractions.

3. Methodology

3.1 Study Area

Ampara District is situated in the Eastern Province of Sri Lanka, encompassing a coastline of approximately 100 km along the Bay of Bengal (Department of Census and Statistics, 2022). The district is endowed with pristine beaches, coral reefs, and rich marine biodiversity, making it a potential hotspot for sea-based water sports tourism. Despite its natural assets, tourism infrastructure including accommodations, water sports facilities, and transportation networks remains underdeveloped, presenting both challenges and opportunities for the sustainable development of niche coastal tourism (Sullivan & et al. 1995).

3.2 Research Design

This study adopts a mixed-methods research design to conceptualize sea-based water sports tourism as a coastal tourist attraction. The approach integrates quantitative and qualitative data to ensure comprehensive insights into both tourist behaviors and stakeholder perspectives (Hirose & Creswell, 2023).

- Quantitative Component: A structured survey was administered to 200 domestic and international tourists visiting Ampara beaches. The survey captured tourist participation, satisfaction, perceptions of destination attractiveness, and key determinants influencing engagement in water sports.
- Qualitative Component: 15 semi-structured interviews were conducted with local stakeholders, including tourism operators, government officials, and community representatives. Interviews explored opportunities, challenges, infrastructure needs, and environmental and community concerns related to water sports tourism development.

3.3 Data Collection

- Survey Instrument: The survey consisted of 5-point Likert scale items (1=strongly disagree, 5=strongly agree) covering dimensions such as natural resources, safety measures, facilities, and promotional strategies. This approach is widely used in tourism research to measure perceptions and satisfaction (Backhaus & et al. 2021).
- Interviews: Semi-structured interview guides allowed stakeholders to discuss infrastructure, environmental management, local capacity, and future planning. Interviews were audio-recorded with consent and transcribed verbatim for analysis.

3.4 Data Analysis

- Quantitative Analysis: Data from surveys were analyzed using descriptive statistics to summarize tourist profiles, preferences, and satisfaction levels. Factor analysis was performed to identify the underlying dimensions influencing the attractiveness of sea-based water sports tourism (Aldrich, 2018).
- Qualitative Analysis: Interview transcripts were analyzed using thematic coding to identify recurrent themes and insights regarding challenges, opportunities, and sustainable development strategies. Coding followed an inductive approach, allowing patterns to emerge organically from stakeholder narratives (Braun & Clarke, 2006).

4. Results

4.1 Tourist Participation Patterns

The survey of 200 tourists revealed distinct participation patterns in sea-based water sports within Ampara District. Among respondents:

- Surfing attracted the highest interest, with 42% of participants engaging in or expressing interest in the activity.
- Snorkeling accounted for 35% of participation.
- Jet skiing was popular among 23% of respondents.

Tourists identified natural beauty, pristine beaches, and safe conditions as the primary motivators for participating in sea-based water sports. These findings align with previous studies suggesting that coastal aesthetics and environmental quality significantly influence tourist choice in water sports destinations (Duan & et al. 2020).

Additionally, tourists reported that clear signage, availability of equipment rentals, and guided services enhanced their willingness to participate, reflecting the importance of service provision and infrastructure in niche tourism products (Wang & et al. 2020).

4.2 Key Determinants of Attractiveness

Factor analysis of survey responses identified four primary determinants influencing the attractiveness of Ampara District as a sea-based water sports destination:

1. Natural Coastal Resources

- Includes beaches, coral reefs, biodiversity, and scenic vistas.
- Tourists ranked these as the most influential factor in destination selection, consistent with global literature emphasizing the primacy of environmental assets in water sports tourism (Duan & et al. 2022).

2. Accessibility and Infrastructure

- Refers to road networks, accommodation, equipment rental services, and availability of transportation.
- Poor accessibility and lack of standardized facilities were noted as constraints, echoing findings from other emerging destinations where infrastructure development is a prerequisite for attracting adventure tourists (El Silisna & Susanti, 2020).

3. Safety and Management

- Encompasses lifeguard presence, safety signage, insurance provisions, and adherence to safety protocols.
- Survey respondents reported that perceived safety strongly influenced their participation, reflecting global evidence that risk management and safety assurance are critical determinants of water sports tourism (Wang & et al. 2020; Mandić & Walia, 2023).

