



ACTUAL PROBLEMS OF MODERN SCIENCE, EDUCATION AND TRAINING

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UDC: 532.516:519.6

COMPUTATIONAL ANALYSIS OF STEADY VISCOUS FLOW PAST A CIRCULAR CYLINDER

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Annotatsiya. Ushbu tadqiqotda aylana silindr atrofidagi statsionar qovushqoq oqim Reynolds soni 300 gacha bo'lgan holatlar uchun sonli usullar yordamida o'rganilgan. Nyuton usuliga asoslangan iteratsion usul hamda chegaraviy shartlarning takomillashtirilgan ko'rinishi taklif etilgan. Natijalar shuni ko'rsatadiki, ($Re = 300$) ga yaqin qiymatlarda uyg'onish zonasida qayta sirkulyatsiya yuzaga keladi va uyg'onish uzunligi qisqaradi, shu bilan birga qarshilik kuchi, bosim taqsimoti va ajralish nuqtasi deyarli o'zgarmasdan qoladi.

Kalit so'zlar. *Statsionar qovushqoq oqim, aylana silindr, hisoblash suyuqliklar dinamikasi (CFD), sonli modellashtirish, chegaraviy shartlar, oqim funksiyasi–uyurmaviylik formulasi, laminar oqim.*

Аннотация. В данном исследовании численно изучается стационарное вязкое течение вокруг кругового цилиндра при числах Рейнольдса до 300. Предложены итерационный метод, основанный на методе Ньютона, и усовершенствованные граничные условия. Полученные результаты показывают, что при приближении числа Рейнольдса к значению $Re = 300$ в следовой области возникает рециркуляция потока и наблюдается сокращение длины следа. При этом коэффициент сопротивления, распределение давления и положение точки отрыва потока остаются практически неизменными.

Ключевые слова. *Стационарное вязкое течение, круговой цилиндр, вычислительная гидродинамика (CFD), численное моделирование, граничные условия, формулировка вихрь, ламинарное течение.*

Abstract. This study numerically investigates steady viscous flow past a circular cylinder for Reynolds numbers up to 300. A Newton-based iterative method and improved boundary conditions are proposed. Results show wake recirculation and wake shortening near ($Re=300$), while drag, pressure distribution, and separation point remain nearly unchanged.

Keywords: *Steady viscous flow, Circular cylinder, Computational fluid dynamics (CFD), Numerical simulation, Boundary conditions, Stream function–vorticity formulation, Laminar flow.*

Introduction

The study of viscous incompressible flow around a circular cylinder has long attracted significant theoretical and computational interest. Despite the development of

numerous numerical techniques and extensive calculations, a Reynolds number of approximately 100 (based on cylinder diameter) has generally remained the highest value for which accurate and complete steady-flow solutions have been successfully obtained. Interest in this problem continues for several reasons. One important motivation is that the circular cylinder serves as a representative model for flow around many practically important bodies. Experimental studies indicate that steady solutions become unstable at Reynolds numbers near 40. The application of flow-control techniques to stabilize such unstable flows may open new possibilities for investigating previously inaccessible flow regimes, which can initially be explored more effectively through numerical simulations. Analytical descriptions of the entire flow field remain difficult because of the many complexities involved. Numerical methods, therefore, are expected to provide deeper insight into the limiting behavior of steady flows as the Reynolds number increases. Several important issues remain unresolved, including the asymptotic behavior of the wake recirculation region, drag characteristics, separation-point location, and the distributions of vorticity and pressure. These topics are essential for improving the understanding of high-Reynolds-number flows, and we get all off the results and figures from Ansys Fluent.

Research Methodology

Mathematics formulation. In terms of stream function Ψ and vorticity ω , satisfying

$$u = \frac{\partial \Psi}{\partial y}, \quad v = -\frac{\partial \Psi}{\partial x}, \quad (1)$$

$$\omega = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}, \quad (2)$$

The Navier-Stokes equation can be formulated

$$\Delta \Psi + \omega = 0, \quad (3)$$

$$\Delta \omega + \frac{Re}{2} \left\{ \frac{\partial \Psi}{\partial x} \frac{\partial \omega}{\partial y} - \frac{\partial \Psi}{\partial y} \frac{\partial \omega}{\partial x} \right\} = 0 \quad (4)$$

here, $\Delta = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2}$ and the Reynolds number Re , based on the diameter d , is

Steady flow past a circular cylinder

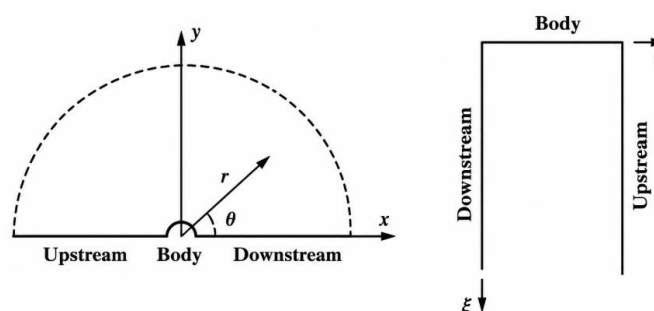


Figure 1. The x, y and ξ, η plane.

$Re = Ud/\nu$. The quantity U is the free-stream velocity and ν is kinematic coefficient of viscosity. We will from now on assume that $U = \frac{1}{2}d = 1$.

It is useful to analyze the deviation from uniform flow in both numerical computations and theoretical investigations.

$$\psi(x, y) = \Psi(x, y) - y \quad (5)$$

instead of with Ψ .

Analysis and Results

Solution. After that we calculate the process in Ansys Fluent, for this model we use edge sizing 96 divisions and 460 bias factor

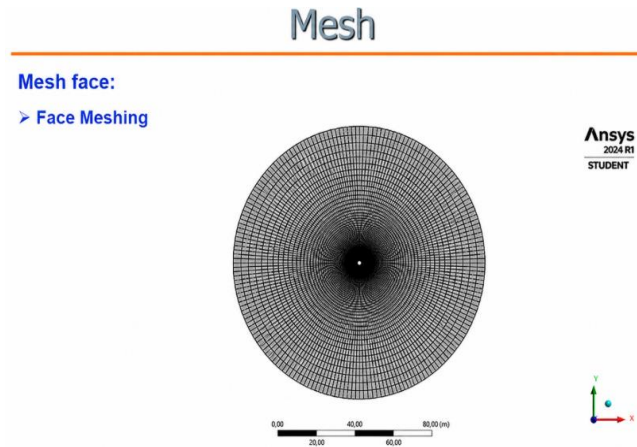


Figure 2. Mesh of the cylinder

Here we will consider an approximate option in order to obtain a recitation for comparisons, for that we will consider the parameters Steady, Laminar and Incompressible

$$\rho = 1 \text{ kg/m}^3, \mu = 1 \frac{\text{kg}}{\text{m s}}, u = (1,0) \text{ m/s}$$

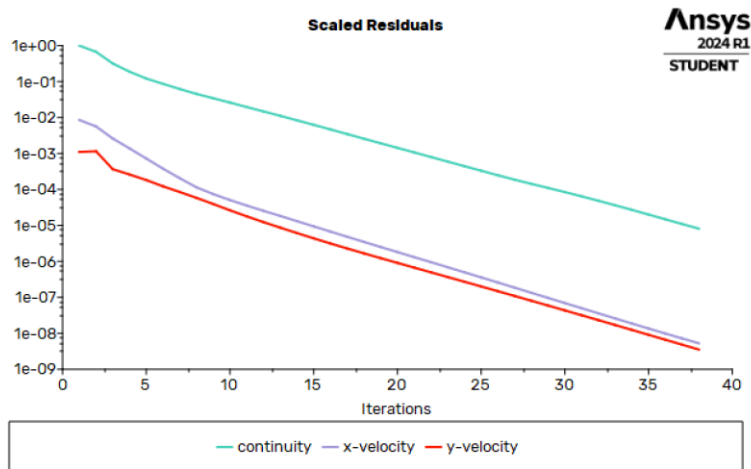


Figure 3. Convergence is achieved after 38 iterations [$u_0=(1,0)$] when $Re=20$.

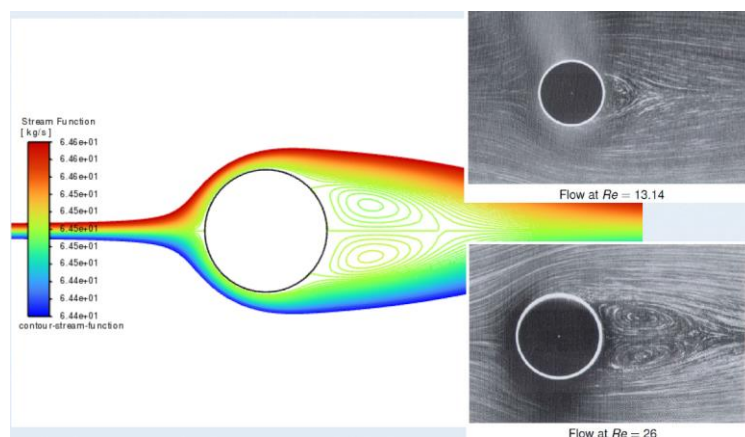


Figure 4. Stream function approximate with real presses.

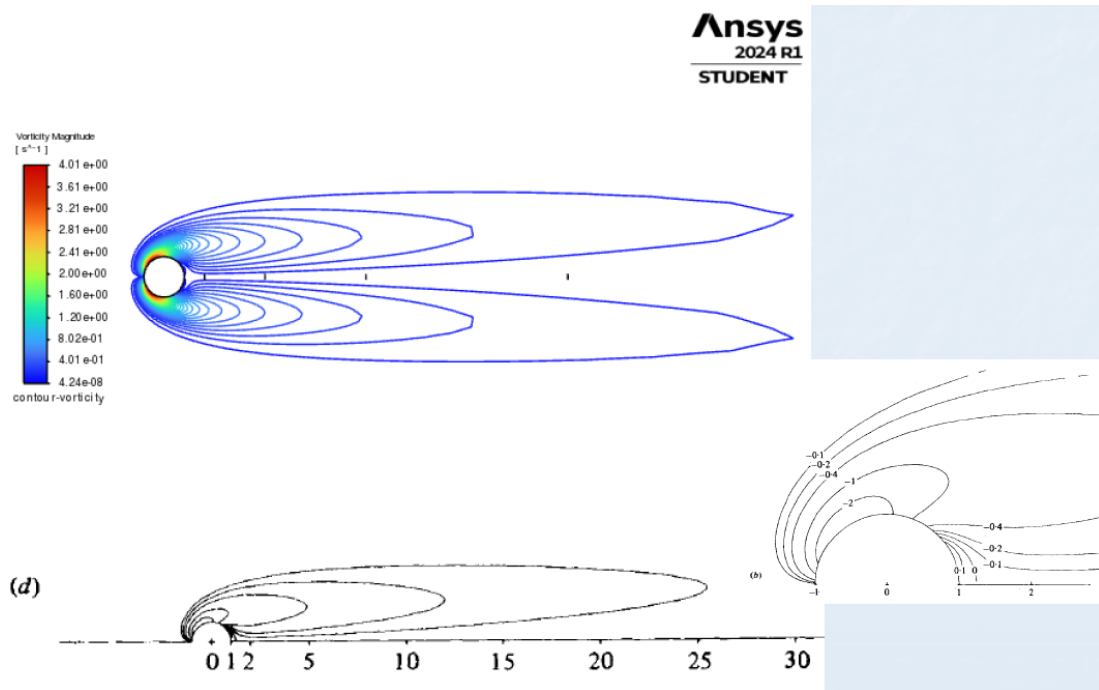


Figure 5. Vorticity magnitude.

Conclusion

In conclusion, this study successfully investigated steady viscous incompressible flow past a circular cylinder using advanced numerical methods for Reynolds numbers up to 300. The proposed Newton-based iterative scheme and improved far-field boundary conditions provided stable and accurate solutions even at higher Reynolds numbers, where earlier methods faced significant difficulties. The results revealed important changes in wake behavior, particularly the recirculation of vorticity and the shortening and widening of the wake region near $Re=300$. At the same time, key flow characteristics such as drag, pressure distribution, and separation point location remained relatively stable. Overall, the research contributes valuable insight into high-Reynolds-number flow behavior and demonstrates the effectiveness of numerical techniques in computational fluid dynamics.

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UDC: 519.6:622.276.031

MATHEMATICAL MODELING OF DYNAMIC NONLINEAR FILTRATION AND NUMERICAL SOLUTIONS TO NONLINEAR EQUATIONS

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Annotasiya. maqolada xususiy hosilali, chiziqsiz differensial tenglamalar bilan ifodalanadigan qatlamli filtrlanish tizimi diamik jarayonini matematik modellashtirish va sonli algoritmni realizatsiyasi, shuningdek tadqiqot jarayonining diskrit modelini kvazichiziqshtirish masalasi qaraladi.

Kalit soʻzlar: *dinamik jarayon, filtrlanish nazariyasi, maqsad funksiyasi, parametrlarni optimallashtirish, matematik model, chiziqsiz tenglama, ayirmali sxemalar, quvish usuli, kvazichiziqshtirish, ketma-ketlik, bir tekis cheklash, iteratsiya jarayoni.*

Аннотация. в статье рассматриваются вопросы математического моделирования динамического процесса пластово-фильтрационных систем, описываемых нелинейными дифференциальными уравнениями в частных производных и численный алгоритм реализации, а также ква

Ключевые слова: *динамический процесс, теории фильтрации, целевая функция, оптимизации параметров, математическая модель, нелинейное уравнение, разностные схемы, метод прогонки, квазилинеризации, последовательность, равномерное ограничение, итерационный процесс.*

Abstract. This article examines the mathematical modeling of the dynamic process of reservoir filtration systems described by nonlinear partial differential equations and a numerical algorithm for their implementation, as well as the quasi-linearization of the nonlinear discrete model of the process under study.

Keywords: *dynamic process, filtration theory, objective function, parameter optimization, mathematical model, nonlinear equation, difference schemes, sweep method, quasilinearization, sequence, uniform boundedness, iterative process.*

Introduction

One of the key challenges in the digitalization and management of energy resource facilities (particularly in oil and gas production) is the creation and development of mathematical models and software. These tools enable computational experiments and provide engineering and technical personnel with the means to formulate specific recommendations for studying and managing the processes that occur in real-world complex technological systems [1].

Literature Review

The mathematical theory of controlling objects with distributed parameters has been greatly developed. With a significant number of scientific works devoted to this field, it is necessary to note the works of Russian scientists A.G. Butkovsky, A.I. Egorov, V.P. Zhivoglyadov, M.V. Meerov, K.A. Lurie, Yu.I. Samoilenko, T.K. Sirazetdinova, A.A. Feldbaum and several others. An important contribution was also made by foreign experts, among whom the names of R.K.S. Wong, V. Malgraj, J.L. Lyons, V. Fleming, A. Friedman are known [2-8]. Rather general necessary conditions for optimizing program control (an analysis problem) are formulated, the controllability conditions are studied relatively completely, and optimality conditions for linear objects described by partial differential equations of parabolic and hyperbolic types are obtained, a number of numerical methods for optimal control of objects and systems with distributed parameters are developed.

Research Methodology

The filtration system under study consists of a productive formation, which is the object of control, and a set of wells (production and injection), referred to as the control object's regulators. The external environment includes interacting formations and interbeds (Figure 1). The effects of input variables can be interpreted as artificial influences on the system's state, whereas interactions with the external environment can be seen as natural interactions between the system and its environment [9].

Let us consider the problem of analyzing the dynamic state of a system during the planar, single-layer filtration of a real gas in a porous medium with heterogeneous reservoir properties, under near-real-world conditions.

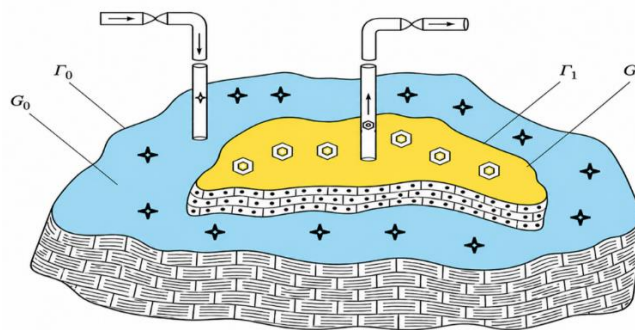


Figure 1. A productive formation and a set of wells as a reservoir-filtration system.

The porosity, reservoir permeability m and k , dynamic viscosity μ and z coefficients are functions of state (pressure) P .

The mathematical model for analyzing the dynamic state of a reservoir filtration system in deformable media, which is developed by a system of production and injection wells, is based on the laws of general continuum mechanics [1].

When formulating problems of optimal control for gas field development, it is particularly important to consider the dynamics of transient processes occurring in the pay zone during its operational life.

The state of the system is described by nonlinear partial differential equations [1, 9].

$$\frac{\partial}{\partial x} \left[\frac{K(p)}{\mu(p)} \frac{p}{Z(p)} \frac{\partial p}{\partial x} p(x, y, t) \right] + \frac{\partial}{\partial y} \left[\frac{K(p)}{\mu(p)} \frac{p}{Z(p)} \frac{\partial p}{\partial y} p(x, y, t) \right] = \frac{\partial}{\partial t} \left[\frac{m(p)}{Z(p)} p(x, y, t) \right],$$

$$(x, y) \in G, t > t_0 \quad (1)$$

Here G - multiply connected domain of a two-dimensional space R^2 , whose boundary is sufficiently smooth and consists of an outer contour Γ and internal circuits $\gamma_1, \gamma_2, \dots, \gamma_n$, appropriate v th well.

The condition on the outer boundary of the domain can be specified as

$$p(x, y, t) = f(x, y, t), (x, y) \in \Gamma \quad (2)$$

or

$$\frac{K(p)}{\mu(p)} \frac{p}{Z(p)} \frac{\partial p}{\partial n} \Big|_{p(x,y,t)=f(x,y,t)} = f(x, y, t), \quad (x, y) \in \Gamma. \quad (3)$$

The first means that the gas pressure at the outer boundary of the filtration region is known over time. The second, in a general case, characterizes the hydrodynamic interaction of the formation across the outer boundary of the filtration area, particularly when $\eta = 0$ the impermeability of the external border is established.

For wells, the boundary conditions depend on the selected production modes. If the well flow rate (control action) is specified $q_v(t)$, that

$$\oint \frac{K(p)}{\mu(p)} \frac{p}{Z(p)} \frac{\partial p}{\partial n} ds = c^{\gamma_v} q_v(t), \quad (4)$$

where $c^{\gamma_v} = P_{atm} T_{pl} / (T_{atm} b)$; $P_{atm} T_{atm}$ - gas pressure and temperature at standard conditions; - reservoir temperature; b - bed thickness.

If a specified bottomhole pressure is maintained in the wells, then

$$p(x, y, t_0) = \psi_v, \quad (x, y) \in \gamma_v. \quad (5)$$

In addition to the boundary conditions, an initial condition must be specified that characterizes the distribution of the state function before the well system is put into operation

$$p(x, y, t) \Big|_{t=0} = \varphi(x, y), \quad (x, y) \in G \cup \Gamma. \quad (6)$$

The task of determining optimal values q_v , based on resource volume and formation pressure distribution $P_{pl}(t)$ and its required uniform decline across the area of the productive gas-bearing formation, can be formulated as follows.

It is required to minimize the functional

$$F(q_1(t), q_2(t), \dots, q_n(t)) = \sum_{v=1}^n [P_{cp}(t) - P_v(t)]^2, \quad (7)$$

where $P_v(t)$ and $P_{cp}(t)$ bottomhole and average reservoir pressure, respectively, calculated using (1) with conditions (2) – (6) and the material balance equations [1]. Solving this problem requires imposing restrictions on the intensity of well operation.

$$-q_v \leq q_v(t) \leq q_v^+ \quad (8)$$

and it is suggested that

$$\sum_{v=1}^n \int_0^T q_v(t) dt = Q, \quad (9)$$

here $-q_v$ and q_v^+ - minimum and maximum allowable well flow rates, Q – planned gas production, and T - the end of the time interval under consideration.

- the end of the time interval in question $(0, T)$ in such a way as to ensure a uniform rate of reservoir pressure decline while meeting the planned gas production volume.

This is a nonlinear programming problem, which can be solved using one of the many methods currently available. The solution to the control problem, which ensures a uniform decline of the state function within the multi-connected domain under consideration, is based on solving the direct problem of analyzing the performance of the reservoir filtration system. This system is described by equation (1) with boundary, initial, and internal conditions (2) – (6). Therefore, it is necessary to conduct research to create adequate numerical models and algorithms for solving real-world analysis problems. The nonlinear boundary value problems presented above do not have an analytical solution. Their numerical solution involves difficulties determined primarily by the multi-connectedness of the domain, its arbitrary configuration, the second-kind boundary conditions, the lack of analytical dependencies of permeability, porosity, viscosity, and supercompressibility on pressure, and the nonlinearity of the differential equation with respect to the pressure function.

For numerical solutions, it is more convenient to switch to new dimensionless variables according to the following formulas

$$P^* = P / P_0, \quad x^* = x / L, \quad y^* = y / L, \quad k^* = k / k_0, \quad \mu^* = \mu / \mu_0, \quad z^* = z / z_0, \quad m^* = m / m_0, \\ t^* = k_0 z_0 P_0 t / (m_0 \mu_0 L^2), \quad q_v^* = c \mu_0 z_0 q_v / (k_0 P_0^2).$$

here P_0 - initial reservoir pressure; L - bed extent; k_0, μ_0, z_0, m_0 - initial values of permeability, dynamic viscosity, supercompressibility, and porosity under normal conditions.

In the new variables, the form of the differential equation and the initial and boundary conditions does not change; the asterisks above the dimensionless variables are omitted, and the following notation is introduced

$$K = k / (\mu z), \quad M = m / (zP).$$

To approximate the boundary value problem by a system of finite difference equations, we introduce spatial and temporal grids as follows

$$\omega_{hi,hj} = \{(x_i, y_i), \quad x_i = x_{i-1} + h_i, \quad i = \overline{m_{1j}, m_{2j}}, \quad j = \overline{0, n_2}, \quad y_j = y_{j-1} + h_j, \quad j = \overline{n_{1i}, n_{2i}}, \quad i = \overline{0, m_2}\}, \\ \omega_{\tau k} = \{t_k, t_k = t_{k-1} + \tau_k, \quad k = 1, 2, \dots\}.$$

here h_i, h_j , - spatial grid step values corresponding to the coordinate axes OX, OY ; t_k - time step size; m_{1j}, m_{2j} и n_{1i}, n_{2i} - indices of the spatial grid nodes corresponding to the boundary of the filtration domain along the axes OX and OY

$$m_2 = \max_{n_1 \leq j \leq n_2} m_{2j}, \quad n_2 = \max_{m_1 \leq i \leq m_2} n_{2i}.$$

To make the wells coincide with the grid nodes, we introduce fictitious wells.

Let l - it's a well with coordinates. (ξ_l, η_l) falls within the quadrilateral with vertices $(x_i, y_j), (x_i, y_{j+1}), (x_{i+1}, y_j)$ и (x_{i+1}, y_{j+1}) . Then, we can assume that fictitious wells operate at these points, with their flow rates determined by the flow rates of the real wells. q_l .

Well production rates q_l distribute among the corresponding vertices of the quadrilateral as follows. We calculate the distance from the point (ξ_l, η_l) to the vertices of the quadrilateral

$$\rho_{i,j}^1 = \sqrt{(\xi_l - x_i)^2 + (\eta_l - y_j)^2}, \quad \rho_{i,j}^2 = \sqrt{(\xi_l - x_{i+1})^2 + (\eta_l - y_j)^2},$$

$$\rho_{i,j}^3 = \sqrt{(\xi_l - x_i)^2 + (\eta_l - y_{j+1})^2}, \quad \rho_{i,j}^4 = \sqrt{(\xi_l - x_{i+1})^2 + (\eta_l - y_{j+1})^2}.$$

Defining $q_{i,j}^l$ - calculating the production rates of notional wells using the formula

$$q_{i,j}^l = \left(0,5 - \rho_{i,j}^l / \sum_{s=1}^4 \rho_{i,j}^s \right) q_m, \quad l = \overline{1,4}.$$

In addition, if the condition $\min_{1 < l < 4} \rho_{i,j}^l < R/\alpha$ is satisfied for some number 1, we consider the well to have intersected the grid node with that number. Here $R = \sqrt{h_1^2 + h_2^2}$, α - a sufficiently large number, chosen based on the required proximity of the coordinates l - of the well to the spatial grid node. Thus, the method and algorithm for solving the problem in question will be applicable both when the well coincides with a grid node and when it does not.

If we consider the outer boundary of the region G_h can be approximated by a step function, which means that the discrete domain G_h can be viewed as a set of nodes of a family of straight lines C_{1j} , $j = \overline{0, n_2}$, parallel to the axis OX or as a set of nodes for a family of straight lines C_{2i} , $i = \overline{0, m_2}$, parallel to the axis OY . According to the theory of economical difference schemes, various approximations of one-dimensional problems are considered on these straight lines. The one-dimensional problems are first solved along the direction of the axis OY (families of lines C_{1j}), then towards OX (families of lines C_{2i}), or vice versa. Homogeneous difference schemes, studied in detail by A.A. Samarskii and his followers [10, 11], are used for the approximation of differential equations.

The greatest attention is devoted to two economical schemes: the locally one-dimensional scheme and the alternating direction implicit (ADI) scheme. A.A. Samarskii provided a theoretical basis for both schemes, which have properties characteristic of economical schemes (the properties of total approximation and additivity).

Applying a locally one-dimensional scheme or an alternating direction implicit (ADI) scheme, we obtain a system of finite-difference equations for the internal nodes of the discrete filtration domain.

According to the first diagram, the system uses direct connections. C_{1j} , $j = \overline{1, n_2 - 1}$, $i = \overline{m_{1j} - 1, m_{2j} - 1}$ has the form

$$\hat{a}_{i,j} \hat{p}_{i+1,j}^2 - \hat{b}_{i,j} \hat{p}_{i,j}^2 + \hat{c}_{i,j} \hat{p}_{i-1,j}^2 = -\hat{d}_{i,j}, \quad (10)$$

where

$$\hat{a}_{i,j} = \sigma K_{i,j+0,5} / (\hbar_j h_{j+1}),$$

$$\hat{c}_{i,j} = \sigma K_{i-0,5,j} / (\hbar_j h_j),$$

$$\hat{b}_{i,j} = \hat{a}_{i,j} + \hat{c}_{i,j} + \hat{M}_{i,j} / (0,5\tau_k),$$

$$\hat{d}_{i,j} = [\overline{M}_{i,j} / (0,5\tau_k) - (1 - \sigma)(\overline{K}_{i+0,5,j} / h_{i+1} + \overline{K}_{i-0,5,j} / h_i) / \hbar_i] \overline{p}_{i,j}^2 + (1 - \sigma)[\overline{K}_{i+0,5,j} \overline{p}_{i+1,j}^2 / h_{i+1} + \overline{K}_{i-0,5,j} \overline{p}_{i-1,j}^2 / h_i] / \hbar_i$$

(σ -circuit parameter),

$$\text{on straights } C_{2i}, i=\overline{1, n_{2-1}}, j=\overline{n_{1j}+1, n_{2i}-1} \quad a_{i,j}p_{i,j+1}^2 - b_{i,j}p_{i,j}^2 + c_{i,j}p_{i,j-1}^2 = -d_{i,j}, \quad (11)$$

where

$$a_{i,j} = \sigma K_{i,j+0,5} / (\hbar_j h_{j+1}),$$

$$c_{i,j} = \sigma K_{i,j-0,5} / (\hbar_j h_j),$$

$$b_{i,j} = a_{i,j} + c_{i,j} + M_{i,j} / (0,5\tau_k),$$

$$d_{i,j} = \left[\hat{M}_{i,j} / (0,5\tau_k) - (1-\sigma)(\hat{K}_{i,j+0,5} / h_{j+1} + K_{i,j-0,5} / h_j) / \hbar_j \right] \times$$

$$\times \hat{p}_{i,j}^2 + (1-\sigma)(\hat{K}_{i,j+0,5} \hat{p}_{i,j+1}^2 / h_{j+2} + \hat{K}_{i,j-0,5} \hat{p}_{i,j-1}^2 / h_j) / \hbar_j.$$

According to the second diagram, the system of equations is represented by straight lines $C_{1j}, j=\overline{1, n_2-1}$ in the form of (10) with the coefficients

$$\hat{a}_{i,j} = \hat{K}_{i+0,5,j} / (\hbar_i h_{i+1}), \quad \hat{c}_{i,j} = K_{i-0,5,j} / (\hbar_i h_i),$$

$$\hat{b}_{i,j} = \hat{a}_{i,j} + \hat{c}_{i,j} + \hat{M} / (0,5\tau_k),$$

$$\hat{d}_{i,j} = [\overline{M}_{i,j} / (0,5\tau_k) - (\overline{K}_{i,j+0,5} / h_{j+1} - \overline{K}_{i,j-0,5} / h_j) / \hbar_j] \times \hat{p}_{i,j}^2 +$$

$$+ (\overline{K}_{i,j+0,5} \hat{p}_{i,j+1}^2 / h_{j+1} + \overline{K}_{i,j-0,5} \hat{p}_{i,j-1}^2 / h_j) / \hbar_j;$$

on straightaways $C_{2i} \quad i=\overline{1, m_2-1}$ in the form of (11), with coefficients

$$a_{i,j} = K_{i,j+0,5} / (\hbar_j h_{j+1}), \quad c_{i,j} = K_{i,j-0,5} / (\hbar_j h_j),$$

$$b_{i,j} = a_{i,j} + c_{i,j} + M_{i,j} / (0,5\tau_k),$$

$$d_{i,j} = [\hat{M}_{i,j} / (0,5\tau_k) - (\hat{K}_{i+0,5} / h_{i+1} + \hat{K}_{i-0,5,j} / h_i) / \hbar_i] \hat{p}_{i,j}^2 +$$

$$+ (\hat{K}_{i+0,5,j} \hat{p}_{i+1,j}^2 / h_{i+1} + \hat{K}_{i-0,5,j} \hat{p}_{i-1,j}^2 / h_i) / \hbar_i.$$

For the sake of definiteness, we have chosen to solve the one-dimensional problems on the lines first $C_{1j}, j=\overline{1, n_2-1}$, after that on $C_{2i}, i=\overline{1, m_2-1}$, therefore $\bar{p}_{i,j}$ corresponds to the solution known from the previous time step t_{k-1} , $\hat{p}_{i,j}$ - an interim solution, $p_{i,j}$ - the desired solution on the computational layer t_k .

To approximate the boundary conditions at the wells, we assume that the wells are located at the grid nodes. Research has shown that a point well can be considered with the same flow rate as a real well, since they practically coincide a short time after the well is put into operation. It should be noted that the pressure at the point well corresponds to the pressure at an upscaled well with a radius commensurate with the spatial grid step at that node, $R_\phi = R_c \hbar$.

It is evident that the pressure in a point-source well is higher than in an actual well, with the difference depending on the well's flow rate. It is also possible to apply certain approximate methods, such as those based on the assumption that at any given moment, the plane-radial flow can be considered steady-state.

Let the wells be located at a node with the coordinates (x_i, y_j) . Let's consider an element of the domain G_h centered at this node, with sides h_i, h_j . Applying the standard method for deriving the flow continuity equation to the domain element under consideration, we obtain the following equation

$$\frac{\partial}{\partial x} \left[\frac{k(p)}{\mu(p)} \frac{p}{z(p)} \frac{\partial p}{\partial x} \right] + \frac{\partial}{\partial y} \left[\frac{k(p)}{\mu(p)} \frac{p}{z(p)} \frac{\partial p}{\partial y} \right] /_{i,j} = \frac{\partial}{\partial t} \left[\frac{m(p)}{z(p)} p \right] /_{i,j} + \frac{q_{i,j}}{h_i h_j}.$$

If the production rate of a point well $q_v = q_{i,j}$ is zero, the equation becomes a differential equation for an internal node. To approximate the differential equation using finite differences, the same formulas used for internal nodes can be applied. Therefore, for point wells, the finite-difference equations will be the same as (10) – (11), with the difference that

$$\hat{d}_{i,j}^\lambda = \hat{d}_{i,j} - \frac{q_{i,j}}{2h_i h_j}, \quad d_{i,j}^\lambda = d_{i,j} = \frac{q_{i,j}}{2h_i h_j},$$

for a diagram of longitudinal and transverse directions

$$\begin{aligned} \hat{d}_\lambda^\lambda &= \hat{d}_{i,j} - q_{i,j} / (h_i h_j), \\ \hat{d}_{i,j} &= d_{i,j} - q_{i,j} / (h_i h_j). \end{aligned}$$

Let us now approximate the boundary conditions on the outer boundary of the filtration domain using finite-difference equations. If the gas pressure at a boundary node is known, we have $p_{i,j} = f_{i,j}$.

