ACTUAL PROBLEMS OF MODERN SCIENCE, EDUCATION AND TRAINING

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CONTENTS

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INVESTIGATION OF SCATTERING Ar^+ IONS FROM CdSe(001) <110> SURFACE AT THE GLANCING INCIDENCE

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Annotatsiya. Ushbu maqolada CdSe(001) <110> sirtidan ψ= 3°, 5°, 7° tushish burchaklarida hamda ionlarning boshlang‘ich energiyasi E_0=3 va 5 keV bo‘lganda sochilgan Ar^+ ionlarining energiya taqsimotlari va xarakterli trayektoriyalari taqdim etilib, tahlil qilinadi. Olingan energiya spektrlarida ikkita intensiv cho‘qqi kuzatiladi; ular sirtning atom qatlami hamda yarim kanal tubidan sochilgan ionlarga mos kelishi aniqlangan. Mazkur ionlarning trayektoriyalari ham hisoblab chiqilgan. Tushish burchagi ortishi bilan sochilgan ionlar trayektoriyasining parallelligi o‘zgarishi va zigzagsimon shaklga ega bo‘lishi ko‘rsatildi. Sochilgan ionlar trayektoriyalarini o‘rganish ionlarning kristall ichki qismiga kirib borish chuqurligini aniqlash imkonini beradi.

Kalit so‘zlar: *ionlarning sochilishi, yarim kanal, kompyuter modellashtirish, energiya spektri, ion trayektoriyasi.*

Аннотация. В данной работе представлены и обсуждаются энергетические распределения и характерные траектории рассеянных ионов Ar^+ от поверхности CdSe(001) <110> при углах падения ψ =3°, 5°, 7° и начальной энергии E_0=3 и 5 кэВ. В полученных энергетических спектрах наблюдаются два интенсивных пика, которые соответствуют ионам, рассеянным от поверхностного атомного слоя и от дна поликанала. Также были рассчитаны траектории этих ионов. Показано, что с увеличением угла падения изменяется параллельность траектории рассеянных ионов, и она

приобретает зигзагообразную форму. Изучение траекторий рассеянных ионов позволяет определить глубину проникновения ионов во внутреннюю область кристалла.

Ключевые слова: *рассеяние ионов, поликанал, компьютерное моделирование, энергетический спектр, траектория иона.*

Abstract. In this paper, we present and discuss the energy distributions and characteristic trajectories of scattered Ar^+ ions from the CdSe(001) <110> surface at the angles of incidence ψ =3°, 5°, 7° and at the initial energy E_0=3 and 5 keV. In the obtained energy spectra, two intense peaks are observed, which are attributed to ions scattered from the surface atomic layer and the bottom of the semichannel. The trajectories of these ions are also calculated. It is shown that as the angle of incidence increases, the parallelism of the scattered ion trajectory changes and has a zigzag shape. Studying the trajectory of scattered ions makes it possible to determine the depth of ion penetration into the interior of the crystal.

Keywords: *ion scattering, semichannel, computer simulation, energy spectrum, ion trajectory.*

Introduction

The methods for studying surfaces refers to a set of methods and approaches used to analyze and study the physical, chemical or structural properties of the surface of various materials. These methods play a key role in materials science, nanotechnology, chemistry, and physics, because the surface of a substance has special properties that may differ significantly from the properties of a volume. One of the methods for studying surface layers is the method of small-angle ion scattering [1, 2].

Cadmium selenide (CdSe) is a binary compound that is often used in research due to its semiconductor and photoelectric properties. Its surface is studied in the context of areas such as photocatalysis, nanotechnology, sensors, LEDs, and solar panels. CdSe can exist in various crystal forms, including wurtzite and sphalerite (cubic) structures.The atomic structure of the CdSe surface strongly influences its properties, such as adsorption, chemical reactivity, and electronic structure. CdSe nanoparticles, known as quantum dots, have unique optical properties that depend on their size. The surface of nanoparticles plays a key role in their light-emitting and photocatalytic properties, so it is important to study surface passivation.

In this paper, we present the characteristic trajectories of scattered Ar^+ ions from the CdSe(001) <110> surface at small angles of incidence with the value of the initial energy E_0=3 and 5 keV [8, 9].