4. Promotion and Awareness

- Includes digital marketing, travel guides, social media campaigns, and tour packages.
- Respondents highlighted low awareness of Ampara's water sports offerings as a barrier to visitation, consistent with studies demonstrating the importance of strategic destination marketing in attracting both domestic and international tourists (Duan & et al. 2022).

4.3 Stakeholder Insights

The qualitative interviews with 15 local stakeholders revealed several recurring themes:

- Human Resource and Skills Gaps: Stakeholders highlighted the shortage of trained water sports instructors and tourism management personnel as a major barrier to developing high-quality services. Similar patterns have been reported in studies on emerging tourism destinations in Sri Lanka, where human capital constraints limit growth potential (Sullivan & et al. 1995).
- Safety and Regulatory Challenges: Lack of standardized safety regulations and formal certification for operators was identified as a risk factor affecting both participation and destination reputation. Stakeholders emphasized the need for government-supported guidelines and monitoring to ensure tourist safety.
- Infrastructure and Marketing Needs: Public-private partnerships were suggested as a means to enhance infrastructure, promote the destination, and provide integrated tour packages. The importance of collaboration between government agencies, local communities, and private operators has been stressed in previous research on sustainable coastal tourism development (Jassintha & Karunarathne, 2019).
- Sustainability and Environmental Practices: There was consensus on adopting eco-friendly practices to protect marine ecosystems, such as regulating boat traffic, waste management, and reef conservation. This aligns with global recommendations for sustainable water sports tourism, emphasizing environmental stewardship alongside economic benefits (Kumar & et al. 2023).

Overall, the results suggest that while Ampara District has strong potential as a sea-based water sports destination, coordinated interventions in infrastructure, safety, marketing, and sustainability are required to maximize its attractiveness and ensure long-term viability.

5. Discussion

The findings of this study indicate that Ampara District possesses substantial potential for developing sea-based water sports tourism, supported by its pristine beaches, coral reefs, and rich marine biodiversity. However, several critical factors need to be addressed to realize this potential effectively.

5.1 Infrastructure Gaps

Tourist responses and stakeholder interviews highlighted the lack of adequate infrastructure including roads, accommodations, and water sports facilities as a key barrier. Similar patterns have been observed in other emerging coastal destinations in Sri Lanka, where insufficient infrastructure limits tourist accessibility and reduces destination competitiveness (Sullivan & et al. 1995; Jassintha & Karunarathne, 2019). Investments in well-planned transport networks, quality lodging, and professionally managed water sports centers are therefore essential to attract both domestic and international tourists.

5.2 Safety and Regulatory Concerns

Safety emerged as a major determinant of tourist participation. The absence of formalized safety standards, certified operators, and lifeguard services can negatively influence tourists' perception of risk and discourage engagement in water sports. This finding aligns with global research emphasizing that safety regulations and risk management protocols are critical for the successful development of adventure and marine sports tourism (Wang & et al. 2020). Implementing standardized safety measures, including insurance options and operator certification, can enhance both tourist confidence and destination reputation.

5.3 Promotion and Awareness

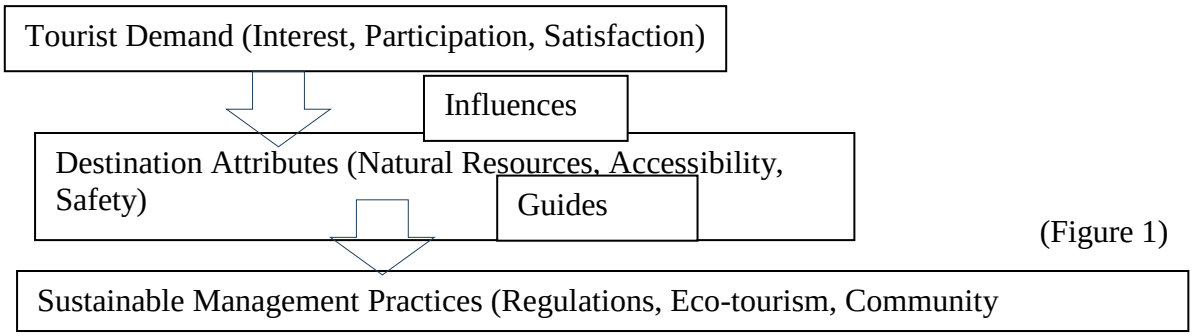
Despite Ampara's natural attractions, promotion remains limited, particularly in digital and international tourism channels. As noted in the literature, effective marketing strategies including social media campaigns, travel guides, and integrated tour packages are crucial for increasing tourist awareness and participation in niche tourism products (Duan & et al. 2022). Collaboration between public and private stakeholders in destination promotion can significantly boost Ampara's visibility as a sea-based water sports destination.