If a boundary condition of the form (3) is specified, we proceed as follows. Let us assume, for example, that on the lines $C_{1,j}$ at the node $i = m_{1j}$ we are given a boundary condition of the form (3). Consider the expansion of the expression $[kp / (\mu z) \partial p / \partial x]$ in a series in the vicinity of the node $i = m_{1j}$. Restricting ourselves to the first-order term, we can write

$$\frac{k(p)}{\mu(p)} \frac{p}{z(p)} \frac{\partial p}{\partial x} /_{i+0,5,j} = \frac{k(p)}{\mu(p)} \frac{p}{z(p)} \frac{\partial p}{\partial x} /_{i,j} + \frac{\partial}{\partial x} \left[\frac{k(p)}{\mu(p)} \frac{p}{z(p)} \frac{\partial p}{\partial x} \right] /_{i,j} 0,5h_i.$$

Taking into account the approximation accuracy of the differential expression for the internal nodes, we obtain

$$\frac{k(p)}{\mu(p)} \frac{p}{z(p)} \frac{\partial p}{\partial x} /_{i+0,5,j} = \frac{1}{2} \frac{k(p)}{\mu(p)} \frac{1}{z(p)} /_{i+0,5,j} \frac{p_{i+1,j}^2 - p_{i,j}^2}{h_i}.$$

Considering that when the locally one-dimensional scheme is applied

$$\frac{\partial}{\partial x} \left[\frac{k(p)}{\mu(p)} \frac{p}{z(p)} \frac{\partial p}{\partial x} \right] /_{i,j} = \frac{\partial}{\partial t} \left[\frac{m(p)}{z(p)} p \right] /_{i,j},$$

and moving on to the notation adopted for the intermediate calculation of the boundary value problem on the current time layer t_k , we are finding

$$\hat{K}_{i+0,5,j} (\hat{p}_{i+1,j}^2 - \hat{p}_{i,j}^2 / h_i = \hat{\eta}_{i,j} (\hat{p}_{i,j} - f_{i,j}) + (\hat{M}_{i,j} \hat{p}_{i,j}^2 - \bar{M}_{i,j} \hat{p}_{i,j}^2) h_i / \tau_k.$$

Applying the scheme of longitudinal-transverse directions, we obtain

$$\hat{K}_{i+0.5,j}(\hat{p}_{i+1,j}^2 - \hat{p}_{i,j}^2) / h_i = \hat{\eta}_{i,j}(\hat{p}_{i,j} - f_{i,j}) + 0,5h_i\{(\hat{M}_{i,j}\hat{p}_{i,j}^2 - \overline{M}_{i,j}\hat{p}_{i,j}^2) / ((0,5\tau_k) - [\overline{K}_{i+0.5,j+1}\hat{p}_{i,j+1}^2 - \hat{p}_{i,j}^2) / h_{j+1} - \overline{K}_{i-0.5,j-1}(\hat{p}_{i,j}^2 - \hat{p}_{i,j-1}^2) / h_j] / \hat{h}_j}\}.$$

A finite-difference approximation of the boundary conditions on straight lines can be obtained in a similar manner C_{1j} , $j = \overline{1, n_2 - 1}$ for a node $i = m_{2j}$: for the locally one-dimensional scheme

$$\hat{K}_{i-0.5,j}(\hat{p}_{i,j}^2 - \hat{p}_{i-1,j}^2) / h_i = \hat{\eta}_{i,j}(\hat{p}_{i,j} - f_{i,j}) - h_i(\hat{M}_{i,j}\hat{p}_{i,j}^2 - \overline{M}_{i,j}\hat{p}_{i,j}^2) / \tau_k;$$

for a diagram of longitudinal and transverse directions

$$\hat{K}_{i-0.5,j}(\hat{p}_{i,j}^2 - \hat{p}_{i-1,j}^2) / h_i = \hat{\eta}_{i,j}(\hat{p}_{i,j} - f_{i,j}) - 0,5h_i\{(\hat{M}_{i,j}\hat{p}_{i,j}^2 - \overline{M}_{i,j}\hat{p}_{i,j}^2) / \tau_k - [\overline{K}_{i+0.5,j+1}(\overline{p}_{i,j+1}^2 - \overline{p}_{i,j}^2) / h_{j+1} - \overline{K}_{i-0.5,j-1}(\overline{p}_{i,j}^2 - \overline{p}_{i,j-1}^2) / h_j] / \hat{h}_j\}.$$

As a result, we obtain a system of finite-difference equations for all nodes of the grid lines. C_{1j} , $j = \overline{1, n_2 - 1}$. A complete system of equations for the lines of the other family is also derived. C_{2i} , $i = \overline{1, m_2 - 1}$.

Thus, the following boundary equations must be added to the above finite-difference equations for the interior nodes:

for a locally one-dimensional scheme, when $j = n_{1i}$,

$$\hat{K}_{i,j+0.5}(p_{i,j+1}^2 - p_{i,j}^2) / h_j = \eta_{i,j}(p_{i,j} - f_{i,j}) + (M_{i,j}p_{i,j}^2 - \hat{M}_{i,j}\hat{p}_{i,j}^2)h_j / \tau_k$$

and also $j = n_{2i}$,

$$\hat{K}_{i,j-0.5}(p_{i,j}^2 - p_{i,j-1}^2) / h_j = \eta_{i,j}(p_{i,j} - f_{i,j}) - (M_{i,j}p_{i,j}^2 - \hat{M}_{i,j}\hat{p}_{i,j}^2)h_j / \tau_k;$$

for a scheme of longitudinal and transverse directions $j = n_{1i}$

and also $j = n_{2i}$

$$\hat{K}_{i,j-0.5}(p_{i,j}^2 - p_{i,j-1}^2) / h_j = \eta_{i,j}(p_{i,j} - f_{i,j}) - 0,5h_i\{(M_{i,j}p_{i,j}^2 - \hat{M}_{i,j}\hat{p}_{i,j}^2) / ((0,5\tau_k) - [\hat{K}_{i+1,j-0.5}(\hat{p}_{i+1,j}^2 - p_{i,j}^2) / h_{i+1} - K_{i-1,j-0.5}(\hat{p}_{i,j}^2 - \hat{p}_{i-1,j}^2) / h_j] / h_i)\}.$$

It can be easily verified that the accuracy of the approximation of the boundary value problem of filtration theory by a system of finite-difference equations on lines

C_{1j} , $j = \overline{1, n_2 - 1}$ и C_{2i} , $i = \overline{1, m_2 - 1}$ is on the order of $O(h^2 + \tau_k)$, where $h = \max_{i,j}(h_i, h_j)$.

Let us now focus on a key aspect of solving problem (1) - (9). When solving a nonlinear problem with iterative methods, it is necessary to specify an initial distribution that satisfies certain conditions. For the problem under consideration, this requirement is a flow rate distribution that satisfies criterion (7) and constraints (8) and (9).

In this regard, it is necessary to represent the analytical dependence of the choice of initial conditions for solving the problem. However, this is not so simple, so below we offer one of the methods for the computational aspect of this problem. The solution is sought in the following form

$$\begin{cases} q_1 = \lambda(q_{1\min} + q_{1\max}) \\ q_2 = \lambda(q_{2\min} + q_{2\max}) \\ \dots, \dots, \dots \\ q_n = \lambda(q_{n\min} + q_{n\max}). \end{cases} \quad (12)$$

To determine λ using conditions (8) and (9), we assume that in the initial stage $\sum_{v=1}^n q_v = Q$. Substituting (12) into this expression, we get

$$\begin{aligned} q_1 + q_2 + \dots + q_n &= \lambda(q_{1\min} + q_{1\max}) + \lambda(q_{2\min} + q_{2\max}) + \dots + \lambda(q_{n\min} + q_{n\max}) = \\ &= \lambda(q_{1\min} + q_{1\max} + q_{2\min} + q_{2\max} + \dots + q_{n\min} + q_{n\max}). \end{aligned}$$

Let's rewrite this expression as a sum.

$$\sum_{v=1}^n q_v = \lambda \sum_{v=1}^n (q_{v\min} + q_{v\max}) = Q.$$

From here
$$\lambda = Q / \left[\sum_{v=1}^n (q_{v\min} + q_{v\max}) \right].$$

Using expression (12), we obtain

$$q_l^{(0)} = Q / \left[\sum_{v=1}^n (q_{v\min} + q_{v\max}) \right] (q_{l\min} + q_{l\max}), \quad l = \overline{1, n},$$

this dependency allows for determining the initial values of the input variables for the influence functions $q_v(t_o)$, thus, a closed computational scheme has been developed that allows for solving problems of analysis and optimal control of reservoir-filtration systems.

Equations (10) and (11) are considered in terms of the squares of the pressures, as is evident from the structure of the system of finite-difference equations, which is presented in a form convenient for its solution.

The nonlinear expressions in (10) and (11) are the coefficients $a_{i,j}$, $b_{i,j}$, $c_{i,j}$ and $d_{i,j}$, dependent on the desired values of the state functions p at the computational time step. It can be verified that the coefficients $a_{i,j}$, $b_{i,j}$, $c_{i,j}$ and $d_{i,j}$, meet the requirements necessary for the system to be well-conditioned and stable on straight lines C_{1j} and C_{2i} . $a_{i,j} > 0$, $c_{i,j} > 0$, $b_{i,j} > (a_{i,j} + c_{i,j})$, which allows the tridiagonal matrix algorithm to be used to solve the system of nonlinear equations.

References [12, 13] describe several methods for constructing an iterative process based on the quasilinearization method, which reduces a system of nonlinear equations to a linear form with respect to p^2 or p . To justify the application of this method, let us consider the solution to a general nonlinear second-order equation that is solved for the highest derivative.

$$U''(x) = f(x, U, U'), \quad a < x < b \quad (13)$$

with general boundary conditions

$$\begin{cases} AU + BU'(a) = 0 \\ cU(b) + DU'(b) = 0. \end{cases} \quad (14)$$

Let $f(x, U, U')$ a strictly convex function of its arguments, then [14]

$$f(x, U, U') = \max[f(x, v, v') + (U - v)f'_v(x, v, v') + (U' - v')f'_{v'}(x, v, v')]. \quad (15)$$

On this basis, we construct the sequence of linear boundary value problems in the following form

$$U''_{n+1}(x) = f(x, U_n, U'_n) + (U_{n+1} - U_n) f'_u(x, U_n, U'_n) + (U'_{n+1} - U'_n) f'_{u'}(x, U_n, U'_n) \quad (16)$$

with respect to the boundary conditions (14) u_{n+1} , that is

$$\begin{cases} AU_{n+1}(a) + BU'_{n+1}(a) = 0 \\ CU_{n+1}(b) + DU'_{n+1}(b) = 0, \end{cases} \quad (17)$$

where $U_0(x)$ is considered known, while $n = 0, 1, 2, \dots$,

Using the iterative process defined by formulas (16) and (17), we find the next approximation to the exact solution of the boundary value problem under consideration. The solution to the boundary value problem for equation (16) will be sought in the class of functions from $C^2[a, b]$, for which the inequality holds

$$\max_{a \leq x \leq b} |U'(x)| \leq N \max_{a \leq x \leq b} |U(x)|, \quad (18)$$

where $0 < N < \infty$, which is known as Bernstein's inequality for the class of trigonometric polynomials, and as Markov's inequality for the class of algebraic polynomials.

Below, we show that the sequences $\{U_n(x)\}_{n=0}^{n=\infty}$ and $\{U'_n(x)\}_{n=0}^{n=\infty}$ exist and are uniformly bounded. The iterative process (16) and (17) converges quadratically to the solution of the boundary value problem (13) – (14); i.e., the following relation holds

$$\max_x |U_{n+1} - U_n| \leq K (\max_x |U_n - U_{n-1}|)^2.$$

Next, we show that under certain conditions on the differential operator, the sequence $\{U_n(x)\}_{n=0}^{n=\infty}$ monotonous.

Theorem. If the homogeneous equation for (16) has only the trivial solution, then the sequence $\{U_n(x)\}_{n=0}^{n=\infty}$, defined by a recurrence relation, exists and is uniformly bounded.

Evidence. Transforming equation (16) into an integral equation in accordance with [7], we obtain

$$\begin{aligned} U_{n+1} = & \int_0^b G(x, y) [f(y, U_n, U'_n) + (U_{n+1} - U_n) f'_u(y, U_n, U'_n) + \\ & + (U'_{n+1} - U'_n) f'_{u'}(y, U_n, U'_n)] dy, \end{aligned} \quad (19)$$

where $G(x, y)$ green's function, which exists by virtue of the conditions of the theorem. The continuity of the Green's function implies its boundedness on the compact set $[a, b]$. It follows that

$$K = \max_{x, y} |G(x, y)| < \infty, \quad 0 \leq x < y \leq b. \quad (20)$$

Let's designate

$$m = \max_{|u| < 1} \max_{|u'| < 1} [|f(y, U, U')|, |f'_u(y, U, U')|, |f'_{u'}(y, U, U')|]. \quad (21)$$

Substituting (20) and (21) into (19) and taking the moduli of both sides of (19), we obtain

$$\begin{aligned}
 |U_{n+1}| &\leq \int_0^b |G(x, y)| [|f(y, U_n, U')| + |U_{n+1} - U_n| |f'_u(y, U, U')| + |U'_{n+1} - U'_n| |f'_u(y, U, U_n)|] dy \leq \\
 &\leq K \int_0^b (m + |U_{n+1}|m + |U_n|m + |U'_{n+1}|m + |U'_n|m) dy.
 \end{aligned}
 \tag{22}$$

Having taken \max_x subtracting from both sides of (22) and using (18), we obtain

$$\max_x |U_{n+1}| \leq K(m + 2m \max_x |U_n|)b.$$

Let's $m_1 = \max_x |U_1(x)|$, $|U_0(x)| < 1$. if $n=0$ we obtain

$$m_1 \leq K(m + 2mm_1 + 2m)b = 3Kmb + 2kmm_1b,$$

from which it follows $m_1 \leq 3kmb / (1 - 2kmb)$.

It is easy to check that for

$$b \in [1/(2km), 1/(5km)] 3kmb / (1 - 2kmb) < 1,$$

therefore $m_1 < 1$.

This line of reasoning can be extended by induction, from which it follows that all $|U_n(x)| < 1$, $0 \leq x \leq b$, $n=0,1,2,\dots$, where $b \in [1/(2km), 1/5km]$, which was to be demonstrated.

Analysis and Results

The numerical algorithm presented is implemented on a computer as a standard procedure. For clarity and simplicity of analysis, the experiments were conducted for a square-shaped filtration area, with wells placed in the center and at the vertices of a square inscribed within the filtration area (Figure 2). The flow rates in all wells are equal $cq=4mln.m^3/sut.$, which corresponds to a dimensionless value $q^*=0,218$, calculated by the formula for conversion to dimensionless variables, where the coefficients are respectively equal to $k_0=0,5$, $\mu_0=0,01212sPz$, $P_{at}=1at$, $b=1000m.$, $P_n=227at$. The results of the computational experiments are presented as graphs showing the change in pressure over time at the central (curves 1a, 1b) and adjacent (curves 2a, 2b) wells during open (curves 1a, 2a) and closed (curves 1b, 2b) production modes (Figure 3).

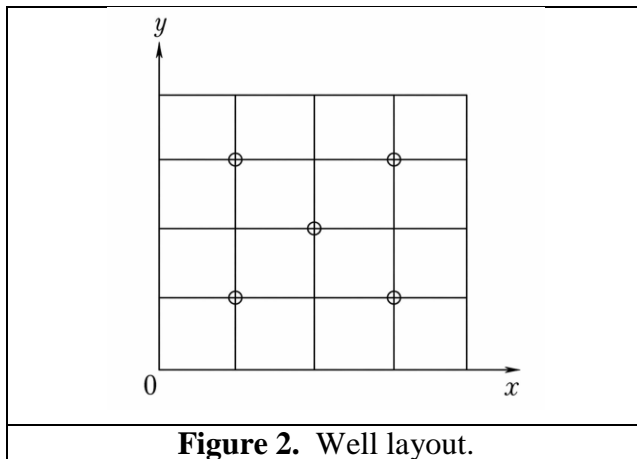


Figure 2. Well layout.

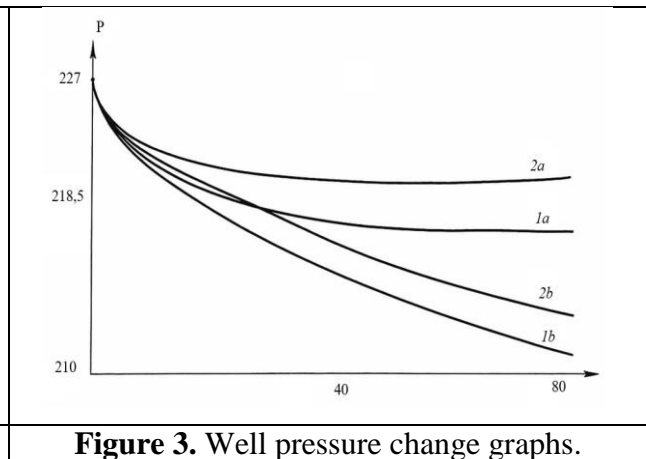


Figure 3. Well pressure change graphs.

Conclusion

The design of the computational model shows that wells can be located at any point within the gas-bearing formation. The calculation algorithm accommodates their arbitrary placement within the discrete domain structure, allowing for more accurate automation of gas-dynamic calculations for the process parameters under review. Thus, a rapidly converging iterative algorithm has been developed for solving two-dimensional boundary value problems of the dynamic process of real gas filtration in a deformable porous medium. It is also efficient in terms of computational time and computer memory usage.

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**MODERN PROBLEMS OF TECHNICAL SCIENCES**

UDC: 544.142.2:546.47:547.752:547.821

**SYNTHESIS, STRUCTURE AND ELECTRONIC PROPERTIES OF A NEW
[Zn(IAA)₂(NA)₂]·2H₂O COORDINATION COMPLEX: A COMBINED
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Annotatsiya. [Zn(IAA)₂(NA)₂]·2H₂O tarkibli yangi aralash ligandli rux(II) koordinatsion birikmasi indol-3-sirka kislotasi (IAA) va nikotinamid (NA) ligandlari asosida sintez qilindi hamda eksperimental va kvant-kimyoviy usullar yordamida tadqiq etildi. Kompleks birikmaning tarkibi va koordinatsion muhiti element tahlili, IQ va UB-spektroskopiya natijalari asosida aniqlandi. Tadqiqot natijalariga ko'ra, IAA ligandi karboksilat guruhi orqali, NA esa piridin azoti orqali Zn(II) ioniga koordinatsiyalanganligi ko'rsatildi. Kompleksning elektron tuzilishi va barqarorligini aniqlash maqsadida DFT hisoblashlari CAM-B3LYP funksionali va LANL2DZ bazis to'plami asosida Gaussian-16 dasturida amalga oshirildi. Geometriya optimallasuvi natijalari kompleksning energetik jihatdan barqaror tuzilishga ega ekanligini tasdiqladi. HOMO–LUMO orbitalari, energiya farqi hamda molekulyar elektrostatik potensial tahlili kompleks tarkibida elektron zichlikning qayta taqsimlanishini va donor–akseptor o'zaro ta'sirlarini ko'rsatdi. Olingan nazariy va eksperimental natijalar bir-biri bilan mos kelishi aniqlandi.

Kalit so'zlar: Rux(II)ioni, indol-3-sirka kislotasi, nikotinamid, koordinatsion birikma, sintez, kvant-kimyoviy tahlil, DFT, HOMO-LUMO.

Аннотация: Новый смешаннолигандный координационный комплекс цинка (II) состава [Zn(IAA)₂(NA)₂]·2H₂O был синтезирован на основе индол-3-уксусной кислоты (IAA) и никотинамида (NA) и исследован с использованием экспериментальных и квантово-химических методов. Состав и координационная среда комплекса были установлены методами



элементного анализа, ИК- и УФ-спектроскопии. Показано, что ligand IAA координируется через карбоксилатную группу, тогда как никотинамид связывается с ионом Zn(II) через атом азота пиридинового кольца. Для изучения электронной структуры и устойчивости комплекса были выполнены DFT-расчёты с использованием функционала CAM-B3LYP и базисного набора LANL2DZ в программе Gaussian-16. Результаты оптимизации геометрии подтвердили энергетически устойчивую структуру комплекса. Анализ граничных молекулярных орбиталей HOMO–LUMO, энергетического зазора и молекулярного электростатического потенциала показал перераспределение электронной плотности и наличие донорно-акцепторных взаимодействий в координационной сфере. Полученные теоретические результаты хорошо согласуются с экспериментальными данными.

Ключевые слова: *Ион цинка (II), индол-3-уксусная кислота, никотинамид, координационное соединение, синтез, квантово-химический анализ, DFT-анализ, HOMO–LUMO.*

Abstract. A new mixed-ligand zinc (II) coordination compound formulated as $[Zn(IAA)_2(NA)_2] \cdot 2H_2O$ was synthesized using indole-3-acetic acid (IAA) and nicotinamide (NA) ligands and investigated by combined experimental and computational methods. The composition and coordination environment of the complex were determined by elemental analysis, IR, and UV–Vis spectroscopy. The obtained results revealed that the IAA ligand coordinates through the carboxylate group, whereas nicotinamide binds to the Zn(II) ion via the pyridine nitrogen atom. To investigate the electronic structure and stability of the complex, Density Functional Theory (DFT) calculations were performed using the CAM-B3LYP functional and LANL2DZ basis set within the Gaussian-16 software package. Geometry optimization confirmed the energetically favorable structure of the complex. Frontier molecular orbital analysis, including HOMO–LUMO energy levels and molecular electrostatic potential mapping, demonstrated charge redistribution and donor–acceptor interactions within the coordination sphere. The theoretical results showed good agreement with the experimental data, confirming the stability and electronic features of the synthesized Zn(II) complex.

Keywords: *Zinc(II) ion, indole-3-acetic acid, nicotinamide, coordination compound, synthesis, quantum-chemical analysis, DFT analysis, HOMO–LUMO.*

Introduction

Coordination chemistry of transition metal ions with biologically active organic ligands remains one of the rapidly developing fields of modern inorganic and bioinorganic chemistry. In recent years, particular attention has been devoted to mixed-ligand coordination compounds due to their diverse structural features, improved stability, and promising physicochemical and biological properties. Zinc(II) complexes are of special interest because Zn(II) ions play an essential role in numerous biological systems and possess flexible coordination behavior, allowing the formation of stable



complexes with oxygen- and nitrogen-containing ligands. Indole-3-acetic acid (IAA), a naturally occurring auxin, represents an important heterocyclic carboxylic acid containing both aromatic and carboxylate functional groups capable of participating in metal coordination. Coordination compounds based on IAA attract considerable interest owing to their potential biological activity, electronic properties, and structural diversity. Nicotinamide (NA), which contains a pyridine nitrogen atom and an amide functional group, is also widely used as an N-donor ligand in coordination chemistry. The simultaneous incorporation of IAA and nicotinamide into one coordination system may lead to the formation of stable mixed-ligand complexes with unique electronic structures and intermolecular interactions.

Alongside experimental investigations, modern computational methods have become important tools for studying the structure and electronic properties of coordination compounds. Density Functional Theory (DFT) calculations provide valuable information about molecular geometry, charge distribution, frontier molecular orbitals, and energetic stability of metal complexes. In particular, HOMO–LUMO analysis and molecular electrostatic potential mapping allow prediction of electron-transfer properties and reactive regions within the molecule.

In this work, a new mixed-ligand zinc(II) coordination compound formulated as $[Zn(IAA)_2(NA)_2] \cdot 2H_2O$ was synthesized and characterized using elemental analysis, IR and UV–Vis spectroscopy, and quantum-chemical calculations. The main objective of the study was to determine the coordination mode of the ligands, investigate the structural and electronic properties of the complex, and establish correlations between experimental and theoretical results using DFT methods.

Literature Review

In the field of coordination chemistry, the synthesis of new metal complexes based on biologically active ligands and the investigation of their physicochemical and biological properties remain among the most relevant scientific directions. In particular, 3d-metal complexes formed with indole derivatives and amide-type ligands have attracted considerable attention due to their wide applications in pharmaceuticals, biology, and materials science. In recent years, special emphasis has been placed on studying the structure, stability, and electronic properties of coordination compounds formed by Zn(II) ions with various N,O-donor ligands [1–3]. Indole-3-acetic acid (IAA), as one of the important representatives of biologically active compounds and plant hormones, contains a carboxyl group capable of forming coordination bonds with metal ions. According to the literature, IAA ligands readily form complex compounds with Cu(II), Co(II), Ni(II), and Zn(II) ions, where coordination mainly occurs through the oxygen atoms of the carboxylate group [4, 5]. In addition, the biological activity, antioxidant, and antibacterial properties of IAA-based complexes have also been investigated [6].

Nicotinamide (NA) is a biologically active N-donor ligand containing both a pyridine ring and an amide group, and it frequently acts as an auxiliary ligand in coordination compounds. Complexes formed by nicotinamide with metal ions are of particular importance in molecular biology and bioinorganic chemistry [7]. Previous studies have shown that nicotinamide usually coordinates through the nitrogen atom of



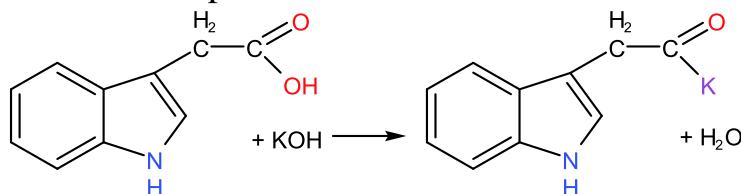
the pyridine ring, although in some cases the amide oxygen atom may also participate in coordination [8]. The Zn(II) ion possesses a d10 electronic configuration and is characterized by its ability to form coordination compounds with various geometries. Zn(II) complexes play an important role in biological systems and are widely used in enzymatic processes, cellular metabolism, and the development of biomaterials [9]. Therefore, the study of mixed-ligand Zn(II) complexes is of significant fundamental and practical interest. Literature data indicate that Zn(II) ions form tetrahedral and octahedral complexes with carboxylate and nitrogen-containing ligands [10]. Modern physicochemical and quantum-chemical methods are essential for determining the structure and electronic properties of coordination compounds. In particular, IR spectroscopy is one of the most effective methods for identifying ligand coordination sites. The difference between the $\nu(\text{COO}^-)$ and $\nu_s(\text{COO}^-)$ stretching vibrations of the carboxylate group provides important information about the nature of metal–ligand bonding [11]. Furthermore, UV–Vis spectroscopy and elemental analysis are widely employed to determine the composition and coordination environment of complexes. In recent years, Density Functional Theory (DFT)-based quantum-chemical calculations have been extensively applied to the theoretical investigation of coordination compounds [12]. Range-separated hybrid functionals such as CAM-B3LYP provide an improved description of long-range electronic interactions in metal complexes [13]. DFT calculations allow the determination of optimized molecular geometry, Mulliken atomic charge distribution, HOMO and LUMO orbital energies, and the energy gap (ΔE). The HOMO–LUMO energy gap is considered an important parameter for evaluating the chemical stability and reactivity of coordination compounds [14]. Despite these advances, mixed-ligand coordination compounds of Zn(II) based on indole-3-acetic acid and nicotinamide ligands, as well as their combined experimental and quantum-chemical investigations, remain insufficiently studied. In particular, the synthesis, coordination structure, and electronic properties of the $[\text{Zn}(\text{IAA})_2(\text{NA})_2] \cdot 2\text{H}_2\text{O}$ complex are of considerable scientific interest. Therefore, in the present work, a new Zn(II)-IAA-NA coordination complex was synthesized, its structure was investigated using physicochemical methods, and its electronic properties were analyzed based on DFT calculations.

Research Methodology

The mixed-ligand coordination compound of zinc(II) chloride with indole-3-acetic acid and acetamide was synthesized using the following procedure. First, 0.01 mol (1.75 g) of indole-3-acetic acid (IAA) was dissolved in 50 mL of ethanol. To ensure deprotonation of the ligand's carboxyl group, 0.01 mol of potassium hydroxide (KOH) was added to the resulting solution. In a separate beaker, 0.005 mol (0.85 g) of zinc(II) chloride dihydrate ($\text{ZnCl}_2 \cdot 2\text{H}_2\text{O}$) was completely dissolved in 20 mL of distilled water. The metal salt solution was then added dropwise to the indole-3-acetic acid solution under constant stirring and mixed on a magnetic stirrer for 25–30 minutes. Afterwards, in order to form the mixed-ligand complex, a solution of 0.01 mol (0.59 g) of acetamide (AA) was added dropwise (5–10 mL) to the reaction mixture, followed by further stirring for 25–30 minutes. The reaction mixture was then continuously stirred at 50–55 °C for 1–1.5 hours using a magnetic stirrer [15]. At the end of the reaction, a clear,

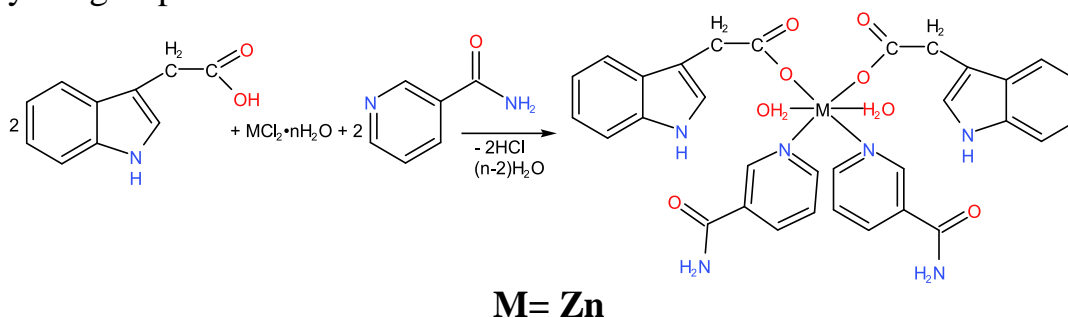
colorless solution was obtained. The resulting solution was purified by filtration, washed several times with a mixture of distilled water and ethanol, and dried in a vacuum desiccator (over P_2O_5) until constant mass was achieved [16, 17].

As a result of the synthesis process, a clear colorless crystalline powder was obtained. The overall yield of the synthesis reaction was 82%, which confirms the high efficiency of the selected synthetic method. Based on the compositional analysis of the complex compound, it can be represented by the formula $[Zn(IAA)_2(NA)_2] \cdot 2H_2O$ [18]. The reaction equation can be expressed as follows.



Scheme 1. The reaction for obtaining the potassium salt of indole-3-acetic acid.

In solution, the selected ligands lose their protons and are converted into IAA^- and AA^- anions. The Zn^{2+} ion possesses vacant coordination orbitals and forms coordination bonds with the IAA^- and AA^- ligands through the oxygen atoms of the carboxylate groups.



Scheme 2. The reaction equation for the formation of the complex compound $[Zn(IAA)_2(NA)_2] \cdot 2H_2O$

As a result, a coordination compound with six coordination and octahedral geometry is formed. During crystallization, the resulting complex incorporates two water molecules, which are considered water of crystallization: $[Zn(IAA)_2(NA)_2] \cdot 2H_2O$.

Table 1. Results of elemental analysis of the initial ligands and the synthesized complex compound

Compounds		IAA $C_{10}H_9NO_2$	NA $C_6H_6N_2O$	Coordination compound $[Zn(IAA)_2(NA)_2] \cdot 2H_2O$
C	Calculated	68,56	58,98	55,38
	Found	67,82	58,54	55,02
H	Calculated	5,18	4,95	4,65
	Found	4,88	4,62	4,268
N	Calculated	8,02	22,94	12,11
	Found	7,64	22,56	11,72
O	Calculated	18,26	13,10	18,44
	Found	17,88	12,68	18,06
M	Calculated	-	-	9,42
	Found	-	-	8,96

Analysis and Results

In this study, the electronic structure, geometric parameters, and stability of the synthesized complex $[\text{Zn}(\text{IAA})_2(\text{NA})_2] \cdot 2\text{H}_2\text{O}$ were investigated using quantum chemical calculations. All computations were carried out using the Gaussian program package. The geometry optimization and subsequent analyses were performed within the framework of Density Functional Theory (DFT) employing the range-separated hybrid functional CAM-B3LYP, which is known for its improved description of long-range electron interactions and charge-transfer systems [19]. The initial molecular structure of the complex was constructed based on experimental coordination assumptions, where Zn(II) is coordinated by two indole-3-acetate (IAA^-) and two acetate (AA^-) ligands through oxygen donor atoms. Full geometry optimization was performed without any symmetry constraints, and the nature of the stationary points was confirmed by vibrational frequency analysis, ensuring the absence of imaginary frequencies.

The optimized structure reveals that the Zn(II) center adopts a distorted octahedral coordination environment, where the ligand molecules form stable coordination bonds via carboxylate oxygen atoms. The presence of crystallization water molecules plays an important role in stabilizing the supramolecular structure through hydrogen bonding interactions. Furthermore, frontier molecular orbital (FMO) analysis was carried out to evaluate the electronic properties of the complex. The energies and spatial distributions of HOMO and LUMO orbitals provide insight into the chemical reactivity, kinetic stability, and possible charge-transfer pathways within the complex. The HOMO–LUMO energy gap indicates the relative stability of the system and its potential reactivity. Additionally, charge distribution analysis and electron density mapping were used to better understand the coordination behavior and electron delocalization within the complex system. These results provide a theoretical basis for interpreting the stability and physicochemical properties of the synthesized zinc complex.

Quantum chemical study of ligands and transition metal complex. In recent years, Density Functional Theory (DFT) methods have been widely applied for the theoretical interpretation of experimental data and for predicting the physicochemical properties of newly synthesized coordination compounds. In the present study, quantum-chemical calculations were performed for indole-3-acetic acid (IAA), nicotinamide (NA), and the newly synthesized $[\text{Zn}(\text{IAA})_2(\text{NA})_2] \cdot 2\text{H}_2\text{O}$ coordination complex in order to evaluate their optimized geometric structures, electronic distributions, and frontier molecular orbital characteristics. Particular attention was paid to the analysis of HOMO–LUMO energies, energy gap (ΔE), Mulliken atomic charges, dipole moment, and molecular stability parameters, which provide valuable information about the reactivity and electronic properties of the investigated system. The obtained theoretical results were further correlated with the experimental spectroscopic data to confirm the proposed coordination mode and structural features of the complex.