Research Methodology

The method of binary collision approximation (BCA) method is widely used in plasma physics, physical chemistry, molecular dynamics, and related fields. It was used to analyze interactions between particles in complex systems where full modeling of all possible interactions is impossible due to computational limitations [10-12]. This method is based on the assumption that paired particle collisions play a key role in the dynamics of a multicomponent system. Instead of taking into account all interactions simultaneously, only collisions between two particles are considered, ignoring their

interaction with the rest of the system during this collision. In this method, the forces, trajectories, and other parameters for each pair of particles are calculated based on the selected potential. Parameters describing collisions are averaged over the entire system to account for the contribution from a large number of particles. Paired collisions are used to obtain analytical or numerical results that approximate the dynamics of the entire system.

In this paper, we used the Ziegler-Birzak-Littmark potential. Inelastic energy losses were calculated using the Kishinevsky formula [13, 14].

Analysis and Results

Figure 1 shows the scheme of semichannels formed on the CdSe(001)<110> surface. This scheme allows us to understand the pattern of ion scattering from a semichannel. Note that the atoms on the CdSe(001) <110> surface are arranged in layers. As shown in the figure, the Cd atoms are located in the surface atomic rows, while the Se atoms are situated at the bottom of the half-channel [10, 11].

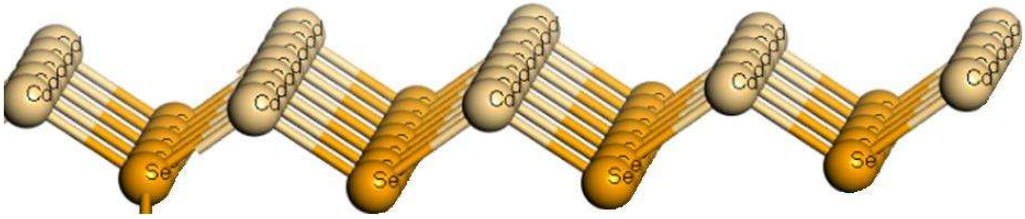

Figure 1. Semichannels formed on the CdSe(001) surface <110> and ion scattering scheme.

Figure 2 shows the energy distributions of scattered Ar+ ions from the CdSe(001) surface <110> at angles of incidence ψ =3°, 5°, 7° and at the value of the initial energy E_0=3 (a) and 5 (b) keV.

The obtained results showed that the energy distributions consist mainly of two intense peaks, which relate to the scattered ions from the surface atomic rows (1) and from the bottom of the semichannel (2). The intensity of the peak formed from the scattering of ions from the surface atomic rows at the considered values of the angle of incidence with an initial energy of 3 keV is less than the peak of scattered ions from the bottom of the semichannel (Figure 2a). The energy of scattered ions at ψ =3° from the surface atoms lies in the range of 2930-2986 eV, and for ions scattered from the bottom of the semichannel lies in the range of 2823-2929 eV. And at ψ =5°, this range is 2930-2986 eV and 2853-2929 eV, respectively [5, 6].

The energy distributions of scattered Ar+ ions at an initial energy of 5 keV are shown in Figure 2b. It can be seen that at ψ =3°, peaks 1 and 2 merge. And peak 2 has a small intensity. This shows that at this value of the initial energy, at small angles of incidence, ions are scattered mainly from the surface atomic rows. Ions scattered from the surface rows have energies in the range-4850-4849 eV, and ions scattered from the bottom of the semichannel have energies in the range 4751-4848 eV. At ψ =5°, peak 2 is more intense than peak 1, and this indicates that most of the incident ions were scattered from the semichannel. Energy of scattered ions from the surface atomic rows but it lies in the range of 4879-4950eV, and the peak of ions. Scattered from the bottom of the semi-channel lies in the range of 4876-4900 eV. At ψ =7°, peak 2 is also more intense than peak 1. In this case, the energy of the corresponding peaks 1 and 2 shifted

to the low-energy part in comparison with the above cases. And, accordingly, the energy of scattered ions from the surface semichannel and the bottom of the semichannel shifted to the low-energy part of the distribution.

We also obtained the trajectories of scattered Ar^+ ions with the CdSe (001) <110> surface, which were scattered from the surface atomic rows (1) and from the bottom of the surface semichannel (2) at ψ =3°, 5°, 7° and E_0=3 and 5 keV.