5.4 Conceptual Framework for Sustainable Development

Based on the study findings, a conceptual framework was developed (Figure 1) to guide the sustainable development of sea-based water sports tourism in Ampara District. The framework links three key dimensions:

1. Tourist Demand – Capturing interest, participation, and satisfaction in water sports.
2. Destination Attributes – Including natural coastal resources, accessibility, and safety measures.
3. Sustainable Management Practices – Encompassing regulatory policies, eco-friendly tourism initiatives, and community involvement.

This framework aligns with the principles of sustainable tourism, which advocate balancing economic development, environmental protection, and social benefits (Kumar & Singh, 2021; Duan & et al. 2022). It can serve as a strategic tool for policymakers, tourism operators, and local communities to plan, implement, and monitor sea-based water sports tourism initiatives, ensuring that the district develops as an attractive yet environmentally responsible destination.



(Figure 1)

5.5 Implications

The study demonstrates that emerging coastal destinations like Ampara can diversify their tourism offerings by promoting niche products such as water sports, but success depends on coordinated actions:

- Infrastructure development to improve accessibility and service quality.
- Enforcement of safety and regulatory standards to protect tourists and ecosystems.
- Targeted promotion to raise awareness locally and internationally.
- Integration of sustainability measures to maintain the long-term viability of marine environments.

In essence, the findings reinforce global research suggesting that niche marine tourism products require an integrated approach, combining environmental, managerial, and marketing strategies to achieve sustainable growth (El Silisna & Susanti. 2020; Duan & et al. (2022).

6. Conclusion

Sea-based water sports tourism represents a promising niche for coastal tourism development in Ampara District, Sri Lanka. The findings of this study highlight that the district possesses substantial natural assets, including pristine beaches, coral reefs, and rich marine biodiversity, which can attract both domestic and international tourists. However, to fully realize this potential, key challenges related to infrastructure, safety regulations, and destination promotion must be addressed.

The study also underscores the importance of integrating sustainability practices into tourism planning. Eco-friendly management, regulatory frameworks, and community involvement are essential to protect coastal ecosystems while ensuring long-term economic and social benefits. By implementing such measures, Ampara District can enhance tourist experiences, stimulate local livelihoods, and maintain environmental integrity aligning with the principles of sustainable coastal tourism (Kumar & et al. 2023; Duan & et al. 2022).

Furthermore, this research provides empirical evidence supporting the conceptualization of sea-based water sports as a key coastal tourist attraction. The proposed conceptual framework, linking tourist demand, destination attributes, and sustainable management practices, offers a practical guide for policymakers, local authorities, and tourism operators to strategically develop water sports tourism in emerging destinations. This framework is not only applicable to Ampara but can also inform similar initiatives in other underdeveloped coastal regions of Sri Lanka and globally (El Silisna & Susanti. 2020.; Wang & et al. 2020).

In conclusion, strategic investment in infrastructure, rigorous safety standards, effective promotion, and sustainability-focused management can transform Ampara District into a model destination for sea-based water sports tourism, fostering economic growth, environmental protection, and social development.

7. Recommendations

Based on the empirical findings and stakeholder insights, several strategic recommendations are proposed to develop Ampara District as a sustainable sea-based water sports destination. These recommendations aim to enhance tourist experiences, stimulate local economies, and protect coastal ecosystems.

7.1 Develop Eco-Friendly Infrastructure

Investment in eco-friendly and sustainable infrastructure is critical to support water sports tourism while minimizing environmental impact. This includes constructing environmentally sensitive accommodations, boardwalks, and water sports facilities that avoid damage to beaches and coral reefs. Infrastructure improvements should also consider accessibility, including better road networks, signage, and transport options, to facilitate tourist movement. Sustainable infrastructure aligns with global best practices, which emphasize that well-planned development enhances destination competitiveness while preserving natural assets (Kumar & et al. 2023; Duan & et al. 2022).