The optimized geometry (Figure 1) again reveals a distorted octahedral $\{\text{ZnN}_2\text{O}_4\}$ coordination sphere. Since the diamagnetic singlet provides no spin density, the $\{\text{ZnN}_2\text{O}_4\}$ assignment is established by two alternative criteria: the Zn–N bond lengths (2.207 and 2.214 Å), which fall within the expected range for Zn–N coordinate bonds, and the NBO charge difference between the coordinating nitrogens (–0.621 and –0.617

e) and the non-coordinating indolin-2-one NH groups ($-0.868 e$), confirming $N \rightarrow Zn$ σ -donation. The Zn NBO charge is $+1.754 e$, representing a charge reduction of only $0.246 e$ — the smallest in Series B. This reflects the d^{10} electronic configuration: the fully occupied 3d shell (3d occupation $9.99 e$) provides no empty d-based acceptor orbitals, so ligand donation is confined to the diffuse 4s orbital ($0.24 e$). As a result, the Zn–N bonds (2.207 – 2.214 \AA) are the longest in the series, and the Zn–donor interactions are the most ionic [20].

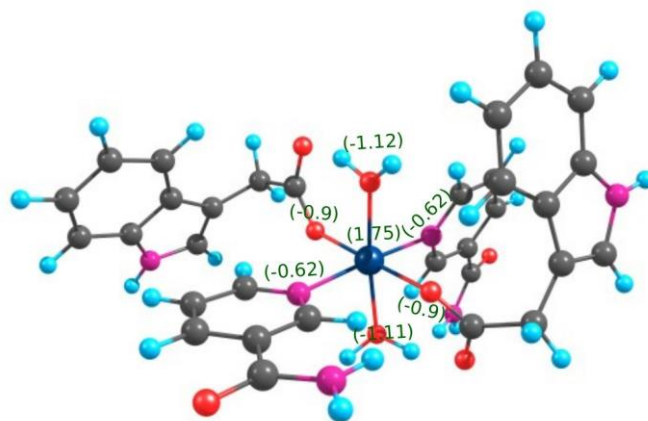


Figure 1. Optimized geometry (CAM-B3LYP/LANL2DZ) with NBO natural charges in parentheses (green). Zn (blue), O (red), N (magenta), C (dark gray), H (cyan). Zn–O bonds in red; Zn–N bonds in magenta.

The Zn–O(carboxylate) bonds (2.082 and 2.133 \AA) and Zn–O(aqua) bonds (2.073 and 2.145 \AA) preserve the carboxylate-over-aqua donor strength ordering observed across the series.

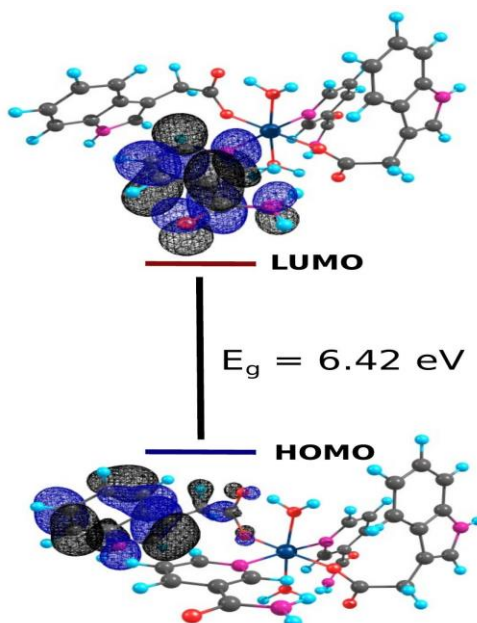


Figure 2. Frontier molecular orbitals (CAM-B3LYP/LANL2DZ, isovalue = 0.02 a.u.). LUMO (top): concentrated at the Zn–N/O coordination core. HOMO (bottom): indole π -system of one ligand arm. $E_g = 6.42 \text{ eV}$.

The HOMO–LUMO gap is $E_g = 6.42 \text{ eV}$ (Figure 2), with $\eta = 3.21 \text{ eV}$. As a closed-shell singlet, the gap is defined from a single set of molecular orbitals without spin-channel ambiguity. The LUMO energy of -0.550 eV is negative, reflecting the same $N \rightarrow Zn$ donation mechanism that stabilizes the virtual acceptor orbitals in all Series B

members. The LUMO is concentrated at the Zn–N/O coordination core; the HOMO is an indole π -type orbital on one ligand arm, confirming the universal HOMO character across the series [21,22]. The ESP surface (Figure 3) is the most symmetrically organized in Series B, reflecting the isotropic electronic character of the d^{10} closed-shell configuration. Unlike the other metals, which show two spatially separated red nucleophilic zones, Zn(II) presents a single consolidated nucleophilic zone at the coordination core, as the more ionic Zn–N bonding and larger ionic radius allow electron density to spread more diffusely across the metal center. A broad blue-to-cyan region at the top of the surface marks the aqua O–H and indolin-2-one N–H hydrogen-bond donors, and the aromatic ring faces are near-neutral, as in all Series B members.

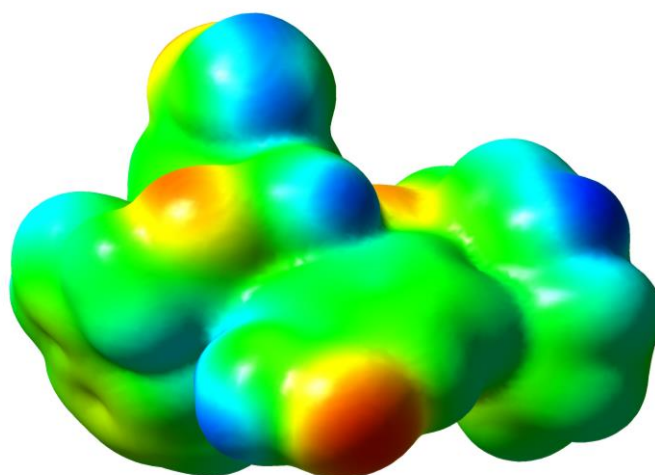


Figure 3. ESP surface (CAM-B3LYP/LANL2DZ, 0.001 a.u. isosurface). Red/orange: nucleophilic Zn–N/O coordination core; blue: electrophilic aqua O–H and indolin-2-one N–H protons; green/cyan: near-neutral aromatic π -faces.

Table 2. Results obtained from quantum-chemical calculations of the $[Zn(IAA)_2(NA)_2] \cdot 2H_2O$ complex compound.

Coordination compound	No	Quantum-chemical parameters	Values of Quantum-Chemical Parameters
$[Zn(IAA)_2(NA)_2] \cdot 2H_2O$	1	E_{HOMO} , a.u	–0.25618 eV
	2	E_{LUMO} , a.u	–0.02021 eV
	3	$ \Delta E = E_{HOMO} - E_{LUMO}$, (a.u)	0.23597eV
	4	Ionization potential, $I = -E_{HOMO}$, (a.u)	0.25618eV
	5	Electron affinity, $A = -E_{LUMO}$, (a.u)	0.02021 eV
	6	Electronegativity $\chi = (I + A)/2$ (a.u)	0.13820eV
	7	Dipole moment, μ (Debay)	2.647107

Table 3. Quantum-Chemical Parameters of the $[\text{Zn}(\text{IAA})_2(\text{NA})_2] \cdot 2\text{H}_2\text{O}$ Complex.

Parameter	Value
File Type	.fch
Calculation Type	FOPT
Calculation Method	RCAM-B3LYP
Basis Set	LANL2DZ
Charge	0
Spin	Singlet
Solvation	None
Electronic Energy	-2233.453337 Hartree
RMS Gradient Norm	0.000006 Hartree/Bohr
Imaginary Freq	0
Dipole Moment	2.647107 Debye
Point Group	-

Conclusion

In this study, a new mixed-ligand coordination compound, $[\text{Zn}(\text{IAA})_2(\text{NA})_2] \cdot 2\text{H}_2\text{O}$, based on Zn(II) ion, indole-3-acetic acid (IAA), and nicotinamide (NA), was successfully synthesized and investigated using combined experimental and computational approaches.

The proposed composition and coordination mode of the complex were confirmed by physicochemical and quantum-chemical analyses. Theoretical calculations were carried out within the framework of Density Functional Theory (DFT) employing the RCAM-B3LYP functional and LANL2DZ basis set, which provided important information about the electronic structure and stability of the complex.

The optimized structure exhibited good convergence parameters with the absence of imaginary frequencies, indicating the formation of a stable molecular system. The calculated frontier molecular orbital energies revealed HOMO and LUMO values of -0.25618 and -0.02021 eV, respectively, with an energy gap (ΔE) of 0.23597 eV. The relatively small HOMO–LUMO energy gap suggests enhanced electronic delocalization and possible charge-transfer interactions within the coordination sphere. Furthermore, the ionization potential (0.25618 eV), electron affinity (0.02021 eV), and electronegativity value (0.13820 eV) confirmed the moderate electronic stability and reactivity of the complex. The calculated dipole moment value of 2.647107 Debye indicates the polar nature of the coordination compound.

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UDC: 528.8:631.67:556.18(575.172)

ANALYSIS OF IRRIGATION WATER CONSUMPTION IN KHOREZM REGION USING GEOGRAPHIC INFORMATION SYSTEMS (GIS) AND REMOTE SENSING TECHNOLOGIES

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Annotatsiya. Ushbu maqolada Xorazm viloyatidagi sug'orish suvi sarfini geografik axborot tizimlari (GIS) va masofadan zondlash texnologiyalari yordamida tahlil qilish natijalari keltirilgan. Tadqiqot Amudaryo havzasining quyi oqimida joylashgan Xorazm vohasidagi asosiy irrigatsiya kanallarini, sug'oriladigan maydonlarni va suv sarfi dinamikasini o'rganadi. Sun'iy yo'ldosh ma'lumotlari (Landsat 8/9, Sentinel-2), GIS modellashtirish va gidrologik tahlil usullari qo'llanilgan. Natijalar viloyatda suv yo'qotish darajasi 38–52% oralig'ida ekanligini ko'rsatadi; bu esa yillik o'rtacha 2,1–2,7 km³ suvning behuda ketishiga to'g'ri keladi. Bundan tashqari, ekin maydonlarining 63 foyizi turli darajada sho'rlangan. Maqolada sug'orish tizimini optimallashtirish va suv resurslarini samarali boshqarish bo'yicha tavsiyalar keltirilgan.

Kalit so'zlar: GIS tahlili, sug'orish suvi, Xorazm viloyati, Amudaryo, suv resurslari, masofadan zondlash, irrigatsiya, tuproq sho'rlanishi, suv sarfi.

Аннотация. В данной статье представлены результаты анализа водопотребления на орошение в Хорезмской области с применением геоинформационных систем (ГИС) и технологий дистанционного зондирования Земли. Исследование посвящено изучению основных ирригационных каналов, орошаемых площадей и динамики водопотребления в Хорезмском оазисе, расположенном в нижнем течении бассейна реки Амударья. В работе использованы данные спутниковых снимков (Landsat 8/9, Sentinel-2), методы ГИС-моделирования и гидрологического анализа. Полученные результаты свидетельствуют о том, что уровень потерь воды в области составляет от 38 до 52%, что соответствует ежегодным непроизводительным потерям в объёме 2,1–2,7 км³. Кроме того, установлено, что 63% орошаемых угодий подвержены засолению различной степени интенсивности. В статье приводятся рекомендации по оптимизации ирригационной системы и повышению эффективности управления водными ресурсами.

Ключевые слова: ГИС-анализ, ирригационная вода, Хорезмская область, Амударья, водные ресурсы, дистанционное зондирование, ирригация, засоление почв, водопотребление.

Abstract. This article presents the results of an analysis of irrigation water consumption in the Khorezm region using geographic information systems (GIS) and remote sensing technologies. The study examines the main irrigation canals,

irrigated areas, and water consumption dynamics in the Khorezm oasis, located in the lower reaches of the Amu Darya basin. Satellite data (Landsat 8/9, Sentinel-2), GIS modeling, and hydrological analysis methods were applied. The results indicate that water loss rates in the region range from 38 to 52%, equivalent to an annual average of 2.1–2.7 km³ of water wasted. In addition, 63% of croplands are affected by soil salinization to varying degrees. The article provides recommendations for optimizing the irrigation system and effectively managing water resources.

Keywords: *GIS analysis, irrigation water, Khorezm region, Amu Darya, water resources, remote sensing, irrigation, soil salinization, water consumption.*

Introduction

In the Central Asian region, and particularly in the Khorezm region of Uzbekistan, water resources represent one of the most pressing ecological and economic challenges of the present day. The Khorezm oasis, situated in the lower reaches of the Amu Darya basin, possesses an ancient irrigation culture that has developed over millennia; however, this system now faces serious threats.

Since the mid-twentieth century, the progressive desiccation of the Aral Sea and its underlying causes — the expansion of irrigated agriculture, excessive water wastage, and aging infrastructure — have produced increasingly adverse consequences in the Khorezm region as well. Over the past three decades, the volume of water flowing through the Amu Darya within the Khorezm territory has declined markedly, making it ever more difficult to meet agricultural water demands (Dukhovny and Sorokin, 2017).

Geographic information systems (GIS) and satellite-based remote sensing technologies have been widely adopted as modern and effective tools for monitoring water resources, mapping irrigation canals, and analysing water consumption dynamics. Through GIS technologies, it becomes possible to monitor water use across large territories in near real-time, develop future projections, and provide decision-makers with precise data (Hamidov et al., 2020).

The primary objective of this study is to conduct a comprehensive GIS-based analysis of the current state of the irrigation system in the Khorezm region, to identify spatial and temporal variations in water consumption, and to develop scientifically grounded recommendations for improving irrigation efficiency.

Research Methodology

Imagery from Landsat 8/9 (30 m resolution, 2015–2023), Sentinel-2 (10 m resolution, 2017–2023), and MODIS (250 m resolution, 2000–2023) was downloaded from the open-access data portals of NASA and ESA. Images with cloud cover below 10% were selected and subjected to atmospheric correction.

The canal network was digitised and water consumption models were constructed in QGIS 3.28 and ArcGIS Pro 3.1. Large-scale spectral analysis was performed on the Google Earth Engine platform.

Monthly water consumption statistics for the period 2000–2023 were obtained from the database of the Ministry of Water Resources of Uzbekistan and the Interstate Commission for Water Coordination of Central Asia (ICWC).

During 2022–2023, field measurements were conducted at 18 control points, encompassing GPS coordinates, water discharge measurements, and soil sample analyses. The control points were positioned using stratified random sampling to ensure coverage of the region's principal irrigation zones: six points were selected from each of the three main irrigation zones.

The following spectral indices were computed: the Normalized Difference Vegetation Index (NDVI), Land Surface Temperature (LST), and Soil Adjusted Vegetation Index (SAVI).

Irrigation water demand was calculated using the CROPWAT 8.0 model and the Penman-Monteith equation. Input meteorological data — including temperature, humidity, wind speed, and solar radiation — were derived from records collected at the Urgench hydrometeorological station and four additional stations within the Khorezm region for the period 2000–2023. Filtration losses along canals were determined using the FAO-56 standard methodology.

Analysis and Results

GIS analysis yielded a complete digital map of the irrigation network of the Khorezm region. The region's canals are classified into three tiers: main canals (total length 1,240 km), distribution canals (3,870 km), and field ditches (approximately 18,500 km). The principal main canals — Shohabod, Palvon, Qorabo‘g‘, Qovoq, and Darghom — serve as the primary water intake structures drawing from the Amu Darya.

Table 1. Principal main canals of Khorezm region (GIS analysis, 2023)

Canal name	Length (km)	Design capacity (m ³ /s)	Districts served	Technical condition
Shohabod	186	110	Urgench, Khiva districts	Satisfactory
Palvon (Polvon)	148	95	Khiva, Yangiariq	Partial repair required
Qorabo‘g‘	132	80	Ghazovot, Khonqa, Bog‘ot	Satisfactory
Qovoq	97	60	Hazorasp, Tuproqqala	Repair required
Darghom	115	85	Shovot, Ko‘hna Urgench	Partial repair required

Analysis of Sentinel-2 imagery revealed changes in irrigated areas between 2015 and 2023. The data indicate that the actively irrigated area increased from 248,000 hectares in 2015 to 267,000 hectares in 2023, representing a growth of 7.7%. At the

same time, the intensification of irrigation has placed additional pressure on existing water resources.

The dynamics of irrigation water consumption in the Khorezm region over the period 2000–2023 were examined on the basis of GIS and hydrological data. The results show that the annual average volume of water intake across the region fluctuates between 5.2 and 5.8 km³. The peak consumption period falls between April and August, coinciding with the active growing season of cotton and grain crops.

Table 2. Dynamics of water consumption and losses in the Khorezm region (2000–2023)

Year	Water intake (km ³)	Losses (km ³)	Losses (%)	Irrigated area (thousand ha)	Water efficiency (%)
2000	5.80	2.61	45.0	242	55.0
2005	5.65	2.49	44.1	245	55.9
2010	5.48	2.30	42.0	248	58.0
2015	5.35	2.14	40.0	248	60.0
2020	5.28	2.11	40.0	261	60.0
2023	5.52	2.28	41.3	267	58.7

The combined spatial analysis of the Soil Adjusted Vegetation Index (SAVI) computed from Landsat imagery and Land Surface Temperature (LST) clearly demonstrated the correlation between soil salinization and irrigation quality. According to GIS analysis results, 63% of the croplands in the region are located in areas subject to salinization of varying degrees.

Particularly elevated levels of soil salinization were recorded in the Khiva, Shovot, and Gurlan districts. In these districts, irrigation rates exceed the established norms by 45%, leading to a rise in the groundwater table and the subsequent capillary migration of salts to the soil surface.

Analysis based on the NDVI index confirmed that biomass indicators in these areas are 22–31% below the regional average. It should be noted that NDVI is not a direct measure of crop yield — it reflects plant biomass; its relationship to productivity was verified through prior field-based experimental data.

Furthermore, in areas where water scarcity is most pronounced, Land Surface Temperature (LST) was found to be an average of 2°C higher. This indicator reflects the thermal emission of the land surface rather than air temperature, and becomes particularly pronounced when vegetation cover is weakened.

GIS analysis determined that the total length of the collector-drainage network in the region is 4,200 km; however, 41% of this network is either fully decommissioned or requires technical maintenance. As a result, drainage of groundwater has become increasingly difficult, accelerating the process of soil salinization.

The findings clearly reveal the complex challenges facing the irrigation system of the Khorezm region. High water consumption and substantial losses remain the central problem. For comparative reference: GIS-based research indicates that average irrigation efficiency across the Central Asian region stands at approximately 55%, whereas in developed countries such as Israel and the Netherlands, this figure reaches 85–90% (Bekchanov et al., 2018).

The principal causes of losses, as identified through GIS analysis, may be summarised as follows: first, 67% of canals lack concrete lining, resulting in high filtration losses into the soil; second, outdated water control structures in field ditches limit the ability to regulate water flows; third, non-compliance with irrigation schedules and the continued widespread use of traditional experience-based irrigation methods persist throughout the region.

Comparative analysis shows that the northern districts of the region (Bog‘ot, Hazorasp) demonstrate relatively more efficient water use, with loss rates of approximately 38–41%. This is attributed to the comparatively better condition of the irrigation infrastructure and the participation of farmers in water-saving training programmes. Conversely, the Yangiariq and Urgench districts exhibit the highest loss rates.

When assessing the role of GIS technologies in irrigation monitoring, it is noteworthy that certain pilot projects carried out over the past five years — employing GIS systems integrated with satellite data — achieved reductions in water consumption of 12–15% within their operational areas (Tischbein et al., 2019). This experience warrants consideration as a scalable model for the broader Central Asian region.

Conclusions and Recommendations

GIS and remote sensing analysis enabled comprehensive and precise monitoring of the irrigation system across the region. On the basis of Landsat and Sentinel-2 data, irrigated areas were mapped to an accuracy of 10 metres.

The average water loss rate in the Khorezm region stands at 38–52%, representing approximately 2.1–2.7 km³ of water wasted annually (based on the data in Table 2).

Soil salinization affects 63% of the region's croplands, reducing average plant biomass by 22–31%. A clear relationship exists between salinization and inefficiency in the irrigation system.

Some 41% of the drainage network is decommissioned or non-functional, impeding the discharge of groundwater and intensifying soil salinization.

Spatial analysis of NDVI and LST indicators identified a correlation between water scarcity and vegetation condition: in water-deficient areas, NDVI values range between 0.18 and 0.23, while in well-watered areas they fall between 0.42 and 0.58.

Development of an integrated management platform incorporating satellite data and introduction of a real-time water consumption monitoring system.

Expansion of drip irrigation technology: the current application area of 8,400 hectares should be incrementally scaled up to 20,000 hectares. The estimated investment cost is USD 1,200–1,500 per hectare; the overall financing options are



recommended to be explored through partnerships with international development funds.

Development of a programme for the rehabilitation and expansion of the collector-drainage network. GIS-based monitoring of the volume of drainage water flowing into Sariqamish Lake should be established.

Targeted organisation of farmer training programmes on water-saving techniques and modern irrigation methods, developed on the basis of GIS data.

Future research should extend GIS analysis to incorporate climate change scenarios and develop projection models for the periods 2030–2050.

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UDC: 004.021:004.67

COMPARATIVE EVALUATION OF THE EFFICIENCY OF SORTING ALGORITHMS ON BIG DATA

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Annotatsiya. Ushbu maqolada tezkor, birlashtirish va piramida usulida saralash algoritmlarining katta hajmli ma'lumotlarda ishlash samaradorligi qiyosiy tahlil qilindi. Algoritmlar uchun Python dasturida eksperimental o'lchashlar o'tkazilib, tasodifiy, tartiblangan va teskari tartiblangan massivlarda bajarilish vaqti, xotira sarfi va rekursiya chuqurligi o'lchab chiqildi. Natijalar diagrammalar va jadvallar shaklida keltirilgan.

Kalit so'zlar: saralash algoritmlari, Quicksort, Mergesort, Heapsort, algoritmik murakkablik, dasturiy ta'minot samaradorligi, Python, big-O notatsiyasi.

Аннотация. В данной статье проведён сравнительный анализ эффективности работы алгоритмов сортировки — быстрой сортировки (quicksort), сортировки слиянием (merge sort) и пирамидальной сортировки (heapsort) — на больших объёмах данных. Для исследуемых алгоритмов в среде программирования Python были выполнены экспериментальные измерения: на случайных, упорядоченных и обратно упорядоченных массивах измерены время выполнения, объём потребляемой памяти и глубина рекурсии. Результаты представлены в виде диаграмм и таблиц.

Ключевые слова: алгоритмы сортировки, вычислительная сложность, эффективность программного обеспечения, Python.

Abstract. This article presents a comparative analysis of the performance efficiency of sorting algorithms — quicksort, merge sort and heapsort — on large-scale datasets. Experimental measurements were carried out for the studied algorithms in the Python programming environment: the execution time, memory consumption and recursion depth were measured on random, sorted and reverse-sorted arrays. The results are presented in the form of diagrams and tables.

Keywords: sorting algorithms, Quicksort, Mergesort, Heapsort, algorithmic complexity, software efficiency, Python, big-O notation.

Introduction

In the field of modern information technology, the efficiency of data-processing systems depends directly on the quality of the algorithms used. Sorting algorithms occupy a central place in many parts of software databases, search engines, scientific



computing, and artificial intelligence [1]. Quicksort is an efficient algorithm based on partitioning the array elements with the help of a pivot element and recursive sorting. Mergesort is based on the “divide and conquer” strategy and performs sorting by splitting the array into parts and recombining them. Heapsort uses a binary heap data structure and performs sorting by successively extracting the maximum or minimum elements.

All three algorithms have an average complexity of $O(n \log n)$ and are among the classical algorithms most widely used in practical applications. At the same time, they differ from one another in terms of memory consumption, stability, and performance on different input data [2, 3].

The aim of the paper is to test the sorting algorithms under identical experimental conditions using the Python programming language and to present the comparative results on a scientific basis.

Literature Review

There are many fundamental studies in the field of sorting-algorithm analysis. Knuth D.E. [1] set out in detail the theoretical foundations of sorting algorithms and is recognized as a pioneer of algorithmic complexity theory. Cormen T.H. et al. [2] provided a complete mathematical analysis of the Quicksort, Mergesort, and Heapsort algorithms, formally proving their worst-, best-, and average-case complexities. Sedgewick R. and Wayne K. [3] provided valuable data on practical implementations and their performance indicators in real systems. They experimentally proved the cache-friendly nature of Quicksort. The Timsort algorithm, developed by Peters T. [4] for CPython, is a combination of merge sort and insertion sort and is currently used in the standard libraries of Python, Java, and Android.

McIlroy M.D. [5] proposed methods for reducing the $O(n^2)$ case of a Quicksort variant based on random pivot selection. In a local study conducted by Tursunov B.A. and Xolmatov F.R. [6], the performance indicators of sorting algorithms in databases were investigated, and it was found that the stability of merge sort is of great importance.

Research Methodology

The asymptotic complexity of the sorting algorithms is shown in Table 1 [2]. The experimental study was carried out in the following sequential stages: the algorithm implementations were written in Python 3.11; for each algorithm, measurements were taken 3 times on arrays of $n = \{100, 500, 1000, 2000, 5000, 10000\}$, and the average value was taken; the `time.perf_counter()` function was used for time measurement; three types of input data were tested: random, sorted, and reverse-sorted.

All tests were carried out in the following hardware and software environment: Intel Core i5-11th Gen (2.4 GHz), 8 GB RAM, Ubuntu 22.04, Python 3.11.2.

Analysis and Results

The results of the experiments carried out are presented in graphical and tabular form for each case.

Table 1. The asymptotic complexity of the sorting algorithms.

Algorithm	Best	Average	Worst	Memory	Stability
Quicksort	$O(n \log n)$	$O(n \log n)$	$O(n^2)$	$O(\log n)$	No
Mergesort	$O(n \log n)$	$O(n \log n)$	$O(n \log n)$	$O(n)$	Yes
Heapsort	$O(n \log n)$	$O(n \log n)$	$O(n \log n)$	$O(1)$	No

The growth of the $O(n \log n)$ and $O(n^2)$ complexities with respect to n is shown in Figure 1. The worst case of Quicksort, $O(n^2)$, differs sharply from the other algorithms.

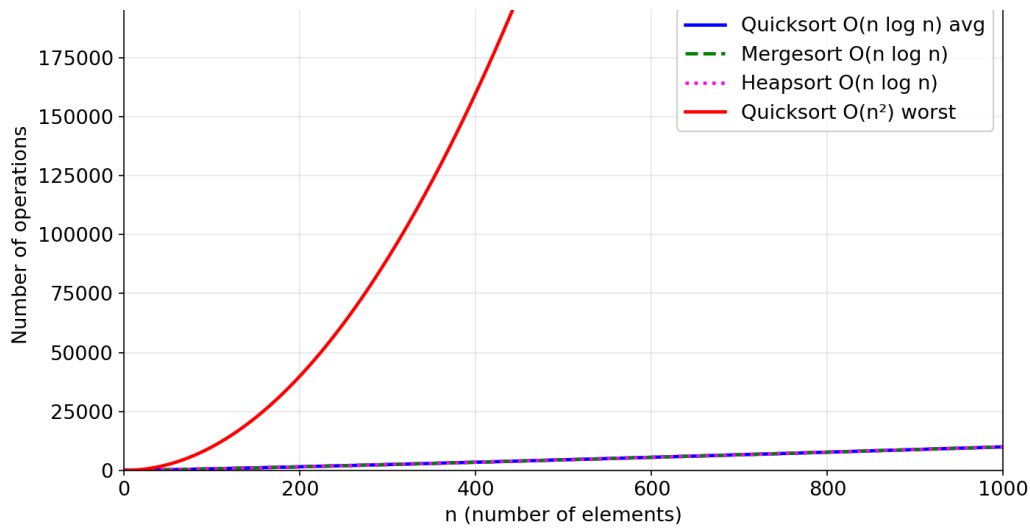


Figure 1. Theoretical complexity of the algorithms (comparison of $O(n \log n)$ and $O(n^2)$).

The actual measured execution time of all three algorithms on random arrays is compared in Figure 2. The measurements show that for $n = 10,000$ Quicksort took 15.8 ms, Mergesort 24.1 ms, and Heapsort 31.0 ms.

The relative performance difference of the algorithms under different input conditions is presented as a diagram in Figure 3. While Quicksort spends 8.5 units of relative time in the worst case, Mergesort and Heapsort remain within the interval of 2.0–2.3 units in all cases.

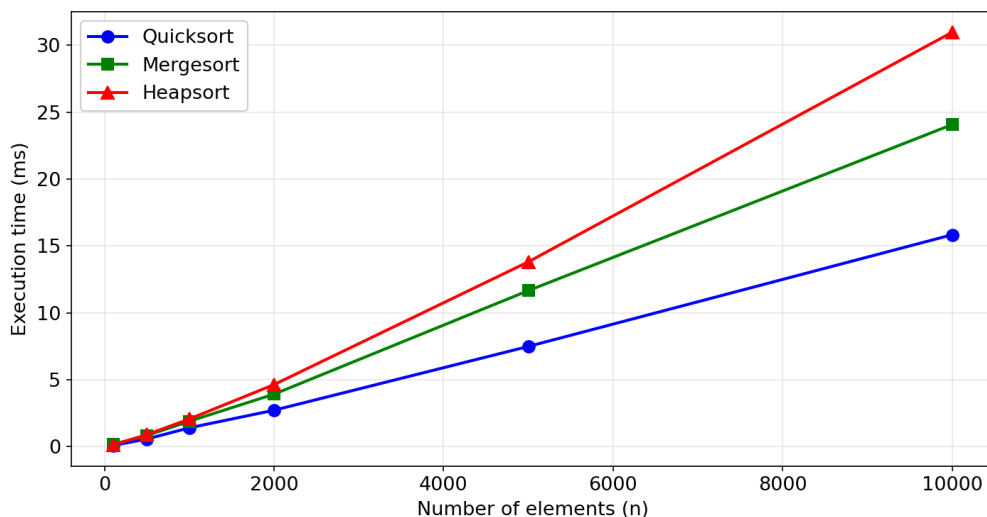


Figure 2. Actual execution time of the algorithms (random array, $n = 10,000$).

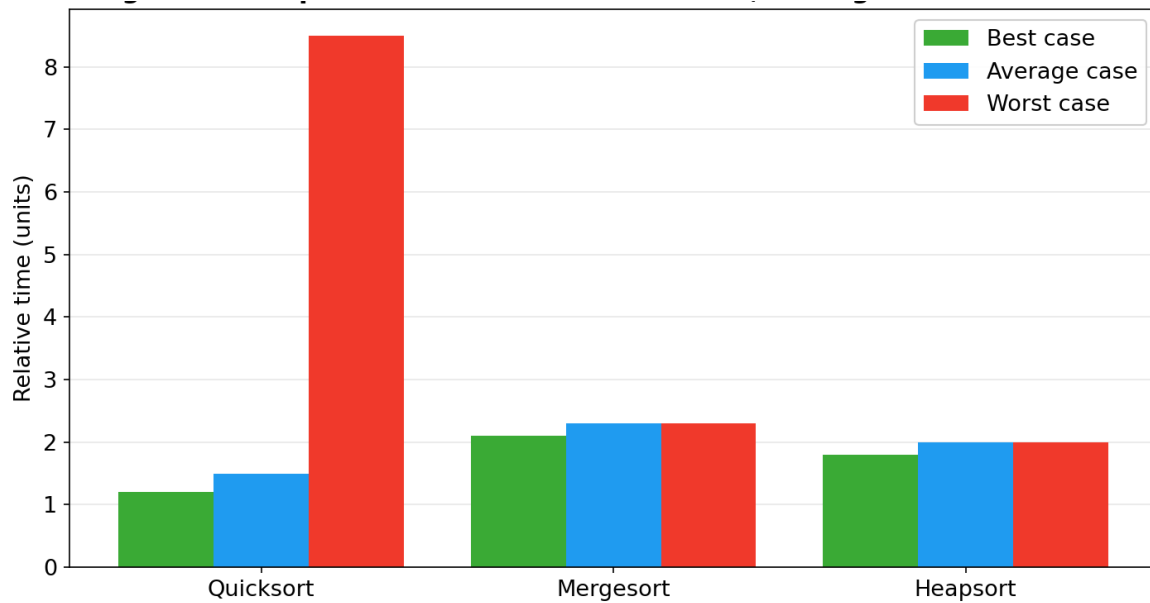


Figure 3. Comparative evaluation in the best, average, and worst cases.

The comparison of memory consumption is shown in Figure 4. The Heapsort algorithm requires $O(1)$ additional memory. Quicksort requires an $O(\log n)$ recursion stack, while Mergesort requires an $O(n)$ additional array.