Figure 3 shows the characteristic trajectories of scattered Ar^+ ions from the CdSe (001)<110> surface at ψ =3° and E_0=3keV, which were scattered from the surface atomic rows (Figure 3a) and from the bottom of the surface semichannel (Figure 3b). From Figure 3a shows that the projections of the incident part and the reflected part of the trajectory coincide, which indicates the scattering of ions from the surface atomic rows. Our calculations show that the ion scattering coefficient in these trajectories is 11. Figure 3b shows several characteristic trajectories of the ions that formed peak 2 in the energy spectrum. The shape of these trajectories repeats the incident part during reflection, and at the very center of the semichannel, the shape of the particle's trajectories looks like a scattered ion from an atomic row. It should be noted, that all incident ions are scattered to the left of the original direction. Figure 4 shows the characteristic trajectories of scattered Ar+ ions from the CdSe (001) <110> surface at ψ =3° and E_0=3 keV, which were scattered from the surface atomic rows (Figure 4a) and from the bottom of the surface semichannel (Figure 4b). It is clear from Figure 4a that deviations from the main direction of incidence to the left side are observed with an increase in the angle of incidence. Our calculations showed that an increase in the angle of incidence also leads to decrease in the ion scattering coefficient. In this case, it is equal to k6. Figure 4b shows the characteristic trajectory of scattered ions from the bottom of the semi-channel. In this case, the ion scattering coefficient is 19-25. This indicates the presence of a trajectory with different values and the formation of a range of energy of scattered ions in the energy spectrum. It should be noted, that by studying the calculated trajectories, it is possible to determine the depth of penetration of scattered ions into the interior of the surface semichannel.

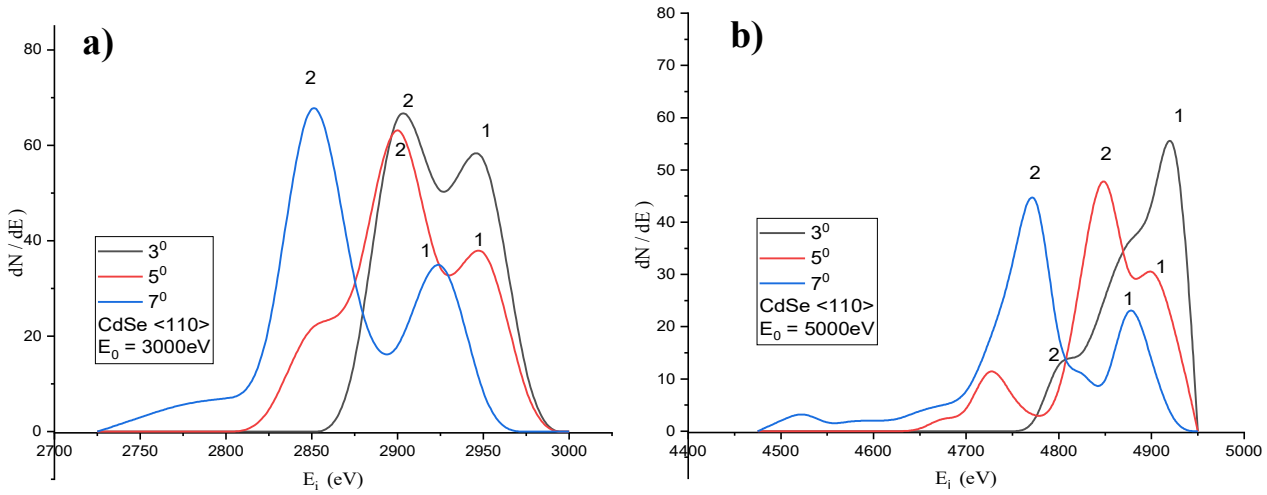

Figure 2. The energy distributions of scattered Ar^+ ions with the CdSe(001) <110> surface for angles of incidence ψ =3°, 5°, 7° and for the initial energy E_0=3(a) and 5 (b) keV.