7.2 Train Local Personnel in Safety and Tourism Management

The study revealed gaps in human resources, including trained water sports instructors, lifeguards, and tourism management personnel. Structured training programs should be established to develop skills in tourist safety, first aid, customer service, and environmental stewardship. Professional certification and adherence to international standards will increase tourist confidence, reduce risks, and improve service quality. Research indicates that human capital development is a major determinant of success in emerging adventure and marine tourism destinations (Wang & et al. 2020; El Silisna & Susanti. 2020).

7.3 Promote Ampara District through Digital Campaigns and Partnerships

Despite its natural beauty, Ampara remains under-promoted in domestic and international tourism markets. Destination marketing strategies should include digital campaigns, social media engagement, partnerships with tour operators, and inclusion in travel guides to raise awareness. Collaborative marketing involving government agencies, private sector stakeholders, and local communities can attract niche tourism segments, particularly adventure and marine sports tourists (Duan & et al. 2022; Mandić & Walia. 2023).

7.4 Implement Regulations to Balance Tourism Growth with Environmental Conservation

Sustainable tourism management requires the establishment of regulatory frameworks that balance growth with ecosystem protection. Measures may include:

- Limiting the number of watercraft and visitors in sensitive areas.
- Enforcing waste management and pollution control practices.
- Certifying operators to adhere to safety and environmental standards.

Such regulations ensure long-term destination viability, protect biodiversity, and align with international practices such as the Blue Flag certification for sustainable beaches (Thirukeswaran & Jayawardena, 2024; Kumar & et al. 2023; Kumar & Singh. 2021).

7.5 Encourage Community Participation in Tourism Planning and Management

Active involvement of local communities is essential for inclusive and sustainable tourism development. Community participation can include engagement in decision-making, employment opportunities, and small-scale entrepreneurship related to water sports tourism. Local stewardship fosters a sense of ownership, enhances social benefits, and ensures that tourism development aligns with community values (Jassintha & Karunarathne, 2019; El Silisna, & Susanti. (2020).

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PRIORITY DIRECTIONS FOR INNOVATIVE DEVELOPMENT OF THE CONSTRUCTION MATERIALS INDUSTRY IN THE REPUBLIC OF KARAKALPAKSTAN

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Abstract. *This article analyzes the current state of the construction materials industry in the Republic of Karakalpakstan. During the research process, production volumes in the region, the mineral raw material base, investment projects, as well as export and import indicators were examined based on statistical data. The results of the analysis indicate that the production volume of construction materials in the region has been increasing annually. However, there remains significant potential to enhance the level of deep processing of raw materials, increase the share of high value-added products, and strengthen export capacity. The article proposes scientific and practical recommendations aimed at further developing the construction materials industry, including the introduction of modern technologies, increasing investment activity, expanding localization processes, and promoting the production of export-oriented products.*

Keywords*: construction materials industry, mineral raw material base, industrial development, investment projects, export potential, localization, innovative technologies.*

Introduction. In recent years, in the Republic of Uzbekistan, the development of industrial sectors across regions, the efficient utilization of local raw material resources, and the expansion of import-substituting production have been considered among the priority areas of state policy [1]. In particular, the Resolution of the President of the Republic of Uzbekistan dated January 28, 2022, No. PQ–60 defines key issues related to regional industrial development, the commissioning of new production capacities, and the attraction of investments [2]. In accordance with this document, specific tasks have been set to attract foreign investment, expand domestic production, and not only meet the needs of the internal market but also further increase export potential.

Furthermore, in the Industrial Development Strategy for 2023–2026, modernization of the construction materials industry, enhancement of localization levels, and expansion of export capacity are identified as key priorities [3]. These documents serve as the regulatory and legal framework for accelerating the development of regional industries, including the construction materials industry in the Republic of Karakalpakstan [4]. In accordance with the Resolution of the Head of State dated December 1, 2025 [1], modern management methods, digitalization, and artificial intelligence technologies are being widely introduced in the industry, along with environmentally friendly and energy-efficient materials, and strengthened integration with science. In addition, customs privileges and credit compensation mechanisms have been introduced for enterprises in the sector.

At present, despite the availability of rich mineral and raw material resources, the share of the construction materials industry in the overall industrial structure of the Republic of Karakalpakstan remains relatively low [5]. At the same time, the issues of broad implementation

of innovative technologies in the utilization of regional raw materials, their deep processing, and the expansion of the product range remain highly relevant [6].