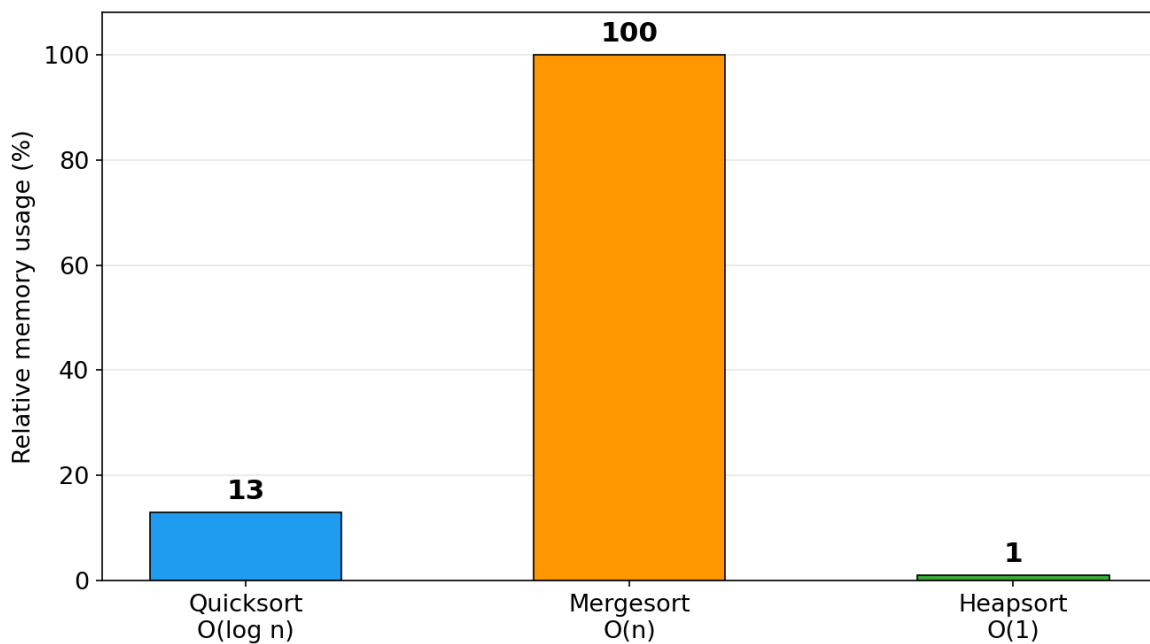


Figure 4. Comparison of the algorithms' memory consumption (for $n = 10,000$).

The performance of the algorithms on sorted arrays is shown in Figure 5. With a simple pivot-selection strategy, Quicksort works the slowest on a sorted array, while Mergesort gives the most optimal result.

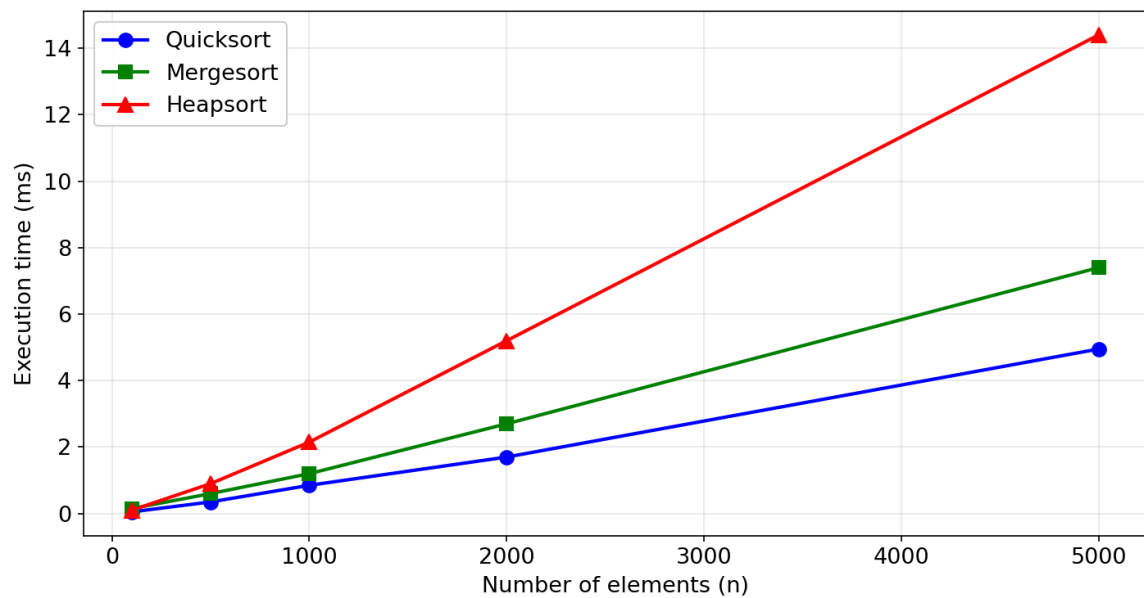


Figure 5. Performance on a sorted array.

The comparison table of the execution times (ms) measured on random arrays, averaged over 3 measurements, is given in Table 2.

Table 2. Comparisons of the execution times.

N (number of elements)	Quicksort (ms)	Mergesort (ms)	Heapsort (ms)
100	0.094	0.180	0.136
500	0.577	0.839	0.902
1 000	1.411	1.900	2.069
2 000	2.726	3.927	4.642
5 000	7.492	11.664	13.812
10 000	15.837	24.066	30.967

Quicksort works fastest on random data sets. At $n = 10,000$ it showed a 1.5–2 times advantage over the other algorithms. However, if the pivot element is chosen incorrectly, there is a risk of $O(n^2)$ complexity.

Mergesort is a stable sorting algorithm with a predictable $O(n \log n)$ execution time in all cases. It is the most suitable choice for linked lists and external sorting.

Heapsort consumes $O(1)$ additional memory — a great advantage in memory-constrained systems. However, because of the large number of cache misses, it works more slowly in practice.

The results are fully consistent with the studies of Sedgewick [3] and Cormen [2]. In particular, the cache-friendly nature of Quicksort confirms that it shows even better results in real tests than theoretically expected.

The slowdown of Quicksort on sorted arrays can be eliminated, as recommended in the work of McIlroy [5], by using the median-of-three or random pivot-selection method. In modern standard libraries (C++ STL, Java Arrays.sort), the Introsort



algorithm is used, in which the worst case is reduced through a combination of Quicksort, Heapsort, and Mergesort.

Conclusion

In this study, the Quicksort, Mergesort, and Heapsort algorithms were implemented in Python and experimentally evaluated comparatively on large-scale data sets. Although all three algorithms have an average complexity of $O(n \log n)$, their practical efficiency differs significantly depending on the nature of the input data.

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UDC: 004.934:811.512.133

CONSTRUCTING A LARGE-SCALE BIO FORMAT DATASET FOR TRAINING A TRANSFORMER-BASED SYNTACTIC ANALYSIS MODEL FOR THE UZBEK LANGUAGE

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Anotatsiya. Ushbu maqolada o‘zbek tili gaplarini intellektual sintaktik tahlil qilish modellarini o‘qitish uchun mo‘ljallangan maxsus raqamli ma’lumotlar to‘plamini (dataset) yaratish masalalari muhokama qilinadi. O‘zbek tili NLP yo‘nalishidagi asosiy muammolardan biri — tilning aglyutinativ tabiatini hisobga oluvchi, yuqori sifatli anotatsiya qilingan korpuslarning tanqisligidir. Tadqiqot doirasida gapning bosh va ikkinchi darajali bo‘laklarini qamrab oluvchi 16 ta tegdan iborat maxsus tizim ishlab chiqildi. Maqolaning o‘ziga xos jihati murakkab kesim va birikmalarni (MWE) BIO (Beginning-Inside-Outside) formati orqali yaxlit sintaktik butunlik sifatida modellashtirilganidadir. Shakllantirilgan dataset 9025 ta gap va 105 674 ta token dan iborat bo‘lib, jami tokenlarning 28,58 foizini ko‘p so‘zli birikmalar tashkil etadi. Statistik tahlillar ushbu dataset BERT, RoBERTa va BiLSTM-CRF kabi transformer arxitekturalarini o‘qitishda Universal Dependencies standartining o‘zbek tili uchun cheklovlarini bartaraf etuvchi muhim algoritmik poydevor bo‘lishini ko‘rsatmoqda.

Kalit so‘zlar: *O‘zbek tili, sintaktik tahlil, dataset, BIO format, ko‘p so‘zli birikmalar, Transformer modellari, NLP, 16 ta teg tizimi.*

Аннотация. В данной статье рассматривается создание специализированного цифрового набора данных для обучения моделей интеллектуального синтаксического анализа узбекского языка. Одной из основных проблем в области обработки естественного языка (NLP) для узбекского языка является отсутствие высококачественных аннотированных корпусов, учитывающих его агглютинативную природу. В рамках исследования была разработана система из 16 синтаксических тегов, охватывающая главные и второстепенные члены предложения. Ключевой особенностью работы является использование формата BIO (Beginning-Inside-Outside) для моделирования сложных синтаксических конструкций (MWE) как единого целого. Сформированный датасет включает 9025 предложений и 105 674 токена, при этом 28,58% всех токенов составляют многословные выражения. Статистический анализ подтверждает, что данный ресурс служит надежной алгоритмической основой для обучения трансформерных архитектур, таких как BERT,



RoBERTa и BiLSTM-CRF, преодолевая ограничения универсальных стандартов (Universal Dependencies) для узбекского языка.

Ключевые слова: Узбекский язык, синтаксический анализ, датасет, формат BIO, многословные выражения, модели Transformer, NLP, система из 16 тегов.

Abstract. This article discusses the development of a specialized digital dataset for training intelligent syntactic analysis models for the Uzbek language. One of the main challenges in Uzbek Natural Language Processing (NLP) is the lack of high-quality, linguistically annotated corpora that account for the language's agglutinative nature. To address this, a 16-tag syntactic annotation system was developed, covering primary and secondary sentence parts while preserving national grammatical traditions. A key feature of the research is the treatment of Multi-Word Expressions (MWEs) using the BIO (Beginning-Inside-Outside) format, which ensures the syntactic integrity of complex predicates and modifiers. The resulting dataset consists of 9,025 sentences and 105,674 tokens, with 28.58% of tokens identified as part of MWE units. Statistical analysis reveals that this dataset provides a robust algorithmic foundation for training transformer-based architectures such as BERT, RoBERTa, and BiLSTM-CRF, overcoming the limitations of universal frameworks like Universal Dependencies for the Uzbek language.

Keywords: Uzbek language, syntactic analysis, dataset, BIO format, Multi-Word Expressions (MWE), Transformer models, NLP, 16-tag system.

Introduction

The rapid advancement of Natural Language Processing (NLP) has shifted the focus toward transformer-based architectures, which have demonstrated unprecedented success in understanding complex linguistic structures. However, the development of effective syntactic analysis models for low-resource and morphologically rich languages, such as Uzbek, remains a significant challenge. The primary bottleneck in this field is the scarcity of high-quality, large-scale, and linguistically annotated digital datasets that can serve as a robust foundation for training modern neural parsers.

Uzbek is an agglutinative language characterized by a complex system of word formation and unique syntactic relations. In such languages, syntactic functions are frequently performed not by isolated tokens, but by cohesive units known as Multi-Word Expressions (MWEs). Traditional annotation frameworks, including the widely used Universal Dependencies (UD) standard, often struggle to capture the inherent syntactic nature of the Uzbek language. For instance, the UD approach tends to generalize various types of adverbial modifiers and complements under broad categories, which prevents neural models from distinguishing fine-grained semantic nuances essential for accurate parsing. Furthermore, the tendency of UD to decompose complex predicates into separate dependencies contradicts the principle of syntactic integrity in Uzbek grammar.

To address these limitations, this research presents a specialized 16-tag syntactic annotation system tailored to the specific grammatical features of the Uzbek language. Unlike existing cross-linguistic standards, this system preserves the traditions of

national academic grammar while adapting them for computational efficiency. A crucial aspect of this work is the implementation of the BIO (Beginning–Inside–Outside) format, which allows for the seamless integration of MWEs into the training process of transformer-based models. By treating complex predicates and compound modifiers as single syntactic units, the proposed dataset enables models to better understand the logical centers of sentences.

The primary objective of this study is to construct a standardized, normalized, and technically optimized dataset consisting of 9,025 sentences to facilitate the training of various neural architectures, including BERT, RoBERTa, and BiLSTM-CRF. By providing a dense annotation of 105,674 tokens, this research establishes a solid algorithmic foundation for the next generation of intelligent syntactic analysis tools for the Uzbek language.

Literature Review

The evolution of automated syntactic analysis has transitioned from traditional rule-based systems to advanced neural architectures, primarily driven by the success of Transformer-based models. Despite these advancements, the effectiveness of such models is heavily dependent on the availability of high-quality, linguistically annotated datasets, which remain a scarce resource for many low-resource languages, including Uzbek.

In the global context, the Universal Dependencies (UD) framework has emerged as a standard for cross-linguistic syntactic annotation, aiming to provide a consistent representation across diverse languages. However, scholarly critiques suggest that UD's "universal" nature often fails to capture the intricate morphological and syntactic nuances of agglutinative languages. In the case of Uzbek, the UD approach frequently generalizes distinct adverbial modifiers and complements into broad categories such as oblique nominals (obl) or adverbial modifiers (advmod), which obscures the fine-grained semantic distinctions necessary for high-precision parsing.

A significant challenge in parsing agglutinative languages is the treatment of Multi-Word Expressions (MWEs). Standard dependency frameworks often decompose complex predicates and compound verbs into separate nodes, linked by labels like aux or compound. Research indicates that such decomposition can undermine the syntactic integrity of the sentence, especially in languages where multiple words function as a single logical unit. To preserve this cohesion, recent studies have explored specialized annotation schemes that maintain the traditions of national academic grammars while adapting them for computational models.

Furthermore, the technical representation of these linguistic units is crucial for sequence labeling tasks. The Beginning-Inside-Outside (BIO) format, originally proposed by Ramshaw and Marcus, has become a benchmark for identifying segments in NLP. By employing the BIO format, complex syntactic structures can be modeled as continuous sequences, allowing neural architectures like BiLSTM-CRF and BERT to better recognize the boundaries of syntactic roles. This methodological shift from simple token-level tagging to sequence-based modeling is essential for capturing the complex predicate-argument structures inherent in Uzbek syntax.

Research Methodology

The development of a robust dataset for the intelligent syntactic analysis of the Uzbek language requires a methodology that balances linguistic depth with computational efficiency. Given that Uzbek is an agglutinative language with complex word formations and syntactic relations, the research adopted a multi-stage approach: (1) designing a specialized 16-tag syntactic hierarchy, (2) implementing a strategy for Multi-Word Expressions (MWEs), (3) performing technical normalization at the Unicode level, and (4) encoding the data into the BIO format for transformer-based sequence labeling.

1. Development of the 16-tag syntactic system. The primary limitation of existing frameworks, such as Universal Dependencies (UD), is their tendency to over-generalize syntactic roles in a way that obscures the unique nature of Uzbek grammar. To address this, a specialized system of 16 syntactic tags was developed. This hierarchy ensures that both primary and secondary parts of the sentence are captured with high granularity. Unlike UD, which often groups various adverbial modifiers under broad categories like *obl* (oblique nominal) or *advmod*, the proposed system distinguishes between six semantic types of adverbial modifiers: manner (VH), place (OH), time (PH), purpose (MH), degree-quantity (DH), and cause (SAH). Furthermore, it differentiates between direct objects (VS) and indirect objects (VL) based on their case markings and postpositional usage.

2. Modeling syntactic integrity and multi-word expressions (MWEs). In Uzbek syntax, functions are frequently performed by cohesive units comprising multiple words, such as compound verbs or analytical predicates (e.g., “e’tibor qaratishingiz kerak”). Standard parsing models often decompose these into separate dependencies, which contradicts the principle of syntactic integrity. In this research, MWEs were initially identified by linking tokens with a "+" symbol during the manual annotation phase. This ensures that the attention mechanism of neural models can recognize the internal cohesion of these units as a single logical center (e.g., a single Verbal Predicate - FK).

3. Technical normalization and unicode standardization. To ensure the dataset is technically optimized for training architectures like BERT, RoBERTa, or XLM-R, a rigorous normalization process was performed. This involved:

- Standardizing apostrophes and specific Uzbek characters: The characters g‘/G‘ and o‘/O‘ were normalized to the U+02BB character, while the hard sign (*tutuq belgisi*) was standardized to U+02BC.
- Cleaning the corpus by removing redundant whitespace and empty lines to prevent tokenization errors.

4. BIO Encoding for sequence labeling. The final stage of the methodology involved converting the annotated corpus into the Beginning-Inside-Outside (BIO) format. This format is essential for mapping syntactic roles to continuous token sequences. Under this schema:

- B-TAG identifies the first token of a syntactic unit.
- I-TAG marks subsequent tokens within a multi-word unit.
- (Outside) is assigned to tokens that do not carry a specific syntactic label, such as punctuation marks.

For example, a complex predicate like “*e’tibor qaratishingiz kerak*” (FK) is encoded as: *e’tibor*/B-FK, *qaratishingiz*/I-FK, *kerak*/I-FK. This methodological choice allows the dataset to be used across various neural architectures for comparative evaluation.

Analysis and Results

The resulting dataset comprises 9,025 sentences and 105,674 tokens, providing a dense and high-quality resource for neural sequence labeling tasks.

Table 1. General statistical indicators of the BIO-formatted syntactic dataset

Metric	Value
Number of sentences	9025
Number of tokens (+ after splitting units)	105674
Tokens annotated with 16 syntactic tags	86393
Tokens annotated with "O" tag	19281 (18.25%)
Number of MWE units (+ syntactic units connected with "+")	13876
Number of tokens within MWEs	30206 (28.58%)
Average sentence length	11.71 tokens
Median sentence length	9 tokens
Shortest sentence	1 token

As shown in Figure 1, the majority of sentences are of short to medium length, which is optimal for training Transformer models with standard sequence lengths (e.g., 128 or 256 tokens).

The distribution of specific syntactic tags reveals the linguistic characteristics of the corpus. Adjectival modifiers (SA), subjects (EG), and verbal predicates (FK) are the most frequent categories.

Table 2. Statistical distribution by syntactic tags

Tag	Number of tokens	Total share	Share within 16 tags
O	19281	18,25%	—
SA	18409	17,42%	21,31%
EG	13284	12,57%	15,38%
FK	11848	11,21%	13,71%
VL	10080	9,54%	11,67%
QA	9101	8,61%	10,53%
VS	6580	6,23%	7,62%
VH	4020	3,80%	4,65%
OK	3500	3,31%	4,05%
OH	2807	2,66%	3,25%
PH	2640	2,50%	3,06%
KR	1252	1,18%	1,45%
DH	838	0,79%	0,97%
MH	824	0,78%	0,95%
SAH	702	0,66%	0,81%
IA	395	0,37%	0,46%
UN	113	0,11%	0,13%

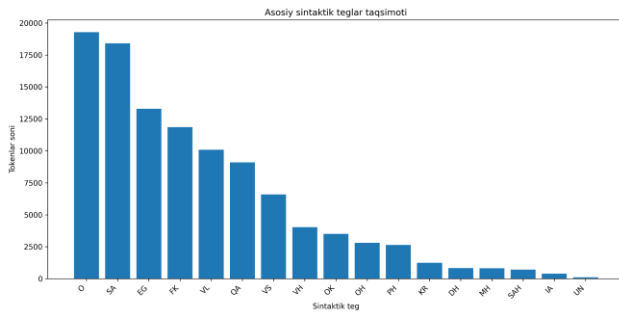


Figure 1. General distribution of syntactic tags including the 'O' category.

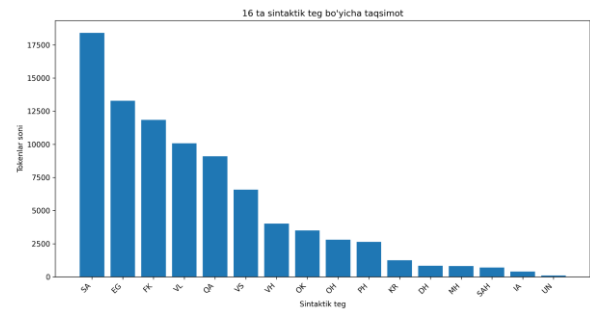


Figure 2. Relative distribution of the 16 core syntactic tags (excluding 'O').

The high frequency of MWEs (28.58% of all tokens) justifies the use of the BIO format. Analysis shows that verbal predicates (FK) and indirect objects (VL) are most likely to appear as multi-word units.

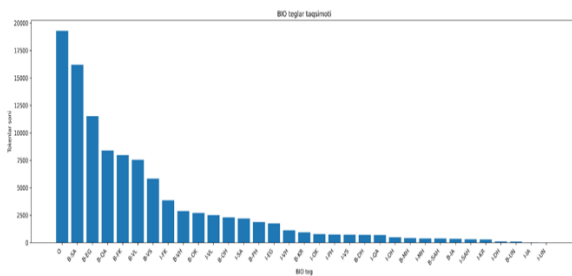


Figure 3. Visual representation of BIO tag frequencies.

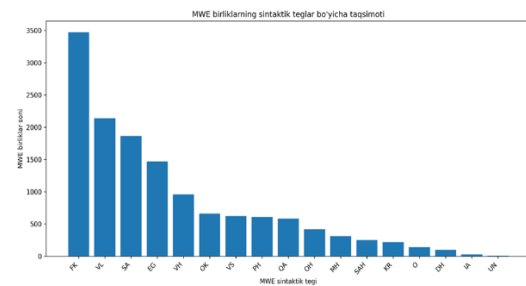


Figure 4. Distribution of MWE units across syntactic categories.

Finally, the complexity of MWEs was analyzed by length. While 86% of MWEs consist of two words, the presence of units containing up to 28 words highlights the necessity for models to handle long-range dependencies.

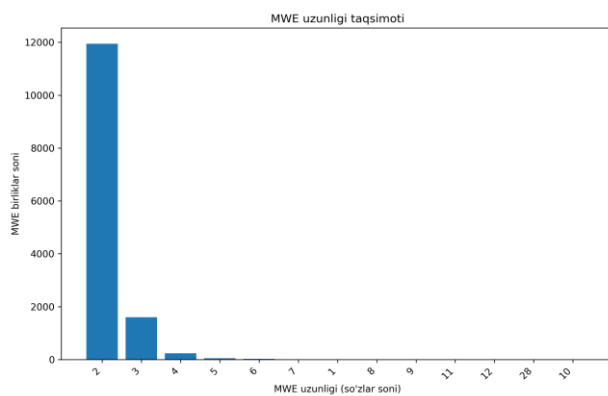


Figure 5. Distribution of MWE lengths.

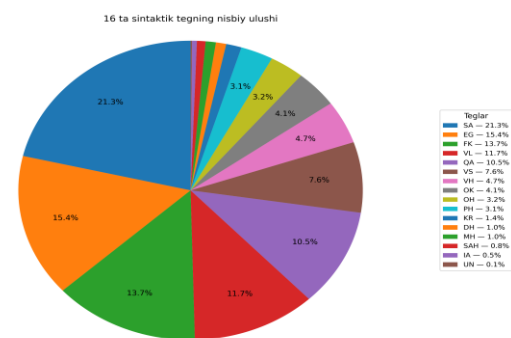


Figure 6. Relative proportions of the 16 syntactic tags in the overall corpus.

Among the evaluated models, mDeBERTa-v3 achieved the best overall effectiveness for Uzbek syntactic analysis, with a mean accuracy of 0.8003, macro-F1 of 0.7385 and weighted-F1 of 0.8016. UzBERT achieved the best efficiency profile and a competitive macro-F1 of 0.7321, while Tahrirchi-BERT produced a lower but still meaningful macro-F1 of 0.7230. These findings confirm that transformer fine-tuning is a viable approach for Uzbek syntactic analysis, but further gains require

targeted improvements in low-resource labels, BIO boundary modelling and syntactically similar label disambiguation.

Conclusion

This research successfully developed a linguistically informed and technically standardized dataset for the syntactic analysis of the Uzbek language. By implementing a 16-tag system that respects national grammatical traditions, the dataset overcomes the limitations of universal frameworks like UD, particularly in capturing the semantic nuances of modifiers and the integrity of complex predicates.

The integration of the BIO format and the explicit modeling of Multi-Word Expressions (which constitute nearly 29% of the corpus) provide a robust algorithmic foundation for training state-of-the-art neural architectures such as BERT, RoBERTa, and BiLSTM-CRF. Statistical analysis confirms that the dataset is sufficiently dense and balanced for high-frequency tags, although the inherent imbalance for rare categories like vocatives (UN) suggests that future modeling should utilize metrics like Macro F1 and Focal Loss. Ultimately, this dataset serves as a vital digital resource, enabling the transition from traditional rule-based parsing to intelligent, context-aware syntactic analysis for Uzbek NLP.

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UDC: 656.025.2:004.9(575.1)

IMPROVING ECONOMIC EFFICIENCY THROUGH THE DIGITALIZATION OF TRANSPORT AND LOGISTICS SERVICES AT NAVOI MINING AND METALLURGICAL COMPANY JSC

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Annotatsiya. Ushbu maqolada “Navoiy kon-metallurgiya kombinati” AJda transport-logistika xizmatlarini raqamlashtirish orqali iqtisodiy samaradorlikni oshirish masalalari yoritilgan. Unda GPS-monitoring, avtomatlashtirilgan boshqaruv, elektron hujjat aylanishi va real vaqt nazoratining logistika xarajatlarini kamaytirishdagi ahamiyati tahlil qilingan. Shuningdek, transport vositalaridan foydalanish samaradorligini oshirish, yoqilg‘i sarfini kamaytirish va bekor turish vaqtini qisqartirish bo‘yicha takliflar ishlab chiqilgan.

Kalit so‘zlar: transport-logistika xizmatlari, raqamlashtirish, iqtisodiy samaradorlik, logistika xarajatlari, GPS monitoring, avtomatlashtirilgan boshqaruv, raqamli texnologiyalar.

Аннотация. В статье рассматриваются вопросы повышения экономической эффективности транспортно-логистических услуг в АО «Навоийский горно-металлургический комбинат» на основе цифровизации. Проанализировано значение GPS-мониторинга, автоматизированного управления, электронного документооборота и контроля в реальном времени для снижения логистических затрат. Разработаны предложения по повышению эффективности использования транспорта, снижению расхода топлива и сокращению простоев.

Ключевые слова: транспортно-логистические услуги, цифровизация, экономическая эффективность, логистические затраты, GPS-мониторинг, автоматизированное управление, цифровые технологии.

Abstract. This article examines ways to improve the economic efficiency of transport and logistics services at Navoi Mining and Metallurgical Company JSC through digitalization. It analyzes the role of GPS monitoring, automated management, electronic document flow, and real-time control in reducing logistics costs. Proposals are developed to improve vehicle efficiency, reduce fuel consumption, and minimize downtime.

Keywords: transport and logistics services, digitalization, economic efficiency, logistics costs, GPS monitoring, automated management, digital technologies.

Introduction

Today, the sustainable development of large industrial enterprises depends not only on production capacities and technological equipment, but also on the effective

organization of transport and logistics services. This issue is especially important in the mining and metallurgical industry, where the extraction of raw materials, their delivery for processing, the supply of auxiliary materials, the storage of finished products, and their delivery to consumers require the uninterrupted operation of the logistics system.

Under traditional management conditions, there are certain limitations in controlling transport movement, accounting for fuel consumption, reducing downtime, and optimizing logistics costs. Delays in information exchange, errors related to the human factor, and insufficient real-time monitoring negatively affect economic efficiency. Therefore, the organization of transport and logistics services based on digital technologies is considered a highly relevant issue.

This article analyzes the issues of improving economic efficiency through the digitalization of transport and logistics services at Navoi Mining and Metallurgical Company JSC. The study examines existing problems, the advantages of digital technologies, and develops scientific and practical recommendations aimed at reducing transport costs and optimizing logistics processes.

Literature Review

Transport and logistics services are among the key systems that ensure the continuity of production processes in large industrial enterprises. This is particularly important in the mining and metallurgical industry, where the extraction of raw materials, their delivery for processing, the management of auxiliary material flows, and the transportation of finished products to their destinations are directly dependent on transport and logistics services [1].

In the literature, digital logistics is interpreted as the management of cargo flows, vehicles, warehouse operations, document circulation, and service processes within a unified information environment. The concept of “Logistics 4.0” involves obtaining data in real time, monitoring cargo movement, and optimizing logistics operations [4].

Studies related to the digitalization of transport systems in the mining industry identify the reduction of operating costs, the improvement of equipment utilization efficiency, and the introduction of flexible management mechanisms as key areas of development [10].

The analysis of the literature shows that the digitalization of transport and logistics services is an important factor in improving the economic efficiency of industrial enterprises. Therefore, this article focuses on reducing costs, increasing the utilization rate of vehicles, controlling fuel consumption, and optimizing logistics processes as the main research directions.

Research Methodology

The theoretical and methodological basis of the study is formed by scientific approaches related to the economics of services, transport and logistics management, the digital economy, and cost optimization. In the study, transport and logistics services were analyzed in relation to the movement of raw materials, warehousing, supply processes, shipment of finished products, and managerial decision-making.

The article employs systematic, economic, factor-based and comparative analysis methods, as well as grouping, induction and deduction, and economic-mathematical assessment methods.

In assessing efficiency, transport costs, fuel consumption, productive working time, downtime, transportation cost per unit, cargo turnover, transportation distance, maintenance costs, and the speed of information exchange were identified as the main indicators. The overall economic efficiency of transport and logistics services was assessed on the basis of the following ratio:

$$E_{tl} = \frac{N_{tl}}{X_{tl}}$$

where, E_{tl} - is the economic efficiency of transport and logistics services; R_{tl} - is the economic result achieved through logistics services; C_{tl} - represents the total costs associated with transport and logistics services.

$$S_d = X_t - X_d$$

where, S_d - represents the economic effect obtained as a result of digitalization; X_t - denotes transport and logistics costs under traditional management conditions; and X_d - denotes transport and logistics costs after the introduction of digital management.

This formula makes it possible to assess the degree of cost reduction achieved as a result of the digitalization of transport and logistics services. The cost structure includes fuel consumption, unnecessary trips, downtime, maintenance, document circulation, and indirect losses caused by delays in management decisions.

In assessing the efficiency of vehicle utilization, the utilization coefficient is considered an important indicator:

$$K_u = \frac{T_p}{T_t}$$

where, K_u - is the vehicle utilization coefficient; T_p - is the productive working time of the vehicle; T_t - is the total available working time of the vehicle.

This coefficient shows how effectively transport vehicles are used during the working period. An increase in K_u indicates a reduction in downtime and an improvement in the organization of transport and logistics processes.

Digital monitoring systems reduce vehicle downtime, optimize routes, and increase productive working time. As a result, the utilization coefficient increases, and the economic effect of transport and logistics services in the production process improves.

To assess the cost of cargo transportation, the following expression may be used:

$$C_c = \frac{X_{tl}}{Q}$$

where, C_c - is the cost of cargo transportation per unit; X_{tl} - is the total transport and logistics cost; Q - is the volume of transported cargo.

This indicator shows the amount of transport and logistics costs per unit of cargo. A decrease in C_c indicates that transportation resources are being used more efficiently, routes are optimized, fuel consumption is reduced, and logistics management is improved through digital technologies.

If cargo turnover is assessed in ton-kilometers, the formula can be expressed as:

$$C_{tkm} = \frac{X_{tl}}{Q \cdot L}$$

where, C_{tkm} is the transportation cost per ton-kilometer, Q is the cargo volume, and L is the transportation distance.

This indicator makes it possible to determine the dynamics of logistics costs by comparing the periods before and after the introduction of digital technologies. A decrease in the transportation cost per unit of cargo indicates an increase in the economic efficiency of transport and logistics services.

In the study, the main factors affecting logistics costs were identified through factor analysis. These factors include fuel consumption, the technical condition of vehicles, transportation distance, loading and unloading time, route optimization, downtime, the speed of information exchange, and the accuracy of managerial decisions. These factors were assessed as important economic parameters that can be monitored and optimized through digital technologies.

The economic impact of digitalization was evaluated on the basis of a comprehensive approach, taking into account not only direct costs but also indirect results. In particular, faster cargo transportation, simplified document circulation, reduced errors, advance planning of maintenance, and decision-making based on real-time data were considered as factors that contribute to improving efficiency.

Analysis and Results

The efficiency of transport and logistics services depends not only on transportation costs, but also on the continuity of production, the flow of raw materials and finished products, the level of equipment utilization, and the promptness of managerial decision-making. Therefore, in assessing the economic results of digitalization, the cost index, fuel consumption, empty mileage, delivery time, document circulation speed, and equipment utilization coefficient were selected as the main indicators.

In the analysis, the state before digitalization was defined as the baseline period, while the state after the introduction of digital management was defined as the improved period. Transport and logistics costs were assessed on the basis of a generalized expression.

$$C_{log} = C_{fuel} + C_{tech} + C_{lab} + C_{idle} + C_{doc} + C_{other}$$

where, C_{log} - is the total logistics cost; C_{fuel} - represents fuel and energy costs; C_{tech} - represents maintenance and repair costs; C_{lab} - represents labor and dispatching costs; C_{idle} - represents losses associated with vehicle downtime; C_{doc} - represents paper-based document circulation and administrative costs; C_{other} - represents other logistics costs.

This model shows that digitalization is not limited only to the monitoring of transport vehicles. It integrates information exchange between transport, warehouse, production, and economic planning departments into a single system. As a result, the decision-making process becomes faster, while unnecessary waiting times and administrative delays are reduced.



Figure 1. Model for the digitalization of the transport and logistics process: reducing costs and increasing service speed.

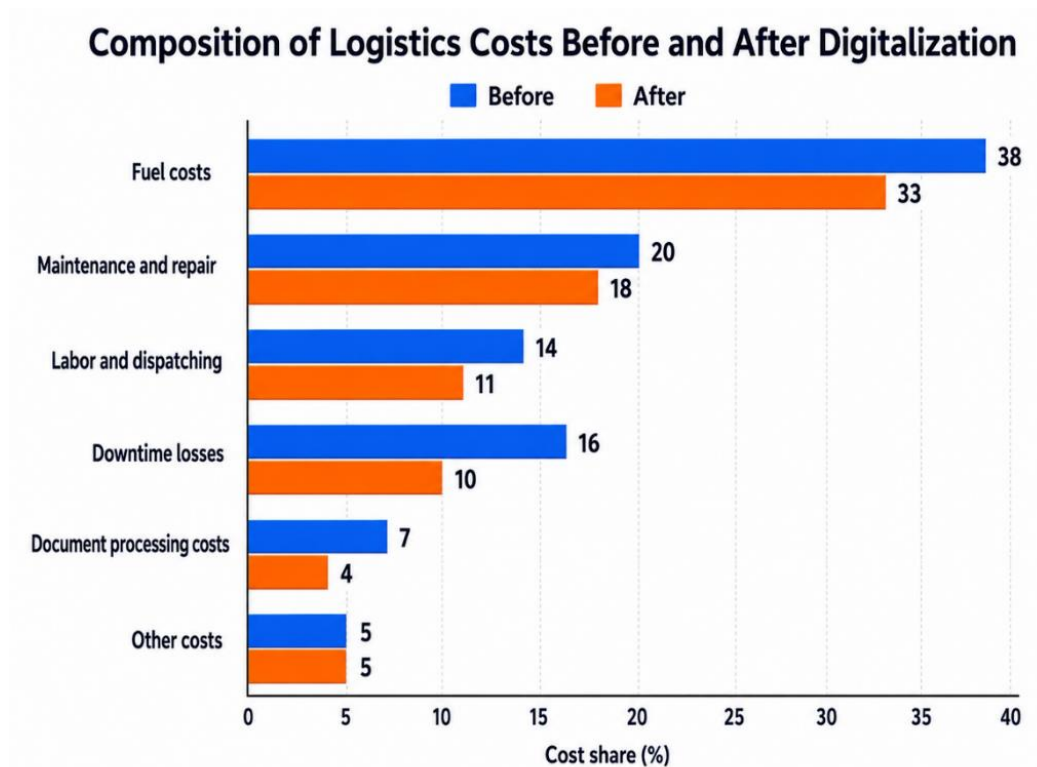


Figure 2. The structure of logistics costs before and after digitalization.

According to the diagram analysis, the economic effect is mainly achieved by reducing idle time, optimizing fuel consumption, and shortening document circulation. The decrease in idle-time costs from 16 units to 10 units increases delivery speed and improves the turnover efficiency of transport vehicles.

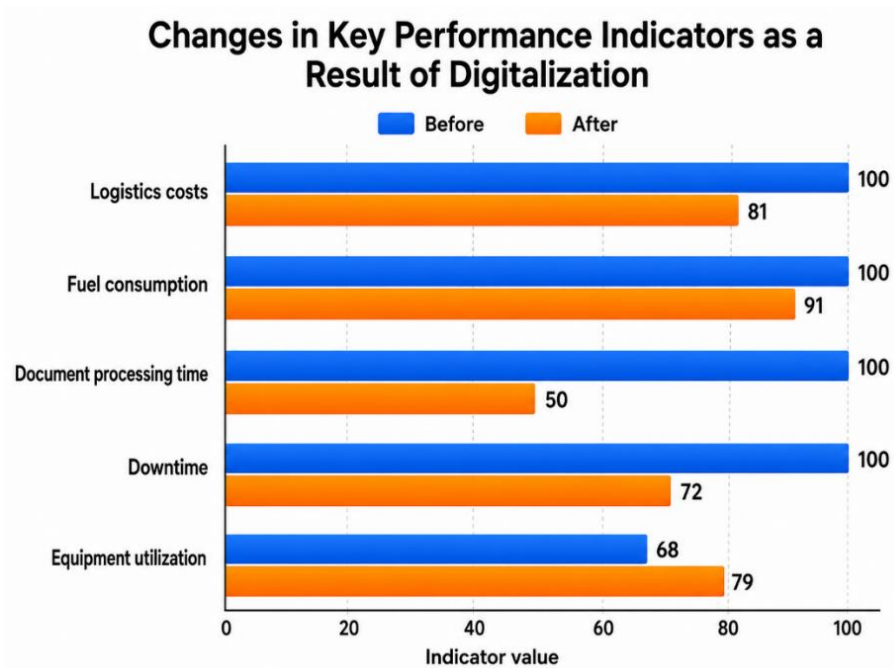


Figure 3. Changes in key efficiency indicators as a result of digitalization.

These results show that digitalization reduces costs through the combined impact of several factors. While route optimization decreases fuel consumption, electronic document management shortens administrative time. GPS monitoring and digital dispatching, in turn, reduce empty runs and unplanned downtime.

Calculation of economic efficiency. The annual economic effect obtained from the digitalization of transport and logistics services can be determined using the following formula:

$$E_y = (C_0 - C_1) \cdot Q$$

where, E_y — annual economic effect; C_0 — logistics cost per unit before digitalization; C_1 — logistics cost per unit after digitalization; Q — volume of transportation performed during the year.

If there are investment costs for the implementation of the digital system, the net economic effect is calculated as follows:

$$E_{net} = E_y - (I_{dig} + C_{op})$$

where, I_{dig} — investment cost for implementing the digital system; C_{op} — costs related to system operation, technical support, and software maintenance.

The payback period of the investment is determined by the following expression:

$$T_p = \frac{I_{dig}}{E_y}$$

If logistics costs are reduced by 19 percent, this provides a significant economic result for a large industrial enterprise. This is because transport and logistics costs are one of the important components of production cost in mining and metallurgical enterprises.

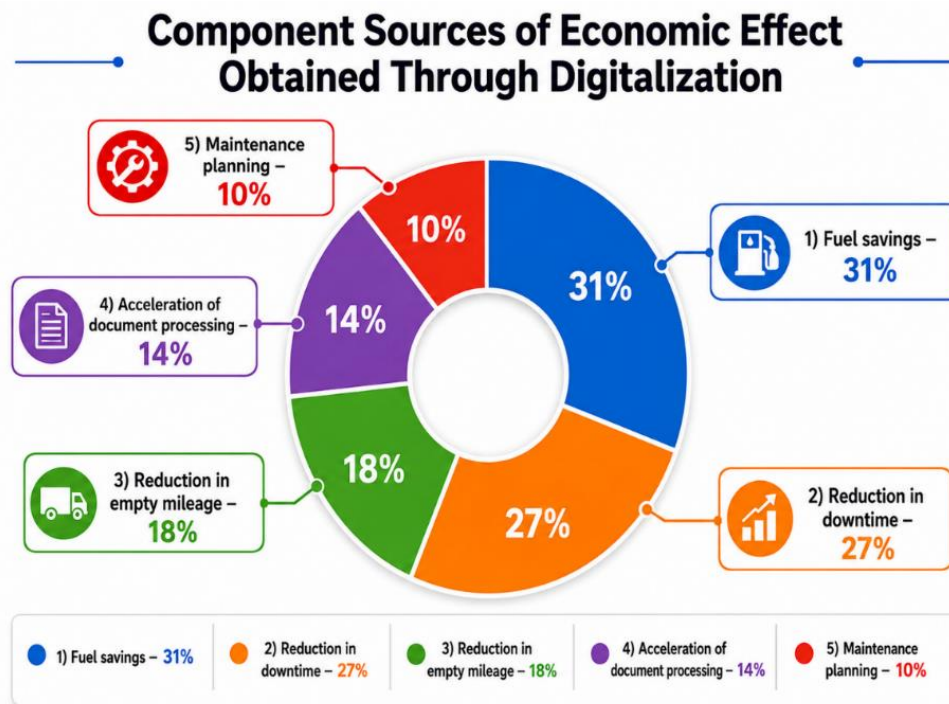


Figure 4. Structural sources of the economic benefits achieved through digitalization.

This diagram shows that the main part of the economic effect is formed due to fuel savings and the reduction of vehicle downtime. This substantiates the need to introduce digital monitoring and planning systems.

According to the analysis results, the digitalization of transport and logistics services reduces empty runs, excessive mileage, fuel consumption, administrative costs, and errors related to the human factor. Electronic dispatching, GPS monitoring, digital document flow, and online control of the technical condition of vehicles increase the efficiency of vehicle operation.

Digitalization helps reduce product cost, ensure the rational use of resources, and support rapid decision-making. Therefore, it is advisable to gradually introduce an electronic logistics platform, automatic route planning, and digital document management.

Conclusion and Recommendations

The conducted analyses show that the digitalization of transport and logistics services in large industrial enterprises is an important factor in increasing economic efficiency. Real-time monitoring, route optimization, electronic document flow, and rapid information exchange between departments help reduce unnecessary costs.

According to the analysis results, after digitalization, the logistics cost index decreases from 100 units to 81 units, which means that total costs are reduced by 19%. Fuel consumption decreases by 9%, document processing time by 50%, and vehicle downtime by 28%, while the equipment utilization indicator increases from 68 units to 79 units.

The economic effect is mainly formed due to fuel savings, reduced downtime, decreased empty mileage, and faster document circulation. Digitalization contributes to reducing product cost, ensuring the rational use of resources, improving the accuracy of management decisions, and maintaining the continuity of production processes.



It is advisable to fully implement GPS monitoring and digital dispatching in the transport and logistics system, use a platform for automatic route planning, digitally control the technical condition of vehicles, and regularly monitor fuel consumption, empty mileage, delivery time, downtime, and total logistics costs.

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UDC: 004.934:811.512.133'34

OPTIMIZING TOKENIZATION IN TRANSFORMER MODELS FOR THE UZBEK LANGUAGE: MORPHOLOGICAL AND ORTHOGRAPHIC CHALLENGES

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Annotatsiya. Ushbu maqolada standart tokenizatsiya algoritmlarining morfologik va orfografik mosligi o'zbek tilining agglutinativ tuzilishi bilan tadqiq etiladi. Transformer arxitekturasiga asoslangan 15 ta turli til modellari— jumladan, global yirik til modellari, ko'p tilli enkoderlar va o'zbek tiliga ixtisoslashgan modellar—empirik baholash orqali tahlil qilinib, muhim lingvistik va hisoblashga oid samarasizliklar aniqlangan. 357 ta noyob affiksdan iborat ma'lumotlar to'plami va 206 ta gapdan tashkil topgan orfografik stress-test korpusi asosida o'tkazilgan tajribalar shuni ko'rsatadiki, Byte-Pair Encoding (BPE) va WordPiece kabi algoritmlar ko'p hollarda "semantik dekontekstualizatsiya"ni keltirib chiqaradi. Ushbu tokenizatorlar so'z asoslarini mantiqan noto'g'ri tarzda bo'ladi hamda apostrofli maxsus grafemalarni (o', g') punktuatsiya chegarasi sifatida noto'g'ri segmentatsiya qiladi. Bunday ortiqcha fragmentatsiya tokenlar ketma-ketligini 54.5% gacha sun'iy ravishda oshiradi, bu esa model inferensiyasi jarayonida soniyasiga bajariladigan suzuvchi nuqtali operatsiyalar (FLOPS) miqdorining 138% ga eksponensial oshishiga olib keladi. Tadqiqot xulosasiga ko'ra, standart tokenizatorlar o'zbek tilidagi NLP vazifalari uchun yetarli emas. Shu sababli semantik yaxlitlikni saqlash va o'zbek tili lingvistik xususiyatlarini hisobga oluvchi tokenizatsiya algoritmini ishlab chiqish orqali tokenlar lug'atini shakllantirish asosida Transformer modellar hisoblash samaradorligini oshirish taklif etiladi.

Kalit so'zlar: *tabiiy tilni qayta ishlash, o'zbek tili, tokenizatsiya, transformer modellari, agglutinativ morfologiya, byte-pair encoding, yirik til modellari.*

Аннотация. В данной статье исследуется морфологическая и орфографическая совместимость стандартных алгоритмов токенизации с агглютинативной структурой узбекского языка. Путём эмпирической оценки 15 различных языковых моделей на базе архитектуры Transformer — включая глобальные большие языковые модели, многоязычные энкодеры и специализированные узбекские модели — выявлены важные лингвистические и вычислительные неэффективности. Экспериментальные результаты, основанные на наборе данных из 357 уникальных аффиксов и орфографическом стресс-тест корпусе из 206 предложений, показывают, что такие алгоритмы, как Byte-Pair Encoding (BPE) и WordPiece, часто вызывают «семантическую



деконтекстуализацию». Эти токенизаторы нелогично разделяют основы слов и неправильно сегментируют специальные графемы с апострофами (o‘, g‘), воспринимая их как границы пунктуации. Подобная чрезмерная фрагментация искусственно увеличивает последовательность токенов до 54.5%, что приводит к экспоненциальному росту количества операций с плавающей запятой в секунду (FLOPS) на 138% в процессе инференса модели. В результате исследования сделан вывод о том, что стандартные токенизаторы недостаточно эффективны для задач обработки естественного языка на узбекском языке. В связи с этим предлагается разработка алгоритма токенизации, учитывающего лингвистические особенности узбекского языка, а также формирование словаря токенов с целью повышения вычислительной эффективности моделей Transformer.

Ключевые слова: обработка естественного языка, узбекский язык, токенизация, трансформерные модели, агглютинативная морфология, byte-pair encoding, большие языковые модели.

Abstract. This article investigates the morphological and orthographic compatibility of standard tokenization algorithms with the agglutinative structure of the Uzbek language. Through empirical evaluation of 15 transformer-based language models—including global large language models, multilingual encoders, and Uzbek-specialized models—significant linguistic and computational inefficiencies are identified. Experimental results based on a dataset of 357 unique affixes and a 206-sentence orthographic stress-test corpus demonstrate that algorithms such as Byte-Pair Encoding (BPE) and WordPiece frequently cause “semantic decontextualization”. These tokenizers illogically split word stems and incorrectly segment special apostrophe-based graphemes (o‘, g‘), treating them as punctuation boundaries. Such excessive fragmentation artificially increases token sequences by up to 54.5%, leading to a 138% exponential increase in Floating Point Operations Per Second (FLOPS) during model inference. The study concludes that standard tokenizers are insufficient for Uzbek NLP tasks. Therefore, it proposes the development of a tokenization algorithm that accounts for the linguistic characteristics of the Uzbek language, along with the construction of a token vocabulary, in order to improve the computational efficiency of Transformer models.

Keywords: natural language processing, Uzbek language, tokenization, transformer models, agglutinative morphology, byte-pair encoding, large language models.

Introduction

Natural Language Processing (NLP) and Artificial Intelligence (AI) technologies are rapidly advancing, fundamentally transforming the computational processing of complex linguistic tasks across various domains. To ensure strict orthographic consistency in developing these advanced NLP resources and throughout the practical implementation of this study, all Uzbek spelling conventions and rules utilized strictly adhere to the guidelines provided in the “Educational Spelling Dictionary of the Uzbek Language” (O‘zbek tilining o‘quv imlo lug‘ati) [1]. Transformer-based pre-trained

language models, such as BERT and GPT, currently serve as the backbone for state-of-the-art NLP solutions [2, 3]. The effectiveness of these modern models is heavily dependent on their tokenization process, which segments input text into processable subword units [4]. However, standard tokenization algorithms like Byte-Pair Encoding (BPE), WordPiece, and SentencePiece were primarily optimized for analytic and partially inflected languages, presenting significant computational and linguistic challenges when applied to the Uzbek language. As a morphologically rich, agglutinative language, Uzbek forms words by sequentially attaching multiple functional affixes to a root, which can generate an almost infinite number of complex word forms [2, 5]. When standard subword tokenizers process such structures, they often segment words into linguistically illogical fragments based on statistical character frequencies rather than morphological rules. This results in “semantic decontextualization” (the erosion of meaning) and an artificial exponential increase in the number of generated tokens.

Recent studies have actively addressed these challenges by developing tailored NLP resources for the Uzbek language and other Turkic languages. Mansurovs introduced UzBERT, the first publicly available pre-trained BERT model for Uzbek, which significantly outperformed multilingual models like mBERT in masked language modeling tasks. However, because UzBERT utilized a standard WordPiece tokenizer, the authors noted the necessity of a carefully crafted morphological tokenizer for highly inflectional texts [4]. Addressing this, Kuriyozov et al. proposed BERTbek, a monolingual transformer model trained using a morphologically-aware tokenizer built upon the Apertium-uzbek segmentation tool. Their results proved that preserving affixes and grammatical boundaries drastically improves performance in downstream tasks like Sentiment Analysis, Text Classification, and Named Entity Recognition [2]. Similarly, Tukeyev and Rysbek proposed a Complete Set of Endings (CSE)-Guided Framework for Turkic languages, which achieved up to a 33% reduction in neural model training time by decreasing the overall sequence length of tokens [4]. Other foundational contributions include dictionary-based tokenization algorithms developed by Saidov et al., which operate at the syllable, affix, and word levels to efficiently handle agglutination and compound words [6]. Furthermore, the creation of cross-script transliteration tools by Salaev et al. and Sobirov et al. has proven essential in standardizing text data across Cyrillic, standard Latin, and the new Latin alphabets, enabling the seamless compilation of large-scale, high-quality training corpora [7, 8].

Building upon this extensive body of related work, this article empirically evaluates the computational and semantic impact of standard subword tokenizers on the agglutinative morphology and special orthographic graphemes of the Uzbek language, aiming to justify the critical need for an optimized hybrid pre-tokenization approach.

Research Methodology

To systematically evaluate the morphological and orthographic compatibility of standard tokenization algorithms (such as Byte-Pair Encoding (BPE), WordPiece, and SentencePiece) with the agglutinative nature of the Uzbek language, a comprehensive experimental methodology was designed. The study analyzes a diverse set of 15 to 16 transformer-based language models, which are categorized into three main groups:

global Large Language Models (LLMs) (e.g., Qwen 2.5, Llama-3.1, GPT-OSS-120B, Mistral, Phi-3), multilingual encoder models (e.g., mBERT, XLM-RoBERTa, mDeBERTa-v3), and Uzbek-specialized models (e.g., UzRoBERTa-v1/v2, BERTbek, Alloma-8B, Tahrirchi-BERT, UzBERT).

Table 1. Classification of tokenization algorithms for the models evaluated in the study.

Model	Core Architecture	Tokenization Algorithm	Language-Specific Features for Uzbek
Alloma 8B	Llama-3	BPE (TikToken)	Adapted for the Uzbek language based on the Llama-3 vocabulary.
Qwen 2.5 (7B)	Qwen2	BPE (Byte-Level)	Utilizes a 152k-sized vocabulary and operates at the byte level.
mBERT	BERT	WordPiece	Performs pre-tokenization by separating words from punctuation in advance.
mDeBERTa v3	DeBERTa	SentencePiece	Treats text as a raw stream.
GPT-2 (Base)	GPT-2	Byte-Level BPE	Robust to Unicode characters; however, it lacks a dedicated Uzbek vocabulary.
UzRoBERTa v2	RoBERTa	BPE (Custom)	Trained from scratch on an Uzbek language corpus.
NLLB-200	NLLB	SentencePiece (SPM)	A universal model covering 200 languages.
Tahrirchi / BERTbek	BERT	WordPiece	Based on the classical BERT tokenizer architecture.

The empirical evaluation was conducted in two primary phases using distinct, specially curated datasets. In the first phase, a linguistic experiment was developed to test how well the tokenizers capture the complex affixal system of the Uzbek language. A comprehensive dataset of 357 unique derivational, inflectional, and syntactic affixes was compiled and classified into four major linguistic categories: noun affixes, verb affixes, adjective/adverb/numeral affixes, and syntactic forms (such as case, possessive, and person-number markers). The vocabulary of each selected transformer model was programmatically queried to determine the presence, absence, or loss of these 357 affixes as independent tokens or logical subwords.

This figure illustrates the iterative process of adapting a transformer model vocabulary for the Uzbek language. The algorithm begins by loading a predefined list of stems and affixes, then sequentially evaluates each element against the existing dictionary. If the element is not present, it is added to the vocabulary, ensuring morphological completeness. The process continues until all elements are processed, resulting in an updated and linguistically enriched dictionary optimized for agglutinative structures.

In the second phase, a specialized “stress-test corpus” consisting of 206 sentences was constructed to assess the specific impact of special Uzbek graphemes on tokenization efficiency. This corpus was deliberately enriched with linguistic units that maximize orthographic and morphological challenges, including complex multi-affix word forms, Uzbek-specific digraphs (sh, ch, ng), and various apostrophe formats (ASCII, Unicode) appearing in special letters (o‘, g‘) and inside word roots (e.g., ma’no, san’at).

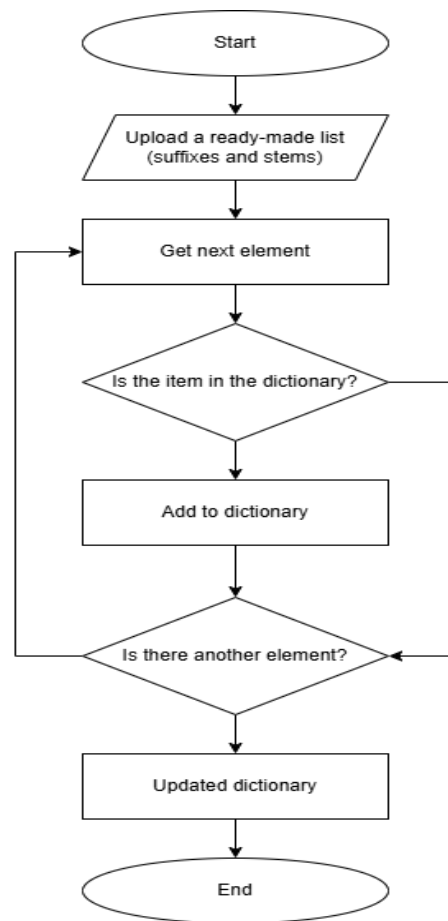


Figure 1. Algorithm for adapting the transformer model dictionary for the Uzbek language.

To precisely quantify the performance and computational efficiency of the models, several evaluation metrics were established. For the morphological analysis, the primary focus was on identifying “semantic decontextualization” (the erosion of meaning), tracking how often logical stems were destroyed or split into meaningless character sequences based purely on statistical frequencies rather than morphological logic. For the orthographic stress-test, three main metrics were applied: (1) Total token count required to represent the 206-sentence corpus; (2) Efficiency coefficient, measured as the average number of characters encoded per token; and (3) Orthographic error rate, which quantified the frequency of mis-segmenting special graphemes (for example, illogically splitting the word “o‘zbek” into the fragments [“o”, “”, “zbek”]). Furthermore, to assess the technical and economic implications of token over-fragmentation, the study incorporated a computational complexity metric. Because the Self-Attention mechanism at the core of Transformer architectures operates with a quadratic computational complexity of $O(N^2)$ (where N is the number of tokens in a sequence), the study calculated how the artificial increase in token sequences directly impacts the exponential rise in Floating Point Operations Per Second (FLOPS), inference speed, and memory consumption during model training.

Analysis and Results

The empirical evaluation across both linguistic and orthographic dimensions revealed significant disparities in how different transformer models handle the unique characteristics of the Uzbek language.

Morphological decontextualization and affix loss. The linguistic experiment evaluating 357 unique Uzbek affixes demonstrated that standard subword tokenizers heavily rely on statistical character frequencies rather than morphological logic, leading to severe “semantic decontextualization”. Because standard algorithms fail to recognize complex affix chains, logical word stems are frequently destroyed. For instance, the word *kulimsira* (to smile) was illogically split into four meaningless syllables (*ku+lim+si+ra*), entirely eroding the root verb *kul* into a semantically empty *ku* token. Similarly, phonetic features like gemination caused erroneous splits, such as *chiquncha* being segmented into *chiq+q+uncha*, where the isolated *q* introduces noise without providing any linguistic Information Gain. Complex structures denoting continuous action, such as *kelayotibmiz*, lost their entire grammatical chain and semantic core. As detailed in the comparative analysis, Uzbek-specialized models (e.g., UzBERT, Tahrirchi-BERT, Alloma-8B, BERTbek) recorded significantly fewer missing affixes across noun, verb, and syntactic categories compared to global LLMs like Mistral-7B and Qwen3.5, which struggled to capture the agglutinative morphology.

Table 2. Overall error rates of Transformer models on unique Uzbek language affixes.

№	Model	Noun Category (Derivational and Inflectional Forms)	Verb Category (Functions and Morphological Forms)	Adjectives, Adverbs, and Numerals	Syntactic Structures
1	uzBERT	18	27	20	8
2	Tahrirchi-BERT	18	27	23	6
3	Alloma-8B	20	27	23	7
4	UzRoBERTa- v2	19	30	23	6
5	BERTbek	19	34	27	10
6	mDeBERTa-v3	26	41	36	9
7	NLLB-re-uz	33	38	43	8
8	Xlm-roberta- base	37	48	45	10
9	GPT-OSS-120B	37	49	45	11
10	mmBERT	45	58	46	13
11	mBERT	46	59	52	14
12	Qwen3.5-35B	53	59	49	14
13	mGPT-1.3B- uzbek	56	62	51	17
14	Llama-3.1-Uz	53	65	53	17
15	Mistral-7B-Uz	70	74	65	19

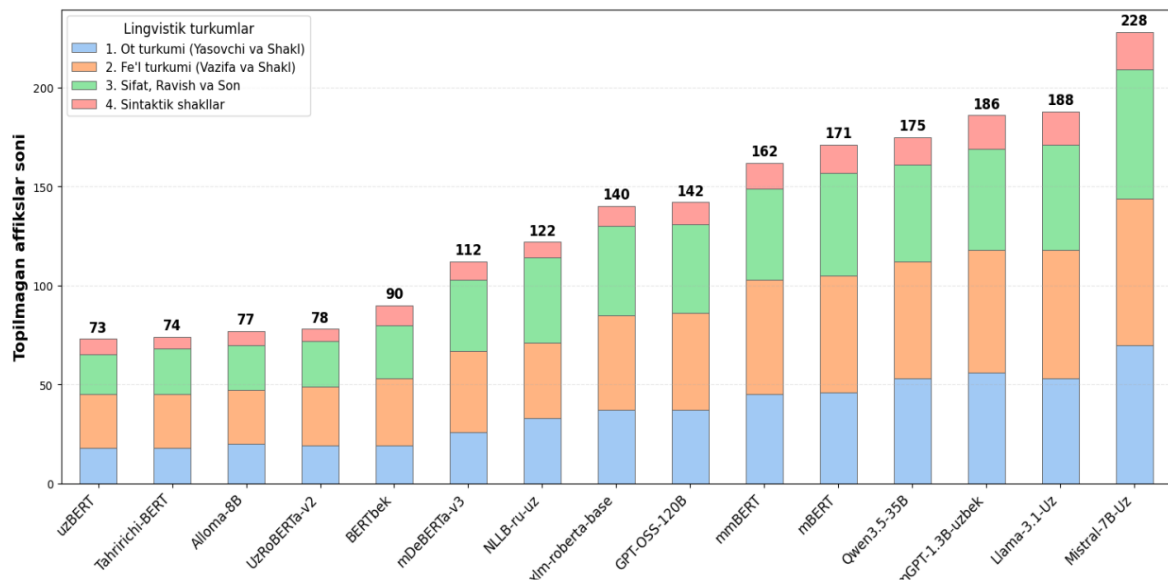


Figure 2. Distribution of model errors across linguistic categories.

Orthographic Efficiency and the Tokenization Paradox. Testing on the 206-sentence stress-test corpus highlighted a critical paradox between sequence compression and orthographic accuracy.

Table 3. Total tokens, sequence efficiency, and orthographic error indicators across evaluated architectures.

Model	Architecture	Total Tokens	Performance	o' (Error)	g' (Error)	sh (Error)	ch (Error)	ng (Error)
UzRoBERTa v2	RoBERTa	2847	4.25	236	102	0	0	0
UzRoBERTa v1	RoBERTa	2963	4.08	236	102	0	0	0
Tahrirchi Base	BERT	2982	4.06	241	102	0	9	0
BERTbek (News)	BERT	3004	4.03	241	102	0	0	0
UzText (Rifkat)	RoBERTa	3054	3.96	236	102	0	0	0
T5-Base (Rifkat)	T5	3157	3.83	241	102	0	0	0
Alloma 8B	Llama-3	3288	3.68	61	18	0	0	0
NLLB-200	NLLB	3776	3.21	75	27	0	0	0
XLM-RoBERTa	RoBERTa	3779	3.20	241	102	0	0	0
mDeBERTa v3	DeBERTa	4065	2.98	241	102	4	2	0
mBERT	BERT	4703	2.57	65	20	7	0	0
Qwen 2.5 (7B)	Qwen	5096	2.38	225	93	0	0	0
Phi-3 Mini	Llama	5387	2.25	241	102	0	0	0
GPT-2 (Base)	GPT-2	5627	2.15	236	102	0	0	0
GPTuz (Rifkat)	GPT-2	6338	1.91	238	102	4	0	5

Models explicitly trained on Uzbek corpora achieved the highest compression rates. For example, UzRoBERTa-v2 encoded the corpus using only 2847 tokens, achieving a highly efficient 4.25 characters per token. However, this efficiency came at the cost of high orthographic error rates; the model mis-segmented the special apostrophe-based grapheme o' 236 times and g' 102 times. This occurs because standard pre-

tokenization steps (especially in WordPiece) tend to treat apostrophes as punctuation boundaries, artificially splitting unified Uzbek letters. Conversely, the Alloma-8B model demonstrated the most optimal balance between efficiency and semantic integrity. It achieved a solid compression rate of 3.68 characters per token while keeping orthographic errors remarkably low (only 61 errors for *o'* and 18 for *g'*). Global models like GPT-2 and Qwen 2.5 performed poorly, essentially defaulting to byte-level or character-level segmentation, consuming up to 5627 tokens for the same text (nearly double the amount used by localized models). Notably, standard Latin digraphs (*sh*, *ch*, *ng*) were processed without errors across almost all architectures, confirming that the primary bottleneck exclusively lies in apostrophe-based graphemes.

Computational complexity and economic implications. The over-fragmentation of tokens causes profound technical and economic bottlenecks due to the $O(N^2)$ computational complexity of the Transformer's Self-Attention mechanism. Empirical data showed that an artificial 54.5% increase in token sequences leads to an exponential 138% (approximately 2.38x) surge in required Floating Point Operations Per Second (FLOPS).

	Asl so'z	Oltin Standart (Morfologik)	Kutilgan tokenlar soni	UzRoBERTa tokenizatsiyasi	Haqiqiy tokenlar soni	Maydalanish darajasi (O'sish)
0	Kulimsira	kul + imsira	2	ku + lim + si + ra	4	2.00x
1	Chiqquncha	chiq + quncha	2	chiq + q + uncha	3	1.50x
2	Kelgusi	kel + gusi	2	kel + gu + si	3	1.50x
3	Kelayotibmiz	kel + ayotib + miz	3	ke + la + yotib + miz	4	1.33x
4	Uchovlashib	uc + ovlashib	2	uch + ov + lashib	3	1.50x

Figure 3. Empirical evidence of the over-fragmentation problem using the UzRoBERTa-v2 model.

Comparing the optimally balanced Alloma-8B model with global LLMs, the latter introduced a 1.7x token overhead. This overhead theoretically increases inference latency by a factor of three, reduces the effective context window memory by 40% (allowing only ~9,000 characters in a 4K context window instead of ~15,000), and makes API usage approximately 70% more expensive.

Table 4. The impact of tokenization efficiency on technical and economic indicators.

Metric	Alloma 8B (Optimal)	Global models (GPT-2/Qwen)	Difference
Number of Tokens (206 sentences)	3288	~5100 – 5600	1.7× increased load
Inference Speed	100% (Baseline)	~35% (Juda sekin)	Latency increases by ~3× (N ²)
Context Capacity (Memory)	~15k belgi (4k oynada)	~9k belgi (4k oynada)	Memory capacity is reduced by 40%
API Cost	\$1.00 (shartli)	\$1.70	Token-based cost is 70% more expensive
Semantic Coherence	Yuqori (Xato: ~80)	Past (Xato: ~340)	Word integrity is broken in global models

These results robustly confirm that applying standard BPE and WordPiece tokenizers directly to the Uzbek language disrupts semantic representation and unjustifiably inflates computational costs.

Conclusion

The empirical findings of this study conclusively demonstrate that standard subword tokenization algorithms, such as Byte-Pair Encoding (BPE) and WordPiece, are fundamentally misaligned with the agglutinative morphology and specific orthographic rules of the Uzbek language. The direct application of these algorithms results in the severe erosion of semantic stems, the loss of grammatical affix functions, and the erroneous segmentation of special apostrophe-based graphemes like o‘ and g‘. Furthermore, this orthographic and morphological mismatch artificially inflates the length of token sequences, which subsequently causes an unjustified, exponential increase in computational complexity, memory consumption, and processing latency due to the quadratic nature of Transformer architectures. To overcome these linguistic and technical bottlenecks, it is imperative to develop a specialized, hybrid pre-tokenization framework optimized for the Uzbek language. Such an approach must explicitly incorporate strict morphological rules, comprehensive affix databases, and orthography-aware mechanisms that process special characters as unified graphemic entities rather than punctuation boundaries. Implementing this developed algorithm and tokenization strategy will ensure improved computational efficiency of large language models developed for the Uzbek language.