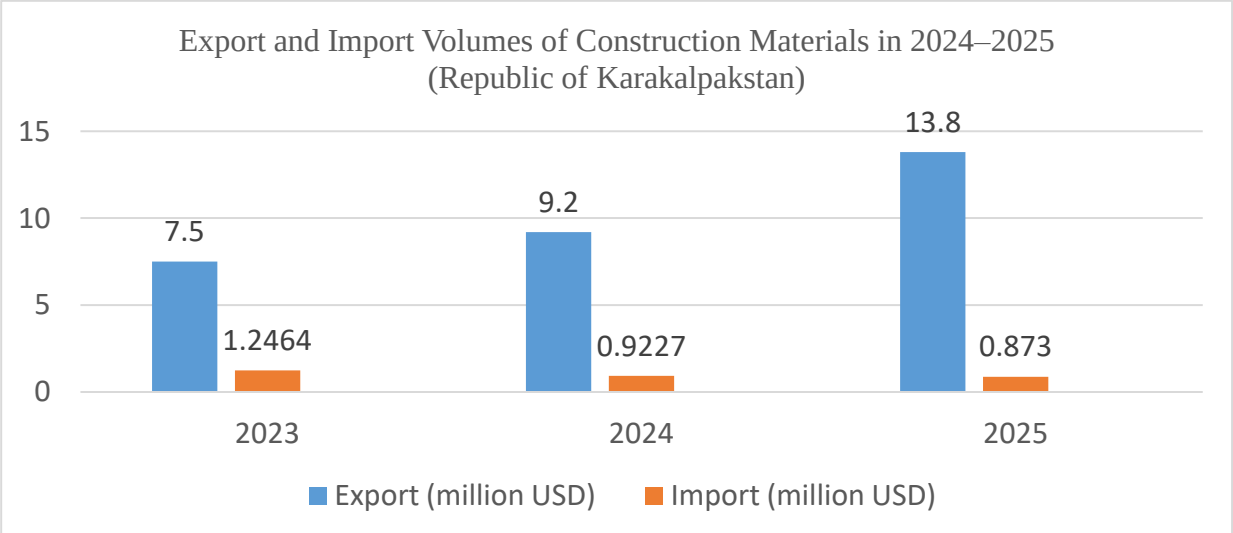
Methods. In this article, in order to comprehensively assess the current state of the construction materials industry in the Republic of Karakalpakstan, official statistical data, regional industrial reports, and the register of investment projects were widely used [7]. In particular, a database for 2023–2025 was compiled, including data on production volumes, the number of industrial entities, mineral resource reserves, investment flows, as well as export and import indicators.

During the research process, the main economic indicators of the construction materials industry were evaluated using statistical analysis methods, while time-series analysis was applied to identify trends in production and export volumes over time [8]. In addition, through comparison and grouping methods, the indicators of the Republic of Karakalpakstan were compared with national average values, which made it possible to determine the region's relative advantages and weaknesses. Based on these sources, effective mechanisms for deep raw material processing, the introduction of innovative technologies, and the expansion of export-oriented production were examined.

To increase the accuracy and reliability of the research results, trends in production, export, and investment indicators were analyzed using graphs and charts [11]. This approach made it possible to identify key patterns in the industry's development, reveal existing problems, and formulate scientific and practical conclusions.

Results. According to statistical data, in 2024 the volume of industrial production in the Republic of Karakalpakstan amounted to 24.6 trillion soums, of which 872 billion soums accounted for the production of construction materials [7]. In 2026, through the expansion of existing production capacities and the commissioning of new projects, it is planned to increase production to 1 trillion soums.

Figure-1



The analysis of export and import volumes of construction materials in 2024–2025, shown in Figure 1, indicates the emergence of positive trends aimed at improving the sector's foreign trade balance. In particular, in 2024, the export of construction materials amounted to 9.2 million USD, representing an increase of 123% compared to 2023. In 2025, this figure is planned to reach 13.8 million USD, corresponding to a growth rate of 150%.