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MODERN PROBLEMS OF PEDAGOGY AND PSYCHOLOGY

UDC: 159.97:794.9

THE ESSENCE AND PSYCHOLOGICAL DESCRIPTION OF ONLINE GAMBLING

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Annotatsiya. Mazkur maqolada onlayn qimor o'yinlarining mohiyati, ularning shaxs psixikasi va jamiyatga ta'siri ilmiy jihatdan tahlil qilingan. Shuningdek, onlayn qimor o'yinlariga qaramlikning psixologik omillari, kognitiv va emotsional mexanizmlari hamda ularning oldini olish bo'yicha profilaktik choratadbirlar yoritilgan. Tadqiqot natijalari zamonaviy raqamli muhitda onlayn qimor o'yinlari tez sur'atlarda tarqalayotgan muhim psixologik muammo ekanligini ko'rsatadi.

Kalit so'zlar: *onlayn qimor o'yinlari, qaramlik, tavakkalchilik, psixologik omillar, kognitiv buzilishlar, motivatsiya, impulsivlik, emotsional holatlar, ijtimoiy-psixologik oqibatlar, profilaktika, psixologik yordam, moliyaviy muammolar, oilaviy nizolar, ijtimoiy izolyatsiya, ruhiy buzilishlar.*

Аннотация. В данной статье проводится научный анализ природы онлайн-азартных игр, их влияния на общество и психику человека. Также рассматриваются психологические факторы, когнитивные и эмоциональные механизмы зависимости от онлайн-азартных игр, а также профилактические меры. Результаты исследования показывают, что онлайн-азартные игры признаются быстро распространяющейся психологической проблемой в современной цифровой среде.

Ключевые слова: *азартные игры в интернете, зависимость, рискованное поведение, психологические факторы, когнитивные расстройства, мотивация, импульсивность, когнитивные расстройства, эмоциональные состояния, социально-психологические последствия, профилактика и психологическая поддержка, финансовые проблемы, семейные конфликты, социальная изоляция, психические расстройства.*

Abstract. This article scientifically analyzes the nature of online gambling, its impact on society and the psyche of the individual. It also examines the psychological factors, cognitive and emotional mechanisms of addiction to online gambling, and preventive measures. The results of the study show that online gambling is recognized as a rapidly spreading psychological problem in the modern digital environment.

Keywords: *online gambling, addiction, risk-taking, psychological factors, cognitive disorders, motivation, impulsivity, cognitive disorders, emotional states, socio-psychological consequences, prevention and psychological support, financial problems, family conflicts, social isolation, mental disorders.*

Introduction

As a result of the rapid development of information technologies, many areas of human life have been digitized. At the same time, new socio-psychological problems have also arisen in the virtual space. One of these is the widespread use of online gambling. Online gambling, which begins as a simple entertainment activity, can gradually turn into a factor in the formation of addiction in a person. This situation is becoming not only an individual psychological problem, but also a social problem.

The essence of online gambling is that it is free from the constraints of space and time, allowing the player to engage in risky activities involving the possibility of financial gain or loss at any time of the day, without leaving the comfort of their own home (for example, their home or workplace)¹. The psychological appeal of this process, and at the same time its destructive effect, is hidden in its presentation through digital platforms, where the feeling of anonymity in the virtual space satisfies the human need to avoid social control and condemnation, as a result of which the individual is temporarily deprived of the ability to fully understand the real consequences of his actions. As noted in the scientific literature, online gambling is a complex interaction of cognitive, emotional and behavioral components, and serious distortions of the perception of existence are formed in a person involved in this activity.²

Among these cognitive errors, the phenomenon of the “Illusion of control”, widely studied in psychology, is of particular importance, in which the player firmly believes that he can control the process controlled by the random number generator on the online platform using his intellectual abilities, experience or specially developed strategies, find the “weak” side of the algorithm and turn it into a source of constant income.³

Literature Review

The issue of risk-taking has been extensively studied by foreign experts such as K. Star, K. Coombs, Yu. Kozeleski, M. Burkman and B. Bremer, H. Moskovich and D. Bann, and these studies have led to scientific studies of the characteristics of risk-taking behavior. Along with the illusion of control, there is another cognitive trap known as the “gambler’s fallacy,” according to which the player establishes a false logical connection between unrelated random events, that is, he comes to the wrong heuristic conclusion that losing several times in a row will definitely lead to a big win in the next step, and continues to spend his financial resources.⁴ It should be noted that, according to the theory of Kardefelt-Winther D., the software of online gambling platforms also has a special design that targets the weak points of the human psyche; for example, the psychology of colors, sound effects and the speed of the game lead the player into a state of deep psychological immersion, called the “flow” or machine zone, similar to a “trance” state. In this zone, the passage of time is not felt, physical needs (hunger, sleep) and social obligations become secondary, and the only reality for the player becomes the virtual world behind the screen, which in turn leads to social isolation of

¹ Petry N.M., 2015, American Psychological Association, 112-bet.

² Ladouceur R., Walker M., 2016, Wiley nashriyoti, 89-bet.

³ Clark L., 2019, Cambridge University Press, 145-bet.

⁴ To‘laganova Z., 2021, O‘zbekiston Milliy universiteti nashriyoti, 34-bet.

the individual and a pathological intensification of the mechanism of escapism (avoidance of life difficulties).⁵

Research methodology

The psychological mechanisms of online gambling addiction are also closely related to individual characteristics, and a number of empirical studies have shown that individuals with high levels of impulsivity, a tendency to sensation seeking, as well as low emotional intelligence and insufficiently developed stress management skills constitute the most at-risk group for gambling addiction.⁶ Moreover, for people suffering from loneliness, depression, and anxiety syndromes in modern society, online gambling is becoming a kind of emotional regulation tool; they aim to distract themselves from their negative emotional states and “turn off” their brains from painful thoughts rather than to achieve success through the game.⁷ Another dangerous psychological parameter of online gambling that differs from traditional gambling is the digitization of funds; since the player sees numbers on the screen (or special virtual coins) instead of physical paper money in his hands, the cognitive connection between the value of money and its purchasing power in real life is broken (dissociation occurs), which leads to betting extremely large amounts of money in a very short time without any feeling of regret or fear, and then experiencing a deep psychological shock.⁸ These financial losses trigger a destructive behavioral cycle in the gambler known as “chasing losses”; at this stage, the person begins to take more and more risks not in the hope of winning, but in the irrational goal of getting out of the debt swamp and returning to their previous stable state, as a result of which, in parallel with the increase in the amount of debt, the psychological degradation of the individual, a sharp decrease in self-esteem, family conflicts and the manifestation of suicidal behavior increase.⁹ Online gambling is a risk-based gaming activity that is carried out over the internet in exchange for money or tangible value. It has the following characteristics:

- constant availability;
- anonymity;
- the possibility of quick results;
- randomness of the prize.

The main motives that attract online gambling are:

- the desire to get rich quickly;
- emotional excitement (adrenaline);
- avoidance of problems;
- social approval and a sense of success.

Cognitive distortions - The following faulty thinking patterns are observed in people addicted to gambling:

- overconfidence that “I will win”;
- illusion of control over randomness;
- perception of losses as temporary;

⁵ Kardefelt-Winther D., 2017, World Health Organization Press, 45-bet.

⁶ Zuckerman M., 2015, American Psychological Association, 220-bet.

⁷ Blaszczynski A., Nower L., 2017, Taylor & Francis, 88-bet.

⁸ Abbott M., 2020, Springer nashriyoti, 142-bet.

⁹ Hodgins D.C., 2016, Elsevier nashriyoti, 215-bet.



- recovery fallacy.

Emotional states - Online gambling can cause the following emotional reactions:

- short-term joy and euphoria;
- stress and anxiety;
- depressive states;
- aggression and frustration.

Behavioral characteristics - when addiction develops, the following signs are observed:

- inability to control the time spent playing;
- continuing to play despite financial losses;
- withdrawal from social life;
- lying and concealment.

Analysis and Results

From a socio-psychological point of view, an environment of codependency is formed around a person addicted to online gambling; family members, spouses or parents initially think that they have solved the problem by helping the gambler pay off his debts, but this help psychologically serves to confirm (enable) pathological behavior and prevents the player from feeling personal responsibility for his actions, contributing to the transition of the disease to a more severe stage.¹⁰ In addition, in the psychology of an addictive individual, there is an overactivation of defense mechanisms, especially such types as denial and rationalization, that is, a person suffering from the disease does not recognize his addiction, tries to justify gambling not as a bad habit, but simply as "Recreation" or "A source of income during a period of temporary failure", which sharply reduces the effectiveness of any psychotherapeutic interventions applied to him.¹¹ Therefore, cognitive behavioral therapy (CBT) in combination with pharmacological agents (e.g., opioid antagonists or antidepressants) is the most effective method for treating online gambling addiction, as this method focuses on identifying the patient's incorrect cognitive schemas related to gambling (overestimation of the probability of winning, illusion of control) and replacing them with realistic, logical thinking.¹² Online gambling addiction leads to the following negative consequences:

- financial problems;
- family conflicts;
- social isolation;
- mental disorders (depression, anxiety);
- criminal tendencies.

Prevention and psychological support - preventive measures to increase the psychological literacy of the population;

- explanatory work among young people;
- strengthening control over Internet platforms.

Methods of psychological support

¹⁰ Orford J., 2019, Wiley nashriyoti, 234-bet.

¹¹ Petry N.M., 2015, American Psychological Association, 218-bet.

¹² Ladouceur R., 2018, Springer nashriyoti, 160-bet.



- cognitive-behavioral therapy;
- motivational interviewing;
- group therapy;
- family counseling.

Conclusion

It can be noted that the essence of online gambling is a complex psychological trap built on heuristic errors and gaps in emotional regulation in the human cognitive system, and to combat it, strengthening psychoeducation (psychological enlightenment) work at the community level, increasing the digital and financial literacy of the population, forming cognitive immunity, as well as radically improving legal and socio-psychological support services (crisis centers, anonymous gamblers groups) are the most urgent strategic tasks facing specialists in psychology, sociology, medicine, and jurisprudence today. Online gambling is a widespread and complex psychological phenomenon in modern society. Its main danger is that it gradually forms an addiction in a person and negatively affects his mental and social life. Therefore, studying this problem, preventing it and providing effective psychological support are urgent tasks.

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UDC: 371.13:37.02

INTEGRATING GAMIFICATION AND INTERACTIVE METHODS TO ENHANCE TEACHERS' PROFESSIONAL COMPETENCE: A PEDAGOGICAL MODEL

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Аннотация. Ushbu tadqiqot zamonaviy ta'lim sharoitida o'qituvchilarning kasbiy kompetentligini rivojlantirishda gamifikatsiya va interfaol o'qitish metodlarini integratsiyalashning samaradorligini tahlil qiladi. Ta'limda shaxsga yo'naltirilgan va raqamli texnologiyalar asosidagi yondashuvlarning kengayishi pedagoglardan pedagogik, kommunikativ hamda raqamli kompetensiyalarni muntazam rivojlantirishni talab etmoqda. Tadqiqot doirasida ballar, nishonlar (badges), reyting jadvallari va topshiriqlar kabi gamifikatsiya elementlari hamda keys-stadi, rolli o'yinlar, aqliy hujum va hamkorlikda o'qitish metodlarini uyg'unlashtiruvchi pedagogik model ishlab chiqildi va amaliy jihatdan asoslandi. Tadqiqot natijalari mazkur integratsiya o'qituvchilarning motivatsiyasi, faolligi, ijodkorligi va dars samaradorligini sezilarli darajada oshirishini ko'rsatdi. Shuningdek, u pedagogik innovatsiyalarni qo'llash, raqamli savodxonlik va reflektiv amaliyotni rivojlantirishga xizmat qiladi. Taklif etilgan pedagogik model an'anaviy va raqamli ta'lim muhitida gamifikatsiyalashgan interfaol strategiyalarni joriy etish uchun tizimli va moslashuvchan asosni taqdim etadi.

Калит so'zlar: *gamifikatsiya, interfaol o'qitish metodlari, o'qituvchining kasbiy kompetentligi, pedagogik model, ta'lim innovatsiyasi, faol ta'lim, raqamli pedagogika, o'qituvchilarni rivojlantirish, motivatsiya, hamkorlikda o'qitish.*

Аннотация. В данном исследовании рассматривается интеграция геймификации и интерактивных методов обучения как инновационный подход к развитию профессиональной компетентности педагогов в условиях современного образования. В связи с расширением личностно-ориентированного и цифрового обучения преподавателям необходимо постоянно совершенствовать педагогические, коммуникативные и цифровые компетенции. В рамках исследования была разработана и обоснована педагогическая модель, объединяющая элементы геймификации (баллы, значки, рейтинговые таблицы и задания) с интерактивными методами обучения, включая кейс-метод, ролевые игры, мозговой штурм и совместную деятельность. Результаты исследования показали, что интеграция геймификации и интерактивных методов



значительно повышает мотивацию, вовлечённость, творческую активность и эффективность педагогической деятельности. Кроме того, она способствует развитию педагогических инноваций, цифровой грамотности и рефлексивной практики. Предложенная педагогическая модель представляет собой структурированную и масштабируемую основу для внедрения геймифицированных интерактивных стратегий как в традиционной, так и в цифровой образовательной среде.

Ключевые слова: геймификация, интерактивные методы обучения, профессиональная компетентность педагога, педагогическая модель, образовательные инновации, активное обучение, цифровая педагогика, профессиональное развитие учителей, мотивация, совместное обучение.

Abstract. This study examines the integration of gamification and interactive teaching methods as an innovative approach to enhancing teachers' professional competence in contemporary education. With the growing demand for learner-centered and technology-enhanced instruction, educators are required to continuously develop their pedagogical, communicative, and digital skills. In this context, the research aims to design and validate a pedagogical model that synthesizes gamification elements—such as points, badges, leaderboards, and challenges—with interactive methods including case-based learning, role-playing, brainstorming, and collaborative activities. The findings reveal that the integration of gamification and interactive methods significantly enhances teachers' motivation, engagement, creativity, and instructional effectiveness. Moreover, it supports the development of key professional competencies, including pedagogical innovation, digital literacy, and reflective practice. The proposed pedagogical model provides a structured and scalable framework for implementing gamified interactive strategies in both traditional and digital learning environments.

Keywords: gamification, interactive teaching methods, teacher professional competence, pedagogical model, educational innovation, active learning, digital pedagogy, teacher development, motivation, collaborative learning.

Introduction

In the context of rapid technological advancement and the digital transformation of education, the role of teachers is undergoing significant change. Modern educational systems require not only subject-specific knowledge but also a high level of professional competence that includes pedagogical, communicative, digital, and reflective skills. As a result, there is a growing need for innovative approaches that can effectively support teachers' continuous professional development and enhance their instructional practices.

Traditional models of teacher training, which often rely on passive knowledge transmission, are no longer sufficient to meet the demands of contemporary education. These approaches tend to limit active participation, reduce motivation, and fail to address the dynamic nature of modern classrooms. In contrast, learner-centered and activity-based approaches have gained increasing attention due to their ability to foster engagement, collaboration, and critical thinking. Among these approaches, interactive



teaching methods and gamification have emerged as particularly promising strategies [1].

Interactive teaching methods, such as brainstorming, case-based learning, role-playing, and group discussions, emphasize active involvement and collaborative problem-solving. These methods create opportunities for teachers to engage in meaningful learning experiences, thereby improving their ability to design and implement effective instructional strategies. At the same time, gamification—the use of game design elements in non-game contexts—has been widely recognized for its potential to increase motivation, engagement, and persistence. Elements such as points, badges, leaderboards, and challenges can transform routine learning activities into dynamic and rewarding experiences.

While both interactive methods and gamification have been extensively studied in educational research, their combined application in teacher professional development remains insufficiently explored. The integration of these approaches offers a synergistic effect, where the motivational power of gamification complements the cognitive and social benefits of interactive learning [2]. This combination not only enhances engagement but also supports the development of key competencies required for effective teaching in digital and hybrid learning environments.

Therefore, the purpose of this study is to develop and substantiate a pedagogical model that integrates gamification and interactive teaching methods to enhance teachers' professional competence.

The study seeks to answer the following research questions: how can gamification elements be effectively integrated with interactive teaching methods in teacher training; what impact does this integration have on teachers' motivation and professional competence; what pedagogical model can be proposed to ensure systematic and sustainable implementation.

The significance of this research lies in its contribution to the theoretical and practical understanding of innovative teacher development strategies. By proposing a structured model, the study provides a foundation for educators, researchers, and policymakers to implement more effective and engaging professional development programs. Furthermore, the findings are expected to support the transition toward more dynamic, technology-enhanced, and competence-oriented education systems.

Literature Review

The concept of teacher professional competence has been widely discussed in educational research, emphasizing the integration of knowledge, skills, attitudes, and values necessary for effective teaching. According to contemporary pedagogical theories, professional competence encompasses not only subject expertise but also pedagogical knowledge, classroom management, communication skills, and the ability to integrate technology into teaching practices. Recent studies highlight that continuous professional development is essential for teachers to adapt to rapidly changing educational environments and learner needs [3].

Interactive teaching methods have gained considerable attention as effective tools for enhancing both student learning and teacher competence. Active learning strategies

such as problem-based learning, case studies, group discussions, and role-playing promote critical thinking, collaboration, and reflective practice. Prince (2004) argues that active learning significantly improves understanding and retention compared to traditional lecture-based approaches. Similarly, Bonwell and Eison (1991) emphasize that interactive methods encourage deeper cognitive engagement and foster meaningful learning experiences. For teachers, the use of such methods contributes to the development of instructional flexibility and pedagogical creativity.

In parallel, gamification has emerged as a powerful approach in education, particularly in the context of increasing motivation and engagement. Deterding et al. (2011) define gamification as the use of game design elements in non-game contexts, while Kapp (2012) highlights its potential to enhance learning outcomes through motivation and feedback mechanisms. Common gamification elements include points, badges, leaderboards, levels, and challenges, which create a sense of achievement and progression. Research indicates that gamification can positively influence learners' intrinsic and extrinsic motivation, as well as their persistence in completing tasks [3].

Despite the growing body of literature on gamification and interactive methods, most studies examine these approaches separately. However, recent research suggests that their integration can produce a synergistic effect. The combination of interactive learning activities with gamified elements not only increases engagement but also enhances collaboration, problem-solving skills, and knowledge retention. This integrated approach is particularly relevant in teacher professional development, where motivation and active participation play a crucial role.

Moreover, the development of digital technologies has facilitated the implementation of gamified interactive methods through various online platforms and tools. Learning management systems (LMS), educational applications, and digital assessment tools enable the effective integration of gamification into interactive learning environments. This aligns with the concept of digital pedagogy, which emphasizes the use of technology to create more flexible, accessible, and engaging learning experiences [4].

Nevertheless, there remains a gap in the literature regarding the systematic integration of gamification and interactive methods specifically aimed at enhancing teachers' professional competence. Few studies provide comprehensive models that combine these approaches within a unified pedagogical framework. Therefore, this research seeks to address this gap by proposing a structured model that integrates gamification and interactive methods, contributing to both theoretical advancement and practical application in teacher education.

Analysis and Results

The present study aimed to evaluate the effectiveness of integrating gamification and interactive teaching methods in enhancing teachers' professional competence. The analysis is based on data collected through a quasi-experimental design involving both quantitative and qualitative approaches [5]. The findings presented in this section reflect the impact of the proposed pedagogical model on multiple dimensions of

teachers' professional competence, including pedagogical, digital, communicative, and reflective skills.

The research was conducted among 60 teachers from secondary and higher education institutions, who were divided into an experimental group and a control group, each consisting of 30 participants. Prior to the intervention, both groups were subjected to a pre-assessment designed to measure their baseline level of professional competence. The results of the pre-test indicated no statistically significant differences between the two groups, confirming their comparability and ensuring the validity of the experimental design. This initial equivalence allowed for a more accurate evaluation of the impact of the intervention.

The experimental group participated in an eight-week professional development program based on the integration of gamification elements and interactive teaching methods. The training sessions were structured around key gamification components such as points, badges, levels, challenges, and leaderboards, which were systematically embedded into interactive learning activities. These activities included case-based learning, role-playing simulations, brainstorming sessions, collaborative problem-solving tasks, and peer discussions. In contrast, the control group followed a traditional professional development program characterized by lecture-based instruction and limited interaction [6].

Following the intervention, a post-assessment was conducted to evaluate changes in teachers' professional competence. The quantitative results revealed a substantial improvement in the experimental group across all measured dimensions. Pedagogical competence demonstrated a significant increase, as teachers became more effective in designing learner-centered lessons, applying diverse instructional strategies, and incorporating interactive elements into their teaching. This improvement can be attributed to the hands-on nature of the training, which allowed participants to actively practice and refine their teaching techniques.

Digital competence also showed a notable increase in the experimental group, reflecting enhanced ability to use educational technologies and digital tools. Teachers became more confident in integrating online platforms, interactive applications, and digital assessment tools into their instructional practices. The gamified structure of the training encouraged participants to explore and experiment with technology in a supportive and engaging environment, thereby reducing resistance to digital innovation [7].

Similarly, communicative competence improved significantly, as participants engaged in collaborative activities that required effective communication, teamwork, and knowledge sharing. The use of interactive methods fostered a sense of community and mutual support, enabling teachers to exchange ideas, provide feedback, and learn from each other's experiences. This collaborative dimension played a crucial role in strengthening interpersonal skills and promoting professional dialogue.

Reflective competence, which involves the ability to critically analyze one's own teaching practices and make informed improvements, also increased considerably in the experimental group. The continuous feedback mechanisms embedded within the gamified system—such as progress tracking, performance indicators, and peer



evaluation—encouraged teachers to reflect on their learning process and identify areas for improvement. As a result, participants developed a more conscious and analytical approach to their professional growth.

In contrast, the control group showed only modest improvements across all competence areas. While some progress was observed, it was significantly lower than that of the experimental group. This suggests that traditional professional development methods may not be sufficient to produce substantial changes in teachers' competence, particularly in the context of modern educational demands.

Statistical analysis using independent and paired sample t-tests confirmed that the differences between pre-test and post-test results in the experimental group were statistically significant ($p < 0.05$)[8]. Furthermore, the comparison between the experimental and control groups in the post-test revealed a clear advantage for the gamified interactive approach. These findings provide strong empirical evidence supporting the effectiveness of the proposed pedagogical model.

The qualitative analysis further reinforced the quantitative results by providing insights into participants' experiences and perceptions. Feedback collected through surveys and observations indicated that teachers in the experimental group experienced higher levels of motivation, engagement, and satisfaction throughout the training process. The gamification elements were particularly effective in creating a sense of achievement and competition, which encouraged active participation and sustained interest.

Participants also highlighted the practical relevance of interactive methods, noting that activities such as role-playing and case-based learning allowed them to simulate real classroom scenarios and develop applicable teaching strategies. This experiential learning approach contributed to a deeper understanding of pedagogical concepts and facilitated the transfer of knowledge into practice [9].

Another important finding of the study is the synergistic effect resulting from the integration of gamification and interactivity. While gamification provided motivational support through rewards and recognition, interactive methods ensured cognitive engagement and skill development. Together, these approaches created a balanced and comprehensive learning environment that addressed both the affective and cognitive aspects of professional development.

The implementation of the proposed pedagogical model also demonstrated its structural effectiveness. The motivational layer sustained engagement, the interactive layer facilitated active learning, the digital layer supported technological integration, the competence development layer ensured targeted skill enhancement, and the assessment layer provided continuous feedback. The coherence and interdependence of these layers contributed to the overall success of the model [10].

However, the analysis also revealed certain challenges. Some participants initially faced difficulties in adapting to gamified environments and digital tools, particularly those with limited prior experience. This indicates the need for preliminary training and gradual implementation to ensure inclusivity and effectiveness. Additionally, the time required to design and implement gamified interactive sessions was identified as

a potential constraint, suggesting the importance of institutional support and resource allocation.

In summary, the results of the study clearly demonstrate that the integration of gamification and interactive teaching methods significantly enhances teachers' professional competence. The approach not only improves key skills and knowledge but also fosters motivation, engagement, and a positive attitude toward continuous professional development. The findings validate the proposed pedagogical model and highlight its potential for broader application in various educational contexts.

Conclusion

The present study has demonstrated that the integration of gamification and interactive teaching methods represents an effective and innovative approach to enhancing teachers' professional competence in modern educational contexts. As education systems continue to evolve in response to technological advancements and changing learner needs, the demand for dynamic, engaging, and competence-oriented teaching strategies becomes increasingly critical. In this regard, the proposed pedagogical model offers a comprehensive framework that combines motivational and participatory elements to support continuous professional development [11].

The findings of the research confirm that gamified interactive methods significantly improve key dimensions of teachers' professional competence, including pedagogical, digital, communicative, and reflective skills. The use of gamification elements—such as points, badges, and leaderboards—was found to increase motivation, engagement, and persistence, while interactive methods—such as case-based learning, role-playing, and collaborative activities—enhanced critical thinking, creativity, and practical problem-solving abilities. The synergy between these approaches created a more effective and meaningful learning environment compared to traditional professional development methods.

Furthermore, the study highlights the importance of integrating digital technologies in implementing gamified interactive strategies. Digital platforms and tools not only facilitate accessibility and flexibility but also enable real-time feedback and performance tracking, which are essential for continuous improvement. The proposed model, with its structured layers—motivational, interactive, and digital, competence development, and assessment—ensures a systematic and scalable approach to teacher training.

At the same time, the research acknowledges certain limitations. The relatively small sample size and the short duration of the experimental intervention may affect the generalizability of the findings. Additionally, some participants experienced initial challenges in adapting to gamified and technology-based approaches, indicating the need for preparatory training and gradual implementation. Future research should focus on long-term studies, larger and more diverse samples, and the exploration of context-specific adaptations of the model.

In conclusion, the integration of gamification and interactive methods offers a sustainable and impactful pathway for improving teachers' professional competence. The study contributes to the growing body of knowledge on innovative pedagogical

practices and provides practical implications for educators, policymakers, and researchers. It is recommended that teacher education programs and professional development initiatives adopt gamified interactive approaches to foster more engaging, effective, and future-oriented teaching practices.

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UDC: 373.31:371.13

NON-STANDARD TASKS DESIGNED TO DEVELOP CREATIVE AND METHODOLOGICAL SKILLS IN FUTURE PRIMARY SCHOOL TEACHERS

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Annotatsiya. Ushbu maqolada boshlang‘ich sinf o‘quvchilarining matematik tafakkurini rivojlantirish va ularning intellektual salohiyatini yuzaga chiqarishga xizmat qiluvchi nostandart masalalar yoritilgan. Bunday masalalarni tanlash o‘qituvchidan ijodiy yondashuvni, ularni o‘quvchilarga tushunarli tarzda izohlash esa puxta metodik tayyorgarlikni talab qiladi.

Kalit so‘zlar: *nostandart masala, topshiriq, Pifagor uchliklari, Paskal uchburchagi, juft son, toq son, tub son, ketma-ketlik.*

Аннотация. В данной статье представлены задачи, направленные на развитие математического мышления и раскрытие интеллектуального потенциала учащихся начальной школы. Подбор таких задач требует от учителя творческого подхода, а их эффективное объяснение учащимся — высокой методической подготовки.

Ключевые слова: *нестандартная задача, задание, «Пифагоровы тройки», «треугольник Паскаля», чётное число, нечётное число, простое число, последовательность.*

Abstract. This article presents tasks aimed at developing mathematical thinking and revealing the potential of primary school students. Identifying such tasks demands a creative approach from the teacher and requires thorough methodological preparation to explain them to students effectively.

Keywords: *non-standard problem, task, Pythagorean triples, Pascal’s triangle, even number, odd number, prime number, sequence.*

Introduction

Mathematics is an environment so mysterious, wondrous, and magical that it is impossible not to be fascinated by it. Certain tasks and engaging questions can captivate even those who initially lack interest in the subject. Every formula discovered in mathematics and the wonders found within numbers have been established since ancient times and continue to be uncovered today. The great German mathematician C. Gauss called arithmetic the “Queen of Mathematics” [1].

The study of non-standard problems by future primary school teachers broadens their knowledge, reasoning, diligence, and cognitive abilities. Through non-standard problems, the methodological skills of future primary school teachers are further developed, making an invaluable contribution to their creative approach in educating the younger generation as comprehensive, creative, and capable individuals with their own independent opinions. Solving non-standard problems allows for the rediscovery

of mathematical beauty and the exploration of various problem-solving situations. Particularly in primary education, greater attention must be focused on raising students to be broad-minded during the process of teaching them how to solve non-standard problems. This process demands a high level of responsibility from the teacher, and success can only be achieved when non-standard problems are taught in a simple manner that fits the students' age and acquired knowledge.

The first-century mathematician N. Gezansky once stated: “Wonderful numbers are beautiful. It is well known that beautiful things are rare” [1].

Research Methodology

This study is based on theoretical analysis, pedagogical observation, and practical problem-solving methods. The research examines the structure and properties of non-standard mathematical tasks used in primary school education and evaluates their effectiveness in developing the creative and methodological skills of future teachers. Mathematical sequences, number patterns, and classical problems such as Pythagorean triples and Pascal's triangle are analyzed as illustrative tools for teacher training. The methodology combines mathematical reasoning with pedagogical theory, drawing on primary school mathematics textbooks used in Uzbekistan and relevant scholarly literature on mathematics education.

The study also applies a comparative approach to examine different types of non-standard problems and their applicability at various levels of primary education. Examples are selected to demonstrate how mathematical creativity can be introduced gradually, from simple numerical sequences to more complex algebraic patterns, ensuring that future teachers develop both content knowledge and the pedagogical competence to teach these tasks effectively.

Analysis and Results

The analysis reveals that non-standard mathematical tasks play a significant role in developing both the intellectual potential of primary school students and the professional skills of their teachers. The following results were obtained through examination of specific mathematical patterns and problems.

While attending a report presentation, the American mathematician S. Ulam began drawing horizontal and vertical lines on a piece of paper, creating a grid of squares. He drew a spiral starting from the central square and consecutively numbered the intersecting squares, circling the prime numbers. Upon examining the resulting grid, he observed that the prime numbers appeared sequentially along the diagonals of specific squares [1]. While attending a report presentation that he found highly tedious, the American mathematician S. Ulam began drawing horizontal and vertical lines on a piece of paper out of boredom, creating a grid of squares. After initially attempting to compose a chess endgame study and failing to yield any results, he drew a spiral starting from the central square of the grid and consecutively numbered the intersecting squares, circling the prime numbers. Upon carefully examining the resulting grid, he observed that the prime numbers appeared sequentially along the diagonals of specific squares [1].



The spiral number grid below demonstrates this remarkable phenomenon:

111	112	113	114	117	118	119	120	121	122	123
110	73	74	75	76	77	78	79	80	81	82
109	72	43	44	45	46	47	48	49	50	83
108	71	42	21	22	23	24	25	26	51	84
107	70	41	20	7	8	9	10	27	52	85
106	69	40	19	6	1	2	11	28	53	86
105	68	39	18	5	4	3	12	29	54	87
104	67	38	17	16	15	14	13	30	55	88
103	66	37	36	35	34	33	32	31	56	89
102	65	64	63	62	61	60	59	58	57	90
101	100	99	98	97	96	95	94	93	92	91

If we examine the numbers arranged in the grid above, we can observe the same remarkable phenomenon witnessed by the American mathematician.

Within this grid, we can also identify the following arrangements:

1. This grid can be expanded indefinitely by arranging the numbers in a spiral manner. The numbers located on the diagonals of any sub-grid extracted from this main grid will consist entirely of either even numbers or odd numbers.

2. If the extracted sub-grids have even dimensions (2×2 , 4×4 , 6×6 , ...), even numbers will be positioned on one of the main diagonals, while odd numbers will be positioned on the other.

3. If the extracted sub-grids have odd dimensions (3×3 , 5×5 , 7×7 , ...), then both of the main diagonals will contain either entirely even numbers or entirely odd numbers.

In exactly the same way, mathematical creativity manifests in various contexts and forms of observation. Through non-standard problems, it is possible to uncover the hidden talents of learners, enable them to demonstrate capabilities characteristic of mathematicians, develop their creative skills, and raise highly potential, active, sharp-minded, and competitive future personnel who can exhibit innovative abilities.

In primary schools, non-standard problems involving operations with numerical sequences are studied. Within primary school mathematics textbooks, we can encounter sequences with “Find the next one” tasks, structured as follows:

- 1) 1; 2; 3; 4; 5; ...
- 2) 1; 3; 5; 7; 9; ...
- 3) 2; 4; 6; 8; 10; ...
- 4) 1; 2; 3; 5; 8; 13; ...
- 5) 1; 2; 3; 2; 4; 6; 3; 6; 9; ...
- 6) 3; 8; 6; 11; 9; 14; 12; 17; ...
- 7) 901; 802; 703; 604; ...
- 8) 10; 10; 20; 30; 50; 80; ...
- 9) $1+1=$



$$2+2=$$

$$4+3=$$

.....

$$10) 1+2=$$

$$3+4=$$

$$7+6=$$

.....

Tasks of this nature are highly engaging, and certain problems do not possess a single, unique solution. This is because the data provided within a sequence can be approached from various perspectives.

Through tasks similar to those mentioned above, sequences with interesting properties can be identified.

Problem 1. Identify the relationship between the given equations and write the next equation.

$$1) 1+3=2^2$$

$$1+3+5=3^2$$

$$1+3+5+7=4^2$$

.....

$$2) 2+4=2+2^2$$

$$2+4+6=3+3^2$$

$$2+4+6+8=4+4^2$$

.....

$$3) 2+6=2 \cdot 2^2$$

$$2+6+10=2 \cdot 3^2$$

$$2+6+10+14=2 \cdot 4^2$$

.....

These presented numerical equations represent some of the wonders of mathematics. Working with tasks of this nature is essential for future primary school teachers; engaging with these assignments teaches prospective educators not only to acquire knowledge but also to apply it in both familiar and unfamiliar situations, prompting a creative approach to every task.

In the process of studying mathematics at school, there is the well-known “Pythagorean theorem.” Numbers that satisfy the “Pythagorean theorem” are called “Pythagorean triples.” For example:

$$3^2+4^2=5^2$$

$$5^2+12^2=13^2$$

$$7^2+24^2=25^2$$

.....

We can identify numerous such Pythagorean triples, and we express them as follows:

$$(3, 4, 5); (5, 12, 13); (7, 24, 25); (9, 40, 41); (11, 60, 61); (13, 84, 85); \dots$$

Let us clarify the relationship among the “Pythagorean triples” mentioned above. The smallest numbers among the given triples form a sequence of odd numbers not less than 3, namely:

$$3, 5, 7, 9, 11, 13, \dots$$

The second number in the given triple is even, and they are as follows:



$$4, 12, 24, 40, 60, 84, \dots \quad (1)$$

And finally, the third number in the given triple consists of the following numbers, which are greater than the second number by exactly one:

$$5, 13, 25, 41, 61, 85, \dots \quad (2)$$

(1) We can identify the following relationship within the sequence as well:

We denote the terms of the sequence 4, 12, 24, 40, 60, 84, ... as $a_1, a_2, a_3, a_4, a_5, a_6, \dots$ respectively.

$$a_2 - a_1 = 12 - 4 = 8 = c_1$$

$$a_3 - a_2 = 24 - 12 = 12 = c_2$$

$$a_4 - a_3 = 40 - 24 = 16 = c_3$$

$$a_5 - a_4 = 60 - 40 = 20 = c_4$$

$$a_6 - a_5 = 84 - 60 = 24 = c_5$$

.....

The sequence $c_1, c_2, c_3, c_4, c_5, \dots$ consists of the sequence 8, 12, 16, 20, 24, ... respectively, meaning it forms an arithmetic progression with a common difference of 4.

Within sequence (2), we can identify a relationship similar to the one established in sequence (1) above:

We denote the terms of the sequence 5, 13, 25, 41, 61, 81, ... as $b_1, b_2, b_3, b_4, b_5, b_6, \dots$ respectively.

$$b_2 - b_1 = 13 - 5 = 8 = d_1$$

$$b_3 - b_2 = 25 - 13 = 12 = d_2$$

$$b_4 - b_3 = 41 - 25 = 16 = d_3$$

$$b_5 - b_4 = 60 - 40 = 20 = d_4$$

$$b_6 - b_5 = 84 - 60 = 24 = d_5$$

.....

The sequence $d_1, d_2, d_3, d_4, d_5, \dots$ consists of the sequence 8, 12, 16, 20, 24, ... respectively, meaning it forms an arithmetic progression with a common difference of 4.

Therefore, the “Pythagorean triples” of the type mentioned above can be determined based on the following rule:

- 1) For the first number in the triple, we take any odd number $(2n-1)$.
- 2) To determine the second number in the triple, we take half of one less than the square of the first number $(2n^2-2n)$.
- 3) To determine the third number in the triple, we take half of one more than the square of the first number $(2n^2-2n+1)$.

In teaching mathematics to upper secondary school students, determining the powers of a binomial is studied using the following formulas:

$$(a + b)^n = C_n^0 a^n + C_n^1 a^{n-1} b + C_n^2 a^{n-2} b^2 + \dots + C_n^{n-1} a b^{n-1} + C_n^n b^n$$

The coefficients $C_n^0, C_n^1, C_n^2, \dots, C_n^{n-1}, C_n^n$ in this formula can also be determined using “Pascal’s triangle.” In primary school mathematics classes, a teacher can introduce “Pascal’s triangle” as a non-standard task in the following manner:

Problem 2: Identify the relationship between the numbers in the given rows and find the numbers for the next two rows.



MODERN PROBLEMS OF PHILOLOGY AND LINGUISTICS

UDC: 81'38:82-1

LINGUOPOETIC FUNCTIONS OF ARTISTIC DEVICES IN THE CREATION OF WORDPLAY IN LITERARY TEXTS

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Annotatsiya. Ushbu maqolada soʻz oʻyining lingvopoetik salohiyati oʻrganiladi. Soʻz oʻyini badiiy matnning estetik jozibadorligi va ifodaviy kuchini taʼminlovchi eng samarali tilshunoslik hodisalaridan biri hisoblanadi. Pun, tajnis (paronimiya) va iyhom (ikki maʼnolilik) kabi soʻz oʻyini yuzaga keltiruvchi badiiy usullarga alohida eʼtibor qaratilgan. Soʻz oʻyining leksik-semantik, fonetik, morfologik va stilistik asoslari klassik hamda zamonaviy oʻzbek adabiyotidan olingan misollar orqali tahlil qilingan. Bundan tashqari, frazeologik birliklarning semantik transformatsiyasi va alliterativ tovush naqshlari tomonidan hosil qilinadigan pragmatik, emotsional-ekspressiv va satirik taʼsirlar asoslab berilgan. Tadqiqot natijalari shuni koʻrsatadiki, soʻz oʻyini badiiy tildagi oddiy bezak vositasi boʻlibgina qolmay, balki muallifning individual uslubini shakllantiruvchi va badiiy diskursning koʻp ovozliligini taʼminlovchi kuchli lingvopoetik mexanizmdir.

Kalit soʻzlar: *lingvopoetika, badiiy matn, soʻz oʻyini, pun, tajnis, iyhom, koʻp maʼnolilik, omonimiya, individual uslub, estetik funksiya, pragmatika, kontekstual semantika.*

Аннотация. В данной статье исследуется лингвопоэтический потенциал языковой игры как одного из наиболее продуктивных лингвистических явлений, обеспечивающих эстетическую привлекательность и выразительную силу художественных текстов. Особое внимание уделяется художественным приёмам, порождающим языковую игру, в том числе каламбуру, таджнису (парономасии) и ийхому (двусмысленности). Лексико-семантические, фонетические, морфологические и стилистические основы языковой игры анализируются на примерах из классической и современной узбекской литературы. Кроме того, обоснованы прагматические, эмоционально-экспрессивные и сатирические эффекты, создаваемые семантическими трансформациями фразеологических единиц и аллитеративными звуковыми моделями. Результаты исследования показывают, что языковая игра является не просто орнаментальным элементом художественного языка, но и мощным лингвопоэтическим механизмом, формирующим индивидуальный стиль



автора и обуславливающим полифонический характер художественного дискурса.

Ключевые слова: лингвопоэтика, художественный текст, языковая игра, каламбур, таджнис, ийхом, полисемия, омонимия, индивидуальный стиль, эстетическая функция, прагматика, контекстуальная семантика.

Abstract. This article examines the linguopoetic potential of wordplay as one of the most productive linguistic phenomena contributing to the aesthetic attractiveness and expressive power of literary texts. Particular attention is paid to the artistic devices that generate wordplay, including pun, *tajnis* (paronomasia), and *iyhom* (double entendre). The lexical-semantic, phonetic, morphological, and stylistic foundations of wordplay are analyzed through examples drawn from classical and contemporary Uzbek literature. Furthermore, the study substantiates the pragmatic, emotional-expressive, and satirical effects produced by semantic transformations of phraseological units and alliterative sound patterns. The findings reveal that wordplay is not merely an ornamental feature of literary language but a powerful linguopoetic mechanism that shapes an author's individual style and contributes to the polyphonic nature of literary discourse.

Keywords: linguopoetics, literary text, wordplay, pun, *tajnis*, *iyhom*, polysemy, homonymy, individual style, aesthetic function, pragmatics, contextual semantics.

Introduction

Literary discourse differs significantly from everyday language due to its aesthetic appeal, imagery, and semantic richness. In artistic creation, writers and poets employ linguistic units not only as means of communication but also as tools for generating aesthetic effects and uncovering hidden semantic relationships. Among the most effective linguistic mechanisms used to create emotional and artistic impact in literary texts is wordplay.

Wordplay possesses unique textual functions that distinguish it from conventional stylistic devices. It introduces multilayered meanings and polyphony into the text, requiring readers to interpret implicit linguistic signals rather than merely perceive surface-level meanings. Consequently, wordplay activates readers' intellectual engagement and enhances the aesthetic experience of literary works.

In Uzbek literary tradition, wordplay is commonly realized through artistic devices such as *tajnis* (homonym-based punning), *iyhom* (double entendre), paronymic constructions, and phraseological transformations. These devices serve not only as decorative elements but also as important means of revealing the ideological content of a literary work, the emotional state of characters, and the author's artistic intentions. Therefore, a systematic investigation of the linguopoetic possibilities of wordplay remains one of the pressing issues in contemporary linguistics and literary studies.

Literature Review

The linguopoetics of literary texts and the phenomenon of wordplay have long attracted the attention of both Western and Eastern scholars. In Western linguistics,

wordplay has primarily been studied within the frameworks of stylistics and pragmatics, whereas Eastern philology traditionally investigates it within the system of rhetorical and poetic arts.

Among Uzbek scholars, M. Yuldashev made a significant contribution to the study of literary text linguopoetics. In his work *Linguopoetics of Literary Text*, he emphasizes the aesthetic function of language and demonstrates how lexical units acquire emotional-expressive and connotative meanings within literary discourse.

The stylistic potential of homonymy and the artistic nature of *tajnis* and *iyhom* were explored by Y. Tojiyev, who argued that the aesthetic impact of puns depends on the semantic layers embedded within linguistic units. Similarly, R. Qongurov and J. Lapasov examined the role of phraseological transformations and sound repetitions in enhancing artistic expressiveness. However, the integrated linguopoetic analysis of homonymy, polysemy, paronymy, and alliteration as mechanisms forming wordplay remains insufficiently systematized in contemporary scholarship.

Research Methodology

The study employs qualitative linguopoetic analysis and comparative literary interpretation. Examples from classical and modern Uzbek literary texts were selected to identify the linguistic mechanisms underlying wordplay. The analysis focuses on three principal levels:

1. Lexical-semantic level (*tajnis* and *iyhom*);
2. Phonetic level (alliteration);
3. Phraseological level (transformation and decomposition of idiomatic expressions).

These examples were examined from semantic, stylistic, and pragmatic perspectives to determine their contribution to artistic meaning and reader response.

Analysis and Results

The analysis demonstrates that wordplay in literary texts is predominantly formed through lexical-semantic, phonetic, and phraseological mechanisms.

Lexical-Semantic Wordplay. The lexical-semantic type relies primarily on homonymy and polysemy.

Tajnis (Pun). Classical Uzbek poetry provides numerous examples of *tajnis*. In such constructions, homonymous lexical units simultaneously activate several meanings, producing artistic and emotional effects. The interaction between lexical ambiguity and contextual meaning contributes to the visualization of characters' psychological states and emotional experiences.

Iyhom (Double Entendre). In contemporary poetry, *iyhom* frequently appears through the contextual activation of multiple meanings within a single lexical form. Such semantic layering encourages readers to engage in deeper interpretation and enhances the cognitive dimension of literary perception.

Phonetic Wordplay (Alliteration). Phonetic repetition creates musicality and expressive force within literary texts. For example, repeated consonant sounds may imitate natural phenomena such as flowing water, wind, or silence. Consequently, alliteration contributes to both phonosemantic symbolism and emotional expressiveness.



Phraseological Wordplay. The decomposition of phraseological units often produces humorous and satirical effects. Authors intentionally manipulate the conventional figurative meanings of idioms by introducing their literal interpretations into specific contexts. Such transformations create semantic surprise and strengthen the stylistic impact of the text.

The findings indicate that wordplay should not be regarded merely as a demonstration of linguistic craftsmanship. Instead, it represents a dynamic transformation of lexical meaning within literary discourse. In the analyzed examples of *tajnis* and *iyhom*, semantic condensation becomes evident: a single linguistic form simultaneously conveys multiple layers of meaning.

This phenomenon allows authors to achieve both semantic density and textual economy. Likewise, alliteration illustrates the interaction between phonetic and semantic levels of language, increasing the pragmatic impact of literary discourse. Phraseological transformations generate unexpected interpretations that challenge conventional linguistic expectations and enrich the artistic structure of the text.

Overall, wordplay functions as a powerful mechanism through which literary texts attain polyphonic complexity and enhanced aesthetic value.

Conclusion

The conducted linguopoetic analysis confirms that wordplay is a complex poetic phenomenon emerging from the interaction of lexical, phonetic, and stylistic levels of language. Artistic devices such as *tajnis*, *iyhom*, paronymy, and phraseological transformations are not merely decorative elements but essential components of literary expression. These mechanisms increase the aesthetic impact of literary texts, facilitate concise yet meaningful communication, and establish intellectual interaction between the author and the reader. The principles of semantic condensation identified in the analysis enable a single linguistic form to convey multiple layers of meaning, thereby creating textual polyphony and reflecting the author's individual linguistic style.

The study demonstrates that wordplay occupies a significant place in literary discourse and should be considered one of the most effective linguopoetic tools for artistic representation and aesthetic communication.

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UDC: 821.512.133-2.09

POETIC MASTERY IN THE HISTORICAL DRAMA MUQANNA

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Annotatsiya. “Muqanna” dramatik asari o‘zbek adabiyotida tarixiy mavzuni badiiy-estetik jihatdan yuksak darajada ifodalagan muhim asarlardan biridir. Asarda VIII asrda arab xalifaligiga qarshi xalq ozodlik harakatiga boshchilik qilgan Muqanna obrazi markaziy o‘rinda turadi. Muallif Hamid Olimjon poetik mahorat orqali tarixiy voqealarni tasvirlab, ularni falsafiy va hissiy jihatdan chuqurlashtiradi. Dramada she’riy tilning musiqiyliigi, obrazlarning ramziyligi va ichki monologlarning emotsional kuchi orqali qahramonlar ruhiy olami yorqin ochib beriladi. Muqanna obrazi jasorat, erkinlik va adolat g‘oyalarining timsoli sifatida yuksaladi. Asarda xalqning ozodlikka intilishi va zulmga qarshi kurashi poetik ifodalar, metaforalar va dramatik kontrastlar orqali kuchli badiiy ta’sirga ega bo‘ladi.

Kalit so‘zlar. *Muqanna, tarixiy drama, poetik mahorat, Hamid Olimjon, ozodlik kurashi, xalq qo‘zg‘oloni, arab xalifaligi, ramziy obraz, dramatik konflikt, tarixiylik, badiiy tasvir, she’riy til, qahramonlik.*

Аннотация. Историческая драма «Муканна» является одним из наиболее значимых произведений в узбекской литературе, художественно воссоздающим восстание под предводительством Муканны против Арабского халифата в VIII веке. В данном произведении Хамид Алимджан демонстрирует выдающееся поэтическое мастерство, гармонично сочетая исторические события с глубоким эмоциональным и философским смыслом. Драма отличается своим лирическим языком, выразительной образностью и символическим воплощением персонажей. Муканна предстает не только как историческая личность, но и как символ свободы, справедливости и сопротивления угнетению. Автор умело использует метафоры, драматические контрасты и эмоционально насыщенные диалоги для раскрытия внутреннего мира героев.

Ключевые слова. *Муканна, историческая драма, поэтическое мастерство, Хамид Алимджан, борьба за свободу, восстание, Арабский халифат, символизм, лирический стиль, драматический конфликт, образность, героизм, поэтический язык, героика.*

Abstract. The historical drama Muqanna is one of the most significant works in Uzbek literature that artistically portrays the uprising led by Muqanna against the Arab Caliphate in the 8th century. In this work, Hamid Olimjon demonstrates remarkable poetic mastery by blending historical events with deep emotional and philosophical meaning. The drama is distinguished by its lyrical language, expressive imagery, and symbolic representation of characters. Muqanna is depicted not only as a historical figure but also as a symbol of freedom, justice,



and resistance against oppression. The author skillfully uses metaphors, dramatic contrasts, and emotionally rich dialogues to reveal the inner world of the characters.

Keywords: *Muqanna, historical drama, poetic mastery, Hamid Olimjon, freedom struggle, rebellion, Arab Caliphate, symbolism, lyrical style, dramatic conflict, imagery, heroism, poetic language, heroics.*

Introduction

Hamid Olimjon's historical drama *Muqanna* occupies a special place in Uzbek dramaturgy from the perspective of transforming historical memory into stage consciousness, elevating the idea of national liberation to the level of artistic conflict, and making poetic discourse serve dramatic action. The history of the work's creation and the scholarly-critical environment in which it was prepared for publication indicate that *Muqanna* is not merely a play with a historical plot, but also a dramatic text that sought to mobilize the people in the spirit of the wartime period, placing motifs of heroism in the struggle for freedom at the center of its artistic conception. As noted in the preface to the collection, the play was completed in August 1942; therefore, it acquired particular socio-aesthetic relevance during the years of the Great Patriotic War. The poetic mastery of the drama is primarily determined by the convergence of three layers at a single point: the artistic reconstruction of concrete historical reality not on the basis of chronological narration, but by prioritizing the logic of conflict and adapting it to the nature of the stage; the profound integration of elements of the national poetic tradition and the spirit of folklore into the system of dramatic dialogues and monologic speech of the characters; and the transformation of the idea of heroism into an aesthetic phenomenon through symbolic imagery and the intonation of rhetorical questioning[1-4].

In this sense, an analysis of the poetics of *Muqanna* should be conducted at the intersection of the theory of artistic creativity, genre studies, intertextual relations, and the aesthetics of stage-oriented discourse.

Research Methodology

The principal aim of this study is to conduct a comprehensive analysis of Hamid Olimjon's poetic mastery as a dramatist in the historical drama *Muqanna*, focusing on its genre and style, rhythm of speech, system of characters, composition, and the nature of dramatic conflict. Based on this objective, the following research tasks are identified [5]:

- to characterize the genre nature of the work (historical drama) and its compositional structure from a poetic perspective;

- to reveal the mechanisms through which the ideas of heroism and freedom are transformed into dramatic conflict;

- to analyze the stage-specific functions of rhetorical forms such as dialogue, monologue, address, oath, and blessing-prayer;

- to determine the semantic significance of symbolic images, including the white garment and mask, the fire temple, spring, and the opposition between the tulip and the flower;



to substantiate, through textual examples, the creative synthesis of folklore and classical literary traditions in the drama;

to relate information concerning textual variants of the play, stage productions, and musical revisions to its poetic analysis.

Analysis and Results

Hamid Olimjon's *Muqanna* occupies a distinctive place in Uzbek dramaturgy as a poetic historical drama created at the intersection of wartime aesthetics and the politics of historical memory. The playwright began collecting materials for the work in 1937 and, after several stages of revision and refinement, completed the drama on May 31, 1942. Why, then, was the play not written earlier? Addressing this question, the literary scholar D. Quronov offers the following observation: "Although the intention to write it had emerged earlier, *Muqanna* remained unwritten for years. Why? Among the possible reasons, it should be noted that during the years of repression, writing a work that could be interpreted in the manner envisioned by the author would have been tantamount to risking one's life. From this perspective, it may even be said that the war created the conditions for the writing of *Muqanna*, since the wartime environment aligned it with a 'social demand.' In other words, the layer directed toward the social and spiritual needs of the wartime period concealed the layer through which the author sought to artistically comprehend his own era and his place within it through the prism of the past." From this, it can be concluded that the author's primary objective was to create an artistic conception of the people's struggle against invaders through the image of a historical leader. In this sense, *Muqanna* is not merely a historical account of a particular period; rather, it represents an attempt to reinterpret and dramatize historical material by connecting it meaningfully with the psychological and moral needs of the wartime era [6-8].

Scholarly conceptions of *Muqanna* (Hashim ibn Hakim) as a historical figure reveal, on the one hand, the diversity of available sources and the abundance of legends surrounding him and, on the other hand, the mythologized image of *Muqanna* as the "Veiled One." Historical accounts describe *Muqanna* as the leader of a rebellious movement in Sogdiana, whose activities—including the fortress near Kesh, military and political episodes connected with Samarkand and Bukhara, as well as narratives concerning the siege and his death—belong to the complex historical context of the second half of the eighth century.

A distinctive feature of Hamid Olimjon's poetic mastery lies in his ability to transform this complex system of historical facts and legendary perceptions surrounding the protagonist into a vivid dramatic conflict suited to the nature of the stage. What drives the dramatic action is not merely the historical fact itself, but rather the legends, myths, and collective aspirations for freedom that have developed around that fact over centuries.

In this context, the poetics of the play should not be understood solely as the use of beautiful poetic lines or verses; rather, it encompasses the system of artistic devices that perform specific dramatic functions. Studies devoted to *Muqanna* note that the text of the drama is constructed on rhymed couplets resembling the structure of the *masnavi*

form. Within a dramatic text, such a flexible rhyming mechanism provides an exceptionally effective rhythmic foundation for stage dialogue.

Hamid Olimjon's exceptional mastery as a dramatist is most clearly manifested in his ability to individualize the speech of his characters and to create artistic and dramatic credibility on stage. Motifs derived from folklore—such as legends, myths, and proverbs—do not function merely as external decorative elements; rather, they serve as mechanisms of dramatic argumentation and as means of revealing the psychological depth of the characters. For example, the stage-specific significance of the image of the “Veiled One” is established through popular rumors and legendary descriptions circulating among the people. Within the structure of the drama, the veil acquires a significant theatrical function. It intensifies the tension between doubt and belief in the popular imagination and serves as one of the central nodes of the play's dramatic conflict.

Conclusion

Hamid Olimjon's *Muqanna* stands as a landmark of Uzbek dramatic literature, demonstrating how historical subject matter can be elevated through exceptional poetic mastery to address the spiritual and ideological needs of its era. The drama successfully integrates the masnavi verse form, folklore elements, and rich symbolism to create a work that transcends its immediate historical context.

The image of *Muqanna*, enriched by centuries of legend and mythology, is transformed in Olimjon's hands into a universal symbol of freedom, justice, and resistance against oppression. The rhetorical devices—dialogue, monologue, oath, and blessing-prayer—serve not merely as literary ornaments but as instruments that reveal the inner world of the characters and drive the dramatic conflict forward.

In sum, the poetics of *Muqanna* represent a creative synthesis of national literary tradition, classical Eastern verse forms, and the demands of modern dramatic art. The work remains a vital object of scholarly inquiry and a testament to the enduring power of poetic drama as a vehicle for historical and national consciousness.

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UDC: 339.9(47)"18/19"

**RUSSIAN'S EXTERNAL ECONOMIC RELATIONS IN THE LATE
19TH - EARLY 20TH CENTURIES: MAIN DIRECTIONS AND
DEVELOPMENT TENDENCIES**

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Annotatsiya. Ushbu maqolada XIX asr oxiri – XX asr boshlaridagi tarixiy davrda Rossiyaning tashqi iqtisodiy aloqalari rivojlanishining asosiy yoʻnalishlari va tendensiyalari tahlil qilinadi. Rossiyada xorijiy tadbirkorlar faoliyatining huquqiy asoslarini shakllantirish, tashqi savdo munosabatlarini kengaytirish hamda mamlakat iqtisodiyotiga xorijiy sarmoyalarni jalb etish masalalarini oʻrganishga alohida eʼtibor qaratilgan.

Kalit soʻzlar: tashqi iqtisodiy aloqalar, qonunchilik-huquqiy baza, Rossiya, xorijiy sarmoya, investitsiyalar, tadbirkorlar, tashqi savdo.

Аннотация. В данной статье анализируются ключевые направления и тенденции развития внешнеэкономических связей России в исторический период конца XIX - начала XX века. Особое внимание уделяется исследованию формирования правовой основы деятельности иностранных предпринимателей в России, расширению внешнеторговых отношений, а также привлечению зарубежного капитала в экономику страны.

Ключевые слова: внешнеэкономические связи, законодательно-правовая база, Россия, иностранный капитал, инвестиции, предприниматели, внешняя торговля.

Abstract. This article analyzes the key directions and development trends of Russia's foreign economic relations during the late 19th and early 20th centuries. Particular attention is paid to the formation of the legal framework for foreign entrepreneurial activity in Russia, the expansion of foreign trade relations, and the attraction of foreign capital into the national economy.

Keywords: foreign economic relations, legislative and legal framework, Russia, foreign capital, investment, entrepreneurs, foreign trade.

Introduction

The historical evolution of foreign economic relations should be considered through the prism of the main directions and aspects of development. This primarily concerns the process of forming the legislative and regulatory framework for foreign economic activity, transforming foreign trade relations, and attracting foreign investment into the national economy.

Centuries of history testify to the complex and contradictory nature of the interaction in the development of the global and Russian economies. It should be noted that periods of mutually beneficial cooperation have repeatedly been replaced by stages of intense

competition. It is precisely these circumstances that largely determine the primary goals and objectives of studying the history of Russia's foreign economic relations.

During the historical period under consideration, Russia was integrated into the system of world historical processes. The country's geopolitical position objectively required its active participation in international politics. At the same time, Russia lagged behind the world's leading countries—Great Britain, the USA, France, and Germany—in terms of the concentration of financial capital.

At the end of the 19th century, Russia faced the strategic task of forming a modern industrial system and accelerating the pace of agricultural development. However, the limited economic resources did not allow the state to implement both directions of modernization simultaneously and in full.

Rapid industrial development in the 1890s, the strengthening of the financial system, and the introduction of the gold rouble stimulated the strengthening of the Russian economy, but these measures were insufficient to ensure equal competition with Western countries in the struggle for world markets.

Research Methodology

Foreign economic relations, including the dynamics of foreign trade, constitute a complex mechanism consisting of the emergence and development of its advanced forms and their interaction at various stages of historical development. The specifics of the evolution of foreign economic activity can only be fully studied and understood within the framework of historical consistency and continuity.

The study of the state of Russia's foreign economic relations should not be limited solely to the collection of historical facts and should not be reduced to a simple description of events. It should be noted that in historical and economic literature, many issues related to the history of Russia's foreign economic development, including a number of fundamentally important aspects, remain the subject of scholarly debate.

Analysis and Results

During the period under review, serious attention was paid to the formation of a legislative and regulatory framework governing the development of Russia's economic relations with foreign countries. Particular attention was paid to creating favorable conditions for attracting foreign direct investment, which is considered one of the most optimal and effective sources of financing for the modernization of the Russian economy.

In this regard, there is a need to develop a mechanism for legal guarantees for the financial and other material investments of foreign entrepreneurs, which, on the one hand, ensures the country's investment attractiveness and, on the other hand, fully meets the interests of the Russian state.

Legislation occupies a decisive place in the system of institutional norms for entrepreneurial activity, as it regulates relations between the state and business structures, as well as between economic entities. In this regard, the formation of a legislative framework defining the activities of foreign entrepreneurs on the territory of the Russian Empire became one of the priorities of state policy.

It should be noted that the legislation regulating foreign investment activities was naturally integrated into the general entrepreneurial legal system of Russia. The state

was very interested in attracting foreign entrepreneurship to the Russian Empire and considered it an important factor in accelerating the country's economic development.

Until the end of the 19th century, the influx of foreign private industrial capital into Russia was very limited. This situation is explained by the insufficient legal protection of foreign companies and citizens, the presence of serious restrictions on their activities, and the instability of the paper ruble exchange rate, which is characterized by depreciation. The monetary reform carried out in 1897 ensured the introduction of a stable national currency, contributing to the strengthening of the country's financial system. The adoption of a new customs tariff in 1891 was also of great importance. This tariff made the import of goods less profitable than the import of capital. As a result, these measures encouraged foreign entrepreneurs to establish subsidiaries and open branches of foreign companies on the territory of Russia [1-3].

It should be noted that in some cases, the norms of domestic legislation regulating the entrepreneurial rights of foreign citizens contradicted the provisions of international treaties concluded by the Russian Empire that defined the legal status of foreigners. The general grounds for the legal status and status of foreign nationals were established by the "Statutes of Status" [4]. The laws of January 1, 1863, and February 9, 1865, marked a turning point in the state's policy toward both Russian and foreign entrepreneurship. Starting from this period, the principles of the official equality of Russians and foreign citizens in the sphere of entrepreneurial activity were proclaimed in the Russian Empire. At the same time, the practical implementation of these principles was disproportionate.

In the 1880s, the government revised a number of regulatory acts defining the foundations of entrepreneurial activity. These legislative changes reflected the transformation of the legal status of foreign entrepreneurs. In particular, the Basic Laws of the Russian Empire enshrined the principle of equality for Russian and foreign citizens in the field of entrepreneurship. Attracting funds from abroad Minister of Finance S.Yu. It became one of the foundations of the economic policy pursued by Witte and his successors. Foreign capital entered the Russian economy mainly in two forms: through investments in economic sectors and loans. At the turn of the 19th and 20th centuries, the volume of foreign investment in shares and bonds of Russian enterprises reached approximately 1 billion rubles, and by the beginning of the First World War, it had increased to nearly 2 billion rubles. Their share accounted for about 1/3 of the country's total share capital. By the beginning of the 20th century, with the help of foreign investment, the "railway miracle" occurred in the country. Of the 50,000 kilometers of existing roads, 35,000 kilometers, or 70% of the total length, have been completed. For these purposes, Russia was provided with foreign loans in the amount of 1.5 billion gold rubles (the same amount after 1900), which was enormous for that period [5, 6].

The impact of foreign investment on the development of the Russian economy was not uniform. On the one hand, the influx of foreign investment served to accelerate industrialization processes. The high rates of industrial growth observed in Russia in the 1890s and from 1909 to 1913 were largely due to the import of capital.

Simultaneously with the influx of capital into the economy, another process that was much more important from a foreign policy perspective—the placement of Russian

loans and securities abroad—increased the financial dependence of the Russian Empire, and after February 1917, the Provisional Government, on foreign states.

The volume of foreign investment received in the form of loans was significantly higher than the volume of foreign direct investment directed into the country's economy. At the turn of the 19th and 20th centuries, it amounted to approximately 4 billion rubles, and by 1913, it had increased to 5.6 billion rubles. During the First World War, Russia's external debt increased sharply, reaching 7.25 billion rubles [7].

The conversion of Russian loans, which caused Russian securities to move from the German financial market to the French financial market, created an important economic foundation for strengthening allied relations with France. This loan, the largest in the history of pre-revolutionary Russia and placed in April 1906, had a significant impact on the tsarist government's subsequent foreign policy toward the Anglo-French Entente.

In this case, not only the government loans themselves but also the government-guaranteed loans of the railway companies were subject to conversion [8].

Although the effectiveness of this cooperation remained limited, the loan of 1909 served to strengthen Russia's interactions with France and Great Britain during the Bosnian crisis. French loans from the pre-war period were closely linked to the development of railway infrastructure in the western border regions of Russia, which corresponded to the tasks of rapid mobilization and deployment of the Russian army in a possible military confrontation with Germany.

The 1914–1917 military loans, in turn, contributed to the consolidation of the Entente powers and partially compensated for Russia's own limited economic potential, which played an important role in the allied struggle.

In the late 19th and early 20th centuries, the foreign trade of the Russian Empire developed at high rates comparable to the dynamics of the world market. Between 1894 and 1913, the total volume of the country's foreign trade turnover more than doubled. However, during this period, Russia's share of world trade increased only insignificantly.

Comparisons of key elements of foreign trade over time can provide useful insights into the developmental characteristics of Russia's economic relations with other countries and the direction of its national production [9].

Despite a significant increase in foreign trade indicators, Russia ranked eighth in the world in terms of foreign trade volume, trailing not only Great Britain, Germany, the United States, and France but also Austria-Hungary, the Netherlands, and Belgium [10]. In terms of foreign trade turnover per capita, Russia lagged far behind not only the leading industrialized nations but also countries such as Turkey, Iran, Bulgaria, and Greece. This situation was explained not only by the relatively low competitiveness of Russian goods in the global market but also by the peculiarities of the structure of the Russian economy: the majority of manufactured products were consumed on the domestic market.

At the end of the 19th and the beginning of the 20th centuries, the agrarian direction of exports remained in Russia: the bulk of exports consisted of agricultural products, accounting for nearly half of the total export volume.



During this period, the structure of imports was also characterized by relative stability. The most important imported goods included machinery and equipment, cotton, wool, tea, chemicals, and coal. The development of industry made it possible to gradually reduce the country's dependence on the import of finished industrial products. Nevertheless, on the eve of World War I, the Russian economy remained significantly dependent on imported machinery and equipment, machine tools, chemical goods, and certain non-ferrous metallurgical products.

There were a number of structural shortcomings in Russia's foreign trade, the process of eliminating which proceeded slowly and gradually. One of the main problems was the lack of significant capital outflow from the country, which limited the country's capabilities in the field of international economic relations. Despite the predominant role of maritime transport in foreign trade turnover, the insufficient development of the merchant fleet remained a serious obstacle. Limited financial resources complicated the creation of an effective system for lending trade operations, organizing cargo transportation, and storing goods.

Partial mitigation of these shortcomings was facilitated by active state support for foreign trade—namely, the implementation of a protectionist customs policy, export bonuses, and other economic incentives.