At the same time, import volumes show an opposite trend — a decrease. In 2024, imports of construction materials amounted to 922.7 thousand USD, a reduction of 26% compared to 2023. In 2025, this figure is expected to decline further to 873 thousand USD. This situation reflects the expansion of local production capacities, an increase in the share of import-substituting products, and a growing satisfaction of domestic market demand through locally produced goods. Overall, the steady growth in exports and reduction in imports indicate an increase in the competitiveness of the construction materials sector, improved production efficiency, and a shift toward an export-oriented development model. These processes are expected to further improve the foreign trade balance and strengthen the resilience of the national economy in the long term.

Currently, despite the fact that export volumes in the sector exceed import figures, several challenges in its development remain. The mineral resource base of the Republic of Karakalpakstan comprises 199 deposits of non-metallic minerals, of which 149 are currently in operation [5]. The majority of these raw materials consist of cement raw materials, limestone, building stone, sand, and silicate materials [6]. However, a significant portion of these resources is limited to the stage of primary processing, which reduces production efficiency and leads to a high cost of finished products.

Regarding investment and export indicators for 2024–2026, the Republic of Karakalpakstan plans to implement 17 investment projects with a total value of 93 million USD. The implementation of these projects is aimed at increasing industrial capacity and creating new jobs [4]. In 2024, the export of construction materials amounted to 9.2 million USD, and by 2026, this figure is expected to reach 13.8 million USD [11]. At the same time, according to international experience, the development of industries based on deep processing of raw materials allows export volumes to increase severalfold [9][10].

Discussion. The results of the analysis indicate that a number of systemic problems persist in the development of the construction materials industry in the Republic of Karakalpakstan. In particular, slow technological modernization, a low share of foreign capital in the investment structure, and insufficient development of logistics infrastructure significantly affect the sector’s efficiency [8][10]. These factors reduce the competitiveness of production processes and constrain regional economic development.

International experience shows that the development of industrial sectors based on a cluster approach and the extensive introduction of advanced innovative technologies can significantly enhance production efficiency. This approach not only optimizes production processes but also improves product quality, promotes more rational use of resources, and increases investment attractiveness. In this context, applying an innovation-cluster approach in the construction materials industry of the Republic of Karakalpakstan is crucial for enhancing the competitiveness of regional industry and shaping a sustainable development strategy.

Conclusion. For the further development of the construction materials industry, it is advisable to implement modern technologies focused on the deep processing of local raw materials, which will increase the added value of products and improve production efficiency [6][11]. At the same time, it is important to create additional incentives for foreign investors within special industrial zones, facilitating the attraction of capital and advanced management solutions [2][4]. Equally significant is the expansion of export-oriented production and diversification of foreign markets, which will reduce dependence on specific export directions and enhance the sector’s resilience [9][11]. In parallel, expanding localization programs and increasing the share of import-substituting products through the use of domestic resources will strengthen the domestic

market and boost the competitiveness of national industry [3]. Implementing these proposals will contribute to ensuring the sustainable development of the region's industrial sector.

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DEVELOPMENT OF ORGANIC FOOD PRODUCTION

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Abstract. *This article examines the state of organic production in agriculture in our country, as well as the main requirements and content of adopted laws on the organization of organic farming.*

Keywords: *organic products, natural, high efficiency, clean, high-quality, competitive, market demands, principles, food products.*

Introduction. It is widely acknowledged that the use of various chemical, biological, and natural products in the agro-industrial sector, particularly in food production, as well as the widespread distribution of GMO seeds, demand for organic products in the global community is growing. For cultivating organic food products in our republic, targeted measures are being established, and activities are being carried out not only for food products but also for other types of products. Organization and management of organic production is the process of growing and effectively managing agricultural products using natural methods, without the use of chemical fertilizers, various pesticides, and genetically modified organisms (GMOs).

This process involves strict adherence to organic product requirements throughout the entire value chain, from planting food or other crops to growing and harvesting, as well as transportation, sorting, cleaning, processing, packaging, and delivery to the consumer, regardless of whether the produce is grown in the field or greenhouse. In recent years, practical successes have also been achieved in this regard. Specifically, from 2020 to date, approximately 50 "Organic" certificates and over 200 "Global GAP" certificates have been obtained based on quality management requirements. These products include cotton (textiles), wheat, melons, medicinal plants, horticultural products, and other goods.

In 2023, two agricultural and food enterprises in the Jizzakh region, Arnasoy Limon Agro LLC, began producing organically certified products. In the Namangan region, four agricultural and food enterprises—Mekhrigiyo LLC, Art Soft Holding LLC, Art Soft Tex Cluster, and Baraka Meva Sanoat Service LLC—have received international organic certification.

In our country, the Law "On Organic Products" was adopted in April 2022 The adopted law establishes that all products produced not only in agriculture but also in the organic sector must be organic and comply with international requirements and standards. The main purpose of the Law "On Organic Products" is to regulate relations in the organic product sector (production, processing, storage, transportation, labeling, and sale of organic products, as well as conformity assessment and authorization).

Organic food products or other types of products are, first and foremost, a set of products that are grown, cultivated, harvested, and transported in specialized vehicles, stored, sorted, processed, packaged—in short, certified—using production technologies that meet the requirements of this legislation and legal and regulatory documents in the field of technical

regulation at all stages. According to this law, the following are the main principles of organic product production in our country:

- ✓ priority to protecting the life and health of citizens, as well as environmental protection;
- ✓ prudence in choosing the direction of organic product production;
- ✓ transparency and openness of information about organic products;
- ✓ use of renewable natural resources;
- ✓ ensuring environmental protection and ecological safety.

The cultivation of organic agricultural products in the global community is defined in accordance with international standards and is based on the following core principles:

- ✓ efficient, open, targeted, and rational use of natural resources (water and soil), as well as systematic and continuous protection of the environment and bioecosystems (plants and animals);
- ✓ complete abstinence from the use of chemical fertilizers and pesticides during planting, processing, cultivation, and harvesting;
- ✓ creation of a stable, clean, and transparent ecosystem – creating conditions for the growth of all plant species growing in a given area and preserving the wildlife living there;
- ✓ systematic and ongoing quality control of manufactured products (regardless of whether they are food or raw materials) – achieving organic production in accordance with international organic certificates;
- ✓ social responsibility for the interests of the state and society – creating safe and fair working conditions for all citizens engaged in organic production, including all categories of specialists and workers in cluster, farm, and dehkan farms, as well as household plots.

General requirements for organic production:

- ✓ high-quality preparation of fertile soil and selection of suitable crops;
- ✓ use of natural fertilizers (compost, black soil, peat, green manure (plant humus)) instead of chemical fertilizers;
- ✓ soil and plant protection using biological means (crop rotation, mixing and composting organic fertilizers and other waste; maintaining a balance of organic matter);
- ✓ selection of crops suitable for the natural climate and soil fertility (conditions);
- ✓ planting and growing crops;
- ✓ pest and disease control using biological means (entomophages, natural fungicides);
- ✓ pest and disease control using manual and mechanized labor; □ Use of water-saving technologies.

Farmers, entrepreneurs, and government agencies are taking significant steps to develop organic production in Uzbekistan. Organic production in our country's agriculture is driven by the growing demand for environmentally friendly and healthy agricultural products. Farmers and farm managers often have questions about the soil composition required for growing organic produce. According to research and official scientific data:

1. for organic production, the soil must have high natural fertility (over 60);
2. soil density of 1.30-1.35 t/m³, porosity of 50-55%;
3. humus content in the arable layer must be over 1%;

4. the soil must be moderately and abundantly supplied with naturally mobile nitrogen, phosphorus, and potassium;

5. non-saline or slightly saline (salt-leached) soils;

6. lands not contaminated by wastewater and not subject to waterlogging;

7. soils not subject to water and wind erosion;

8. lands not affected by industrial and household waste;

9. lands must be sufficiently supplied with a natural water source.

The quality and composition of water supplied to crops for organic production must meet the following requirements:

In our republic, surface water resources are divided into the following categories based on quality indicators:

* very clean (SII-0.3 or less);
* moderately clean (SII-11-2.5);
* polluted (SII-2.51-4.0);
* impure (SII-4.1-6.0);
* very polluted (SII-6.1-10.0);
* extremely polluted (SII-10.0+).

For organic agricultural production, it is recommended to use water categories 1-2.

Requirements for organic and mineral products. Chemical mineral fertilizers cannot be used for organic production.

Organic farming strictly prohibits the use of chemical fertilizers and instead requires attention to the natural transformation of the soil and the enhancement of biological processes to maintain, restore, and improve soil fertility.

What products (resources) should be used instead of chemical fertilizers?