The Russian government attached great importance to the development of foreign trade, especially exports. The proceeds from the excess of exports over imports allowed for a positive balance of payments and served as “one of the most powerful drivers of economic progress” [11]. Indeed, in the period from 1904 to 1913 alone, foreign trade turnover contributed approximately 3.2 billion rubles to the country's economy.

For Russia, which had embarked on the path of industrialization, the creation of an effective system for the protection of the domestic market was of particular importance. Under these conditions, in 1891, the Russian government introduced a new foreign trade tariff characterized by extremely high customs rates.

By 1893, the 1891 tariff was maintained only for those countries that had granted Russia the most-favored-nation treatment. Additional bonuses have been established for other countries: 30% for finished products and 20% for semi-finished products. Later, protectionist policies were further intensified: in 1900, customs duties on luxury items were increased [12].

At the beginning of the 20th century, the Russian customs tariff was revised, and the new tariff came into legal force after its approval by the Emperor on 13 January 1903.

Customs duties have been significantly increased for 91 out of 218 articles of the previous tariff. The increase in rates primarily affected chemical products, machinery and equipment, machine tools, ferrous and non-ferrous metals, and products made from them. The introduction of the new tariff indicated the continuation and further strengthening of the government's protectionist economic policy.

The adoption of the 1903 tariff was closely linked to preparations for the revision of conventional trade agreements concluded by Russia in the 1890s.

Russia maintained the most intensive foreign trade relations with economically developed countries, primarily with European countries. In the pre-war years, they accounted for about 90% of Russian exports and 76% of imports, indicating a high degree of Russia's integration into the European international trade system [13].

A distinctive feature of Russian foreign trade was its orientation toward a relatively narrow circle of traditional trading partners.

Throughout the 19th century, the Russian economy maintained a system of foreign trade relations in which the excess of exports over imports was primarily ensured by stimulating the export of agricultural products, timber, and raw materials. The funds received were directed toward financing the import of industrial products. This system of trade and economic relations has undergone a long historical evolution: although the nomenclature of foreign trade turnover changed, its core economic essence remained unchanged.

Conclusion

During the period under review, Russia was not only an active participant in the European and global markets but also held leading positions in certain types of exports.

Overall, the development of Russia's economic ties with foreign countries in the late 19th and early 20th centuries was characterized by stable positive dynamics and was accompanied by the formation of a relatively multi-vector foreign economic policy.

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UDC: 316.346.32-053.9:061.2

THE SOCIAL ACTIVITY OF OLDER ADULTS IN THE INSTITUTIONAL DEVELOPMENT OF CIVIL SOCIETY: PARTICIPATION, EXPERIENCE, AND SOCIAL CAPITAL

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Annotatsiya. Ushbu maqolada qariyalarning fuqarolik jamiyati institutsional rivojidadagi ijtimoiy faolligi fuqarolik ishtirokchiligi, ijtimoiy tajriba va ijtimoiy kapital tushunchalari asosida tahlil qilingan. Tadqiqotda qariyalarning fuqarolik jamiyati institutlarida faol ishtirok etishi ijtimoiy barqarorlik va institutsional yetuklikni ta'minlashning muhim omili ekani ilmiy jihatdan asoslab berilgan. Sifatiy hamda aralash tadqiqot metodlariga tayangan holda olingan natijalar qariyalarni faqat ijtimoiy himoya ob'ekti sifatida emas, balki fuqarolik jamiyati rivojiga hissa qo'shuvchi faol ijtimoiy sub'ekt sifatida qayta talqin qilish zarurligini ko'rsatadi.

Kalit so'zlar: *qariyalar, fuqarolik jamiyati, ijtimoiy faollik, fuqarolik ishtirokchiligi, ijtimoiy kapital, institutsional rivojlanish.*

Аннотация. В данной статье социальная активность пожилых людей в институциональном развитии гражданского общества анализируется через призму понятий гражданского участия, социального опыта и социального капитала. В исследовании научно обосновано, что активное участие пожилых людей в институтах гражданского общества является ключевым фактором обеспечения социальной стабильности и институциональной зрелости. На основе качественных и смешанных методов исследования результаты демонстрируют необходимость переосмысления роли пожилых людей не как пассивных получателей социальной защиты, а как активных социальных акторов, вносящих вклад в развитие гражданского общества.

Ключевые слова: *пожилые люди, гражданское общество, социальная активность, гражданское участие, социальный капитал, институциональное развитие.*

Abstract. This article analyzes the social activity of older people in the institutional development of civil society through the concepts of civic engagement, social experience, and social capital. The study substantiates that the active participation of older people in civil society institutions is a key factor in ensuring social stability and institutional maturity. Using qualitative and mixed research methods, the findings demonstrate the need to reinterpret older people not as passive recipients of social protection but as active social actors contributing to civil society development.

Keywords: *older people, civil society, social activity, civic engagement, social capital, institutional development.*

Introduction

In contemporary societies, the development of civil society institutions is intrinsically linked to the active participation of various social groups, within which the social activity of older adults occupies a distinct and significant place [1]. In the context of intensifying demographic aging trends, there is an increasing need to reconsider older persons not merely as objects of social protection, but as active social subjects capable of ensuring the sustainable development of civil society [2].

In traditional societies, older adults played an essential role in collective decision-making processes, local governance systems, and the facilitation of intergenerational dialogue [3]. Their life experience, moral authority, and position within networks of social relations functioned as stabilizing factors that reinforced internal social cohesion. However, under the conditions of modern civil society, the effective utilization of these resources remains insufficiently explored at both scientific and institutional levels [4].

Amid processes of globalization, urbanization, and institutional reforms, the functions of civil society institutions have expanded, with increasing emphasis placed on efficiency, transparency, and civic participation [5]. In such circumstances, the involvement of older adults in public organizations, local self-government bodies, non-governmental non-profit organizations, and systems of public oversight emerges as a key indicator of the institutional maturity of civil society [6,7].

The aim of this article is to examine the social activity of older adults within the process of institutional development of civil society from the standpoint of social participation, accumulated life experience, and social capital, thereby providing a scientific justification of their contribution to social stability and institutional advancement [8].

Literature Review

In contemporary socio-humanitarian research, the development of civil society is increasingly interpreted in relation to the expansion of social participation among diverse segments of the population. In particular, the concept of “civic participation” has emerged as a significant theoretical category denoting individuals’ involvement in public affairs, non-governmental organizations, local governance processes, and mechanisms of public oversight.

Within the scholarly literature, civic participation is widely regarded as one of the fundamental factors ensuring institutional stability and democratic maturity. According to this approach, the activity of social groups and their inclusion in collective decision-making processes are intrinsically linked to the effective functioning of civil society institutions. However, in many studies, civic participation has been examined primarily through the lens of working-age populations, while the participation of older adults has been interpreted as limited or secondary.

Research Methodology

This study was conducted through an integrated application of qualitative and mixed-methods research approaches in order to achieve a comprehensive and multidimensional understanding of the social activity of older adults in the institutional

development of civil society. The theoretical and methodological foundation of the research is grounded in the concepts of civic participation and social capital.

Within the qualitative research framework, a content analysis method was employed to systematically examine scholarly sources related to civil society, the social activity of older adults, and social capital. This approach enabled the generalization of existing theoretical perspectives and the identification of key conceptual directions.

Within the mixed-methods framework, a comparative-analytical approach was applied to examine and contrast the role of older adults in civic participation across traditional and modern societal models. This approach facilitated an analysis of how the social activity of older adults adapts to evolving institutional environments.

The combination of these methodological approaches was aimed at ensuring the scientific validity, objectivity, and reliability of the research findings.

Analysis and Results

The findings of the study indicate that the social activity of older adults within civil society is directly associated with the level of institutional maturity of society. In contexts where active civic participation is well established, older adults emerge as significant social actors within non-governmental organizations, local governance bodies, and systems of public oversight.

The accumulated social experience and life knowledge of older adults may contribute to enhancing the effectiveness of civil society institutions. From the perspective of social capital, older individuals function as resources that stimulate collective action through trust-based relationships, informal networks, and intergenerational communication.

However, it was also observed that in contemporary societies, value systems oriented toward competitiveness and efficiency may constrain the civic participation of older adults. Such limitations reduce their social activity and hinder the full utilization of their existing social capital.

The discussion highlights the necessity of reinterpreting older adults not as passive objects of civil society but as active contributors to its institutional development.

Conclusion

This study provides scientific justification for considering the social activity of older adults as a significant social resource in the institutional development of civil society. The analysis demonstrates that the participation of older persons in civil society extends beyond age-related or social protection concerns and directly influences social stability and institutional maturity.

The research reveals that the integration of social participation, accumulated life experience, and social capital among older adults can enhance the effectiveness of civil society institutions. In particular, their involvement in non-governmental organizations, local self-government bodies, and public oversight mechanisms serves as an important factor in strengthening social trust and cooperative environments.

The findings further indicate that the increasing prioritization of efficiency and competitiveness in modern societies may limit the civic engagement of older adults. Such constraints impede the full mobilization of their social capital and reduce the developmental potential of civil society.



From this perspective, it is essential to reinterpret older adults not as passive beneficiaries of civil society, but as active social subjects contributing to its institutional advancement. This, in turn, necessitates the introduction of policy mechanisms aimed at encouraging and supporting the social participation of older persons in civil society processes.

In conclusion, expanding the civic participation of older adults and relying on their social capital constitute important conditions for strengthening civil society. The findings of this study may serve as a theoretical and practical foundation for strategies aimed at civil society development, social policy reform, and the promotion of intergenerational cooperation.

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UDC: 329:502.15

THE ROLE OF ECOLOGICAL PARTIES IN THE IMPLEMENTATION OF HUMAN ECOLOGICAL INTERESTS

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Annotatsiya. Ushbu maqolada, ekologik partiya jamoatchilikni tabiatning ahamiyati, uning ichki qiymati va atrof-muhitning tanazzulga uchrashi oqibatlarini to'g'risida tushuntirishga ustuvor ahamiyat berishlari kerakligi, bunga targ'ibot-tashviqot ishlari, maktablarda ta'lim dasturlari va jamoatchilikni targ'ib qilish tashabbuslari orqali erishish mumkinligi ochib berilgan. Shuningdek, ekologik partiya hayotning barcha jabhalarida, jumladan, qishloq xo'jaligi, transport, energiya iste'moli va chiqindilarni boshqarishda barqaror amaliyotlarni targ'ib qilishlari va qo'llab-quvvatlashlari kerak. Bu ekologik toza xatti-harakatlarni rag'batlantirish, barqaror amaliyotni qo'llaydigan korxonalarni qo'llab-quvvatlash va barqarorlik tamoyillarini shahar rejalashtirish va rivojlantirishga integratsiyalashuvini targ'ib qilishni o'z ichiga oladi.

Kalit so'zlar: ekologik partiya, ekologik etika, ekologiya, inson, tabiat, ekologik sivilizatsiya, antroposentrizm, ekologik muvozanat, ekologik qadriyat, bag'rikenglik, insonparvarlik, atrof-muhitni oqilona boshqarish, ekologik tajriba, taraqqiyot, atrof-muhit, ekologik inqiroz.

Аннотация. В данной статье показано, что экологические партии должны уделять приоритетное внимание просвещению населения о важности природы, ее внутренней ценности и последствиях деградации окружающей среды, чего можно достичь посредством информационно-просветительской работы, образовательных программ в школах и инициатив по повышению осведомленности общественности. Зеленая партия также должна продвигать и поддерживать устойчивые практики во всех аспектах жизни, включая сельское хозяйство, транспорт, энергопотребление и управление отходами. Это включает в себя поощрение экологически ответственного поведения, поддержку предприятий, внедряющих устойчивые методы работы, и содействие интеграции принципов устойчивого развития в городское планирование и развитие.

Ключевые слова: зеленая партия, экологическая этика, экология, человек, природа, экологическая цивилизация, антропоцентризм, экологический баланс, экологическая ценность, толерантность, человечество, рациональное управление окружающей средой, экологический опыт, развитие, окружающая среда, экологический кризис.



Abstract. This article reveals that ecological parties should give priority to educating the public about the importance of nature, its intrinsic value and the consequences of environmental degradation, which can be achieved through advocacy work, educational programs in schools, and public awareness initiatives. The green party should also promote and support sustainable practices in all aspects of life, including agriculture, transportation, energy consumption, and waste management. This includes encouraging environmentally friendly behavior, supporting businesses that adopt sustainable practices, and promoting the integration of sustainability principles into urban planning and development.

Keywords: *green party, environmental ethics, ecology, human, nature, ecological civilization, anthropocentrism, ecological balance, ecological value, tolerance, humanity, rational environmental management, ecological experience, development, environment, ecological crisis.*

Introduction

In the contemporary world, scientific and technological innovations have become the principal arena of international strategic competition, and rivalry for leadership in the frontiers of science and technology has reached an unprecedented level of intensity. In this context, strengthening ideological and political leadership, ensuring that representatives of science and technology strictly adhere to political discipline and established norms, promoting alternative forms of scientific research, and mobilizing efforts against the erosion of moral and ethical standards acquire particular urgency. Comprehensive support for specialists engaged in science and technology, encouraging them to actively confront the most complex challenges, creating the necessary conditions for achieving successful outcomes, and enhancing the role of political parties in attaining leading positions within advanced technological systems and the global scientific and innovation hierarchy are of paramount importance. The advancement of innovative initiatives, ensuring their consistent development, and reinforcing national technological sovereignty increasingly emerge as key strategic factors driven by political forces.

Literature Review

By the 1960s, various theories concerning environmental protection began to manifest in the “green” political movements of active non-governmental organizations and ecological political parties. Despite their diversity, these movements were united by a common orientation toward environmental protection, democratic decision-making, social justice, and a collective commitment to nonviolence. These movements were reflected in efforts to oppose ecoterrorism, deforestation, and environmental destruction caused by the mining industry. Furthermore, ecological movements came to be recognized and supported as a fundamental democratic right of individuals in modern society. Illustrative examples include protest campaigns in the 1970s and 1980s against the flooding of Lake Pedder and the damming of the Franklin River in Tasmania, nuclear accidents such as those at Three Mile Island in 1979 and Chernobyl in 1986, subsequent protests in the United States and Western Europe against the development of nuclear energy, long-standing demonstrations against uranium mining in northern Australia, including those related to the impacts on Aboriginal communities

at the Kabiluka site, and protests against deforestation in the Amazon basin in Indonesia and Brazil. These examples indicate that the primary objective of ecological movements is the protection of human rights. For instance, the Chipko movement in India, which links forest conservation with women's rights, and the Assembly of the Poor in Thailand advocate for the right of people to participate in environmental and developmental decision-making processes.

In developed countries, ecological movements have also been utilized within political competition to mobilize voters and to gain the support of socially vulnerable segments of the population. Existing "green" parties seek to apply the values of ecological philosophy to all aspects of national policy, including foreign policy, defense, and socio-economic strategies. The nomination of environmentally oriented candidates and the registration of green political parties in the early 1970s serve as clear examples of this trend. These parties emerged as new political organizations that incorporated environmental protection movements directly into governmental executive mechanisms, thereby making environmental protection a central component of state policy and contributing to the further democratization of state institutions. Notable early examples include the Values Party in New Zealand and the United Tasmania Group in Australia. Subsequently, in 1979, a green party was elected to the Swiss national legislature for the first time. By the mid-1990s, green political actors were also contesting mayoral positions in major European capitals such as Dublin and Rome. By the late 1980s, eco-activism had evolved into both a global and national political force. Several environmental non-governmental organizations, including Greenpeace, Friends of the Earth, and the World Wildlife Fund, established offices and centralized headquarters worldwide, becoming influential international institutions vis-à-vis developed states and their governments. A significant contributing factor to this development was the growing international support for ecological thinking.

Following the United Nations Conference held in Stockholm in 1972, the process of concluding multilateral environmental agreements and undertaking environmental obligations accelerated globally. This culminated in the 1992 United Nations Conference on Environment and Development in Rio de Janeiro, which brought together nearly 180 states, as well as representatives of business groups and non-governmental organizations, fundamentally transforming the nature and content of public discourse on environmental issues. In December 1997, an agreement signed in Kyoto by 192 countries to address global climate change collectively, along with subsequent summits organized under the auspices of the United Nations and agreements established in 2008 that brought together heads of state, significantly intensified the activities of government representatives, policymakers, industrial leaders, and investors. Over the past three decades, these major international environmental initiatives have acquired substantial importance. However, following the dissolution of the former Soviet Union, insufficient development in environmental governance within post-socialist states, combined with environmentally unsustainable practices and irrational use of natural resources, led to serious consequences. Today, ecological principles constitute one of the fundamental pillars of sustainable societal development. Humanity increasingly recognizes that the Earth, irrespective of geographical location or level of development, is a shared home. Accordingly, the



program of the Ecological Party of Uzbekistan emphasizes the humanistic character of this institution, underscoring that the protection of human interests, particularly the right to a healthy and clean environment, is central to ongoing reforms and highlights the urgent necessity of preserving and restoring the natural environment.

Analysis and Results

The study relies on the methods of objectivity, systematicity, continuity, comparative analysis, analysis and synthesis, generalization, historicity, and logical reasoning in scientific inquiry.

Human beings are composed of the same matter as the land, animals, and plants that surround them. However, in contemporary society, this fundamental reality is often neglected, as individuals tend to perceive themselves as the pinnacle of creation and view nature not as an integral part of existence but as an object of domination. Such attitudes and behaviors toward nature, along with increasing alienation from it, have led to indifference, ecological inequality, and environmental crises. Although measures are being taken to maintain ecological balance, existing international agreements and conventions remain insufficient to resolve these crises. Environmental degradation arises not only from natural causes such as global warming, droughts, floods, and glacial processes but also from anthropogenic activities. This form of degradation may be characterized as artificial destruction. Decisions made without consideration of environmental interests have both immediate and long-term consequences. Examples include deforestation for construction purposes, such as housing, roads, and bridges, and the reduction of green spaces. Influential international organizations, including the United Nations, have identified both natural environmental challenges, such as global warming, glaciation, and desertification, and anthropogenic problems, including deforestation and the pollution of air, water, and soil. The principle of resource sustainability seeks to ensure economic expansion in accordance with the vital interests of future generations and the natural environment.

Alienation from nature may hinder sustainable health for several reasons. Primarily, such alienation signifies a disconnection from one's own essence and origins. From a physical health perspective, returning to nature and reducing this alienation is essential. Various psychological studies demonstrate that a sense of connection with surrounding people or animals provides strong protection against depression and cardiovascular diseases. Caring for plant and animal life contributes positively to human well-being; for example, elderly individuals who tend to indoor plants often experience improved emotional states. These observations underscore the intrinsic connection between humanity and nature.

Conclusion

The large-scale implementation of such measures highlights the significant role of ecological parties, which can be explained by several factors. First, ecological parties often act as defenders of environmental protection and conservation, raising public awareness about the importance of nature and the consequences of its degradation, thereby fostering a deeper connection between society and the natural world. Second, these parties directly influence the formulation of public policies related to environmental protection, with their electoral campaigns and participation in

government contributing to the preservation of natural habitats, the reduction of pollution, and the mitigation of climate change impacts. Third, ecological parties frequently collaborate with local communities to promote sustainable practices and cultivate a sense of environmental stewardship through initiatives such as clean-up campaigns, tree planting, and other community-based activities. Finally, ecological parties cooperate with organizations at both national and international levels to address global environmental challenges, participating in conferences, agreements, and initiatives aimed at developing coordinated strategies for the protection of natural resources and biodiversity.

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ACTUAL PROBLEMS OF NATURAL SCIENCES

UDC: 574.2:614.7(575.172)

ECOLOGICAL FACTORS AND THEIR INFLUENCE ON THE HEALTH OF THE POPULATION OF THE REPUBLIC OF KARAKALPAKSTAN

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Annotatsiya. Mazkur maqolada Qoraqalpog‘iston Respublikasi aholisining salomatligi bo‘yicha tibbiy-geografik vaziyatning hozirgi holati tahlil qilingan. Tadqiqot natijasida tabiiy va antropogen omillarning aholi salomatligiga ko‘p omilli ta‘siri aniqlanib, ekologik inqiroz hududi hisoblangan Qoraqalpog‘iston Respublikasida kasallanish darajasining shakllanishiga ta‘sir etuvchi asosiy zamonaviy omillar yoritilgan. Shuningdek, hududlar kesimida kasalliklarning tarqalish qonuniyatlari o‘rganilib, ekologik jihatdan nisbatan qulay janubiy hududlardan noqulay shimoliy hududlarga tomon kasallanish darajasining ortib borishi kuzatilgan.

Kalit so‘zlar: *Qoraqalpog‘iston Respublikasi, aholi salomatligi, ekologik inqiroz, Orol dengizi, sho‘rlanish jarayoni, kasalliklarning hududiy tarqalishi, tabiiy omillar, antropogen omillar.*

Аннотация. В статье проанализировано современное медико-географическое состояние здоровья населения Республики Каракалпакстан. В результате исследования выявлено многофакторное влияние природных и антропогенных факторов на состояние здоровья населения, а также определены ведущие современные особенности формирования заболеваемости в экологически кризисном регионе. Кроме того, изучены закономерности территориального распространения заболеваний, при этом установлено увеличение частоты их возникновения от экологически более благоприятных южных районов к менее благоприятным северным районам.

Ключевые слова: *Республика Каракалпакстан, здоровье населения, экологический кризис, Аральское море, процесс засоления, территориальное распространение заболеваний, природные факторы, антропогенные факторы.*

Abstract. This article analyzes the current medical and geographical situation of public health in the Republic of Karakalpakstan. The study identifies the



multifactorial impact of natural and anthropogenic factors on population health and reveals the major contemporary factors influencing disease patterns in this ecologically crisis-affected region. Furthermore, the territorial distribution of diseases was examined, showing that the incidence of most diseases increases from the relatively environmentally favorable southern areas toward the less favorable northern areas.

Keywords: *Republic of Karakalpakstan, public health, ecological crisis, Aral Sea, salinization process, territorial distribution of diseases, natural factors, anthropogenic factors.*

Introduction

Currently, the scientific challenges of assessing the impact of environmental factors on human health are considered priority tasks of state environmental policy in almost all countries worldwide. Modern anthropogenic factors, reflecting various harmful effects on the environment, significantly influence overall biopotential, including the formation of public health. In this regard, the problem of conducting an effective environmental policy aimed at developing and implementing a systematic strategy for improving the living environment and self-purification of the natural environment is one of the pressing issues. Research aimed at developing the scientific basis for a comprehensive assessment of the state of natural and anthropogenic ecosystems is of great scientific and practical importance in the preservation of biodiversity [1-6].

The study of indicators of diseases of the population and the anthropoecosystem, as well as environmental parameters in various districts of the Republic of Karakalpakstan, is relevant.

Literature Review

Numerous studies related to the influence of various factors and the state of public health have convincingly proven that pollution of the environment and living conditions negatively affects public health (Abdirrov et al., 1995; Ataniyazova et al., 1998; Yeschanov 2001; Kurbanov et al., 2002, Mambetullaeva 2004a; 2004b; Ataniyazova et al., 2011; Kudaybergenova, 2017; Turdimambetov et al., 2024). Health is widely used in scientific research as a key indicator, reflecting humanity's ability to relatively effectively perform its social and biological functions under specific regional conditions. Novikov and Sakiev Berdnik, 2000; Pinigin Shandala Zvinyatskovsky. 2001; and others Rakhmanin., 2002, 2005; Tulakin et al., 2005, 2007; Krasovsky et al. 2008; Wright, 2002; et al. Hales., 2003).

Research Methodology

This study employs a comprehensive ecological, epidemiological, and statistical methodology to assess the influence of environmental factors on the health of the population of the Republic of Karakalpakstan. The research is based on the analysis of official morbidity data collected from health institutions across the districts of Karakalpakstan over the period from 2010 to 2024. Statistical data on disease prevalence were systematically gathered and categorized by nosological class, district, and age group to identify territorial patterns of morbidity distribution.

Environmental parameters, including the composition of atmospheric air and drinking water quality indicators such as sulfur dioxide, nitrogen dioxide, dust content, chlorides, and sulfates, were analyzed using correlation analysis to determine their relationship with overall morbidity rates among both adult and child populations. A medical-geographical zoning approach was applied to differentiate between the Northern and Southern zones of Karakalpakstan based on their ecological conditions. The conceptual transmission model of ecological pollution factors was used to trace the pathways of pollutant exposure — from pollution sources through environmental media (soil, air, and water) — to their potential health effects on the population. Literature data from regional and international scientific sources were incorporated to support and validate the obtained findings.

Analysis and Results

Problems of studying the impact of environmental pollution on human health:

- The impact of salt aerosol from the dried bottom of the Aral Sea on the ecological situation in the Southern Aral Sea region is not limited to soil salinization and plant erosion. It is known that an increase in the concentration of aerosols in the air affects the kinetics and dynamics of atmospheric processes;
- The accumulation of salts in soils creates arid climatic conditions due to the acceleration of the salinization process, the mineralization of groundwater, and the intensification of the evaporation state of the water regime;
- High demand for clean, high-quality water (due to the hot climate);
- Transboundary nature of large rivers;
- Agriculture is mainly oriented towards irrigation;
- Strong annual trend of increasing pollution of open water sources and groundwater reserves;
- Low level of centralized water supply, especially in rural settlements.

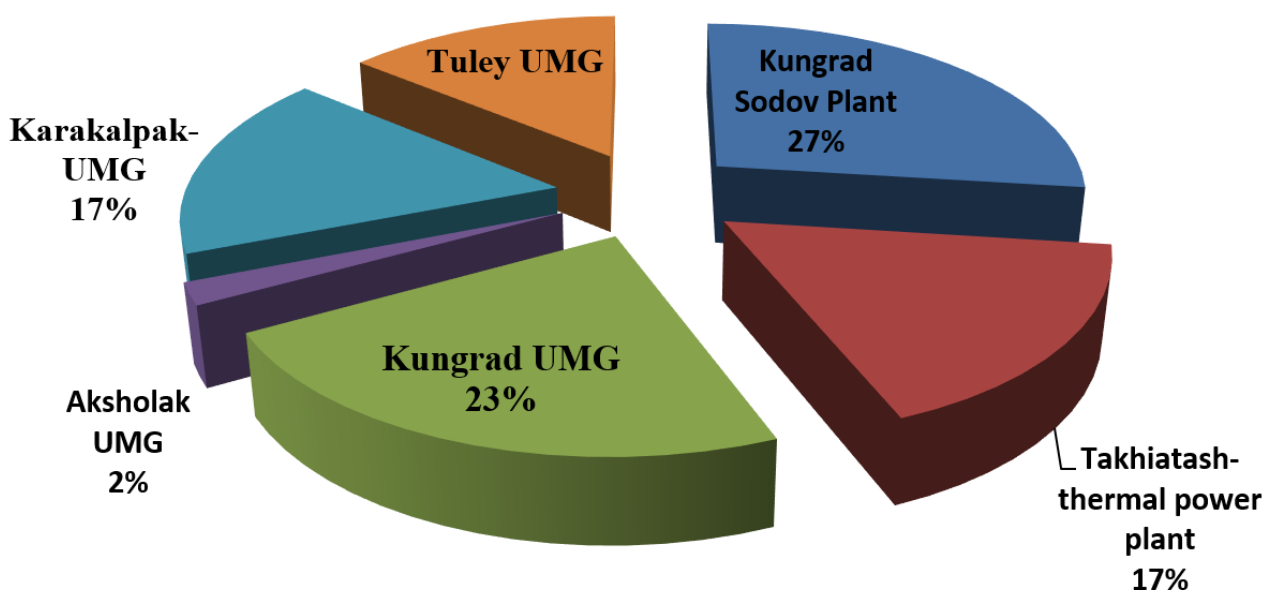
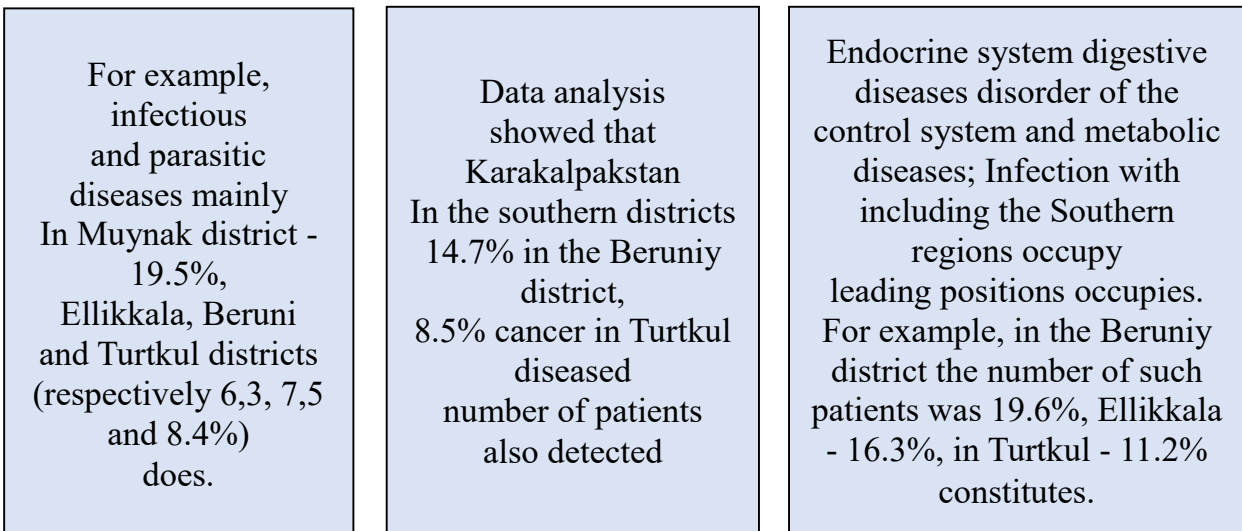


Figure 1. Dynamics of pollutant emissions from large enterprises in the Republic of Karakalpakstan.

Territorial by districts of the Republic of Karakalpakstan are distinguished by the fact that they differ from each other. By distribution Separate detection of the disease of registered patients. The highest percentage is mainly observed in the southern regions of Karakalpakstan.



According to a comparative analysis of the overall morbidity structure of the population of the Republic of Karakalpakstan, in 2010 the largest share of the overall morbidity structure was accounted for by blood diseases - 44.7%, respiratory diseases - 15.3%, endocrine diseases - 7.8%, and digestive diseases - 6.2%. By 2024, these diseases will reach 23.7; 22.1; 7.9; It changed to 8.3.

The high morbidity rate of the population of Karakalpakstan, including the classes of diseases and nosologies called environmental indicators by the World Health Organization (WHO), requires the improvement of sanitary and epidemiological methods and approaches, taking into account the specifics of the region.

Conceptual model of transmission and ecological factors of influence

- source of pollution
- The factor is transmitted through carriers (production, consumer goods, waste flows, etc.)
- environment, soil, air, water
- potential effect of a factor

Scientists have found that when pesticides enter the body, depending on the dose, acute chronic intoxication can develop. At the same time, any amount of them, like substances synthesized by the evolution of a foreign and unknown person, acquires xenobiotic properties and leads to adaptive changes in the body. The state of the body plays a significant role in the development of intoxication. Children, adolescents, sick and ill people, as well as pregnant and breastfeeding women are very sensitive.

Characterized by a variety of clinical manifestations. Functional disorders of the nervous system are expressed mainly in asthenic syndrome and vegetative-vascular dystonia associated with a pathological process of the cardiovascular system (hypotension, disruption of the rhythm of cardiac activity, function of cardiac muscle conductivity and contractility). Hypertrophic and subatrophic changes in the mucous membrane of the upper respiratory tract. Frequent chronic gastritis, hepatocholecystitis, hepatitis, inflammation, skin diseases, asymptomatic ulcer disease [7, 8, 9].

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During the analysis, a reliable correlation was revealed between the levels of some parameters in the composition of drinking water and atmospheric air and the overall morbidity of the adult and child population of Karakalpakstan. Thus, we found a weak correlation with the composition of atmospheric air, i.e., with sulfur dioxide ($R = 0.18$), with nitrogen dioxide ($R = 0.66$), and with the dust content of the surface air layer ($R = 0.54$).

The quality of drinking water is also related to the general morbidity of the population: the level of chlorides ($R = 0.43$) and sulfates ($R = 0.73$) in the water. The general morbidity of the child population is closely related to the quality of drinking water (with sulfates in water $P = 0.83$ and with chlorides $P = 0.52$). The analysis revealed a correlation with atmospheric air pollution: with nitrogen dioxide ($R = 0.58$) and with dust ($R = 0.53$). Although the environment consists of separate components, they are one whole.

Conclusion

As a result of the analysis of the current state of the medical and geographical situation in the health of the population of the Republic of Karakalpakstan, the general multifactorial influence of natural and anthropogenic factors was revealed, and the leading modern feature of the formation of morbidity of the population of the Republic of Karakalpakstan as an ecologically crisis region was identified.

Diseases intensively associated with environmental conditions were identified: diseases of the cardiovascular system, respiratory and digestive organs. The incidence

of these diseases is 69.5%, and their prevalence among the population of various regions of Karakalpakstan is 74.1%.

In the subpopulation of the Republic of Karakalpakstan, the main regularities of the territorial distribution of nosology in most cases are an increase in the frequency of occurrence from ecologically more favorable regions (Southern zone) to less favorable ones (Northern zone).

It was established that the prognostic indicators of the incidence of diseases of the genitourinary and circulatory system in the population have a significant tendency to increase, and fluctuations are cyclical in nature. The obtained prognostic regression models will serve as the basis for compiling a forecast of the overall morbidity of the population of the Republic of Karakalpakstan.

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