The following alternative organic fertilizers are recommended for organic production:

Compost, per hectare – 0-40 tons (depending on soil condition);

Manure (well-rotted) – 20-60 tons;

Green manure, plant residues, chopped grass, etc. (green manure);

Bone meal (for phosphorus) – 500-1000 kg;

Wood ash (for potassium) – 500-1500 kg;

Phosphate rock (for phosphorus) – 300-600 kg;

Biofertilizers (beneficial microorganisms) – based on special strains are recommended.

In organic farming, it is more practical to improve soil fertility naturally than to use chemical fertilizers. Intensive use of natural plant protection products against diseases and pests, the most important of which are:

* use of biological pesticides instead of chemical (synthetic) pesticides (e.g., beneficial insects, bacterial preparations, plant extracts).

* use of environmentally friendly methods – use of natural insects against pests (e.g., beetles that consume small generations of pests).

* natural improvement of soil fertility – use of mycorrhizal fungi and beneficial bacteria.

Efficient use of irrigation and water resources:

* implementation of drip and sprinkler irrigation systems – saves water and prevents soil erosion.

* regulate the timing and amount of watering to maintain optimal moisture levels for each plant species.

* use clean and safe water sources – never use water contaminated with sewage or industrial waste.

For always using healthy seeds and seedlings:

* avoid GMOs and chemically treated seeds.

* use local and certified organic seeds.

* natural seed protection is recommended, such as soaking seeds in standardized herbal infusions or using biofungicides.

For improving soil fertility, it is advisable to rotate crops annually.

Organic production requires attention to efficient land use, maintaining and improving soil fertility, taking into account specific environmental factors. In these cases:

• proper placement of each crop type depending on soil and climatic conditions;

• for organic production – cultivating the land using resource-saving technologies, extensive use of organic fertilizers, planting green manure crops, and growing companion crops between main crops;

• for improving soil fertility – taking measures to prevent salinization, poisoning, waterlogging, soil erosion, soil pollution, and soil contamination with various wastes;

• in organic production – using biological and agronomic measures to control weeds, pests, and diseases in the fields.

• it is important to grow local crop species and varieties adapted to climatic conditions, resistant to diseases and pests, and providing high economic efficiency.

What types of crops are included in green manure fertilizers and how to use them. In organic farming, crops are specifically planted, grown, harvested at the appropriate time, crushed, and added to the soil as green manure. The benefits of green manure include:

• the soil accumulates a large amount of organic matter;

• favorable environment for the development of soil microorganisms is created, enabling the transfer of nutrients from a bulk form to a mobile form, which can be absorbed by plants;

• root system of green manure crops forms reserves of mineral nutrients in the deep soil layers;

• mechanical, physical, and microbiological properties and characteristics of the soil are improved;

• green manure fertilizers save water by conserving moisture in the fields, which is of great importance.

It is recommended to widely use alfalfa, soybeans, and beans as green manure fertilizers.

Seed requirements for agricultural crops in organic production. Seed production systems are of great importance in organic production. Therefore, it is advisable to ensure a high variety and quality of seeds for each crop grown. Organic farming is farming based on natural processes and incorporating scientific advances. This is a vast complex, encompassing such important requirements as increasing the amount of organic fertilizers in cultivated areas, plowing depending on the crop species and type, widespread use of "green" fertilizers, improving the mechanical and physical properties of the soil (deep loosening, incorporation of organic matter at various depths into the soil layers, mulching the surface with "green" fertilizers made from organic waste), using scientifically proven irrigation methods, selecting the right irrigation methods and components, and systematically and sustainably increasing the number of beneficial microorganisms in the soil.

Organic agricultural production is a priority in our country, and despite being a relatively new area, it holds great promise. Considering that in developed countries, such products sell at

higher prices than products grown using traditional agricultural technologies, farmers, farms, household plots, and agro-clusters that decide to work in this direction will have the opportunity to significantly increase their income.

Conclusion The implementation of the above-described procedures and requirements for organic agricultural production in agriculture will, first and foremost, create opportunities for organic producers to earn high incomes, produce competitive products in domestic and foreign markets, and establish a strong position in the global food market. For achieving this status, it is advisable to enhance the professional potential of farmers, farms, and agro-clusters, as well as to focus on awareness-raising and information exchange in this area to increase the number of economic entities producing organic products in our country.

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