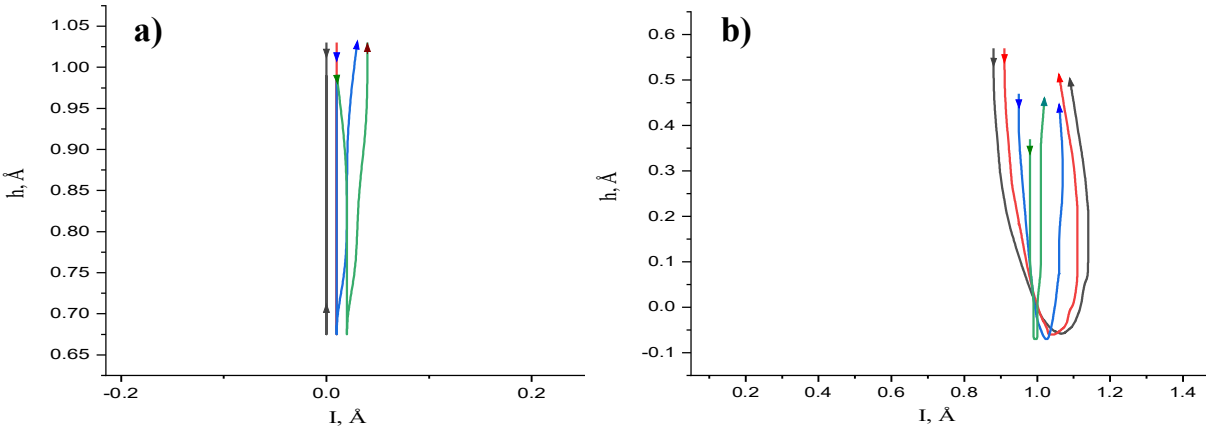

Figure 3. Characteristic trajectories of scattered Ar^+ ions with the CdSe (001) <110> surface at $\psi = 3°$ and $E_0=3$ keV, which were scattered from the surface atomic rows(a) and from the bottom of the surface semichannel (b).

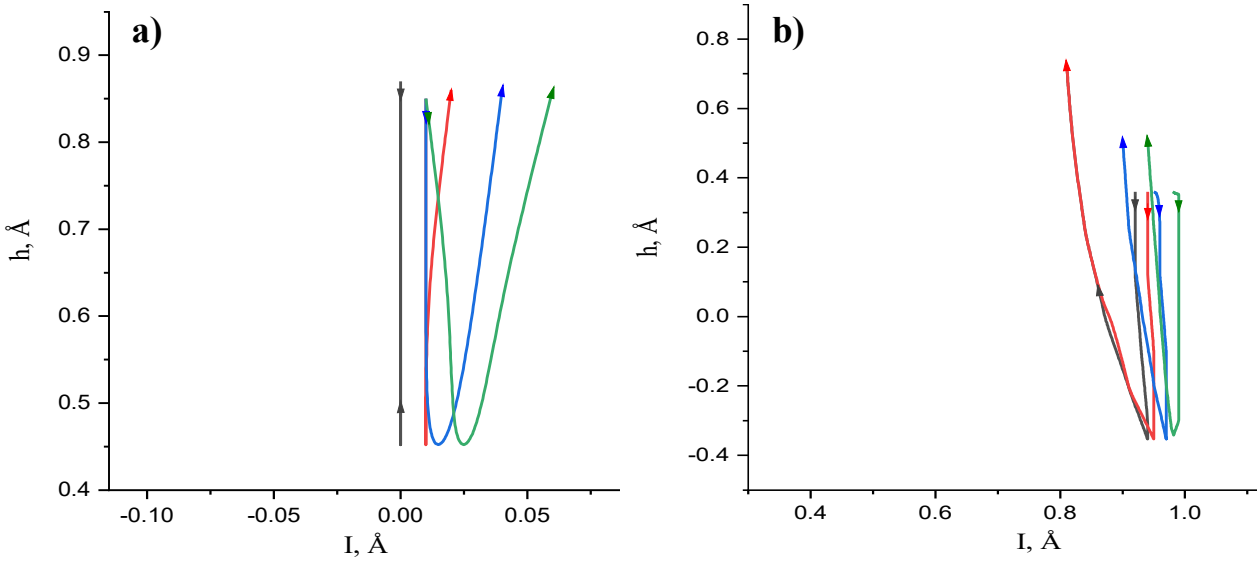

Figure 4. Characteristic trajectories of scattered Ar^+ ions with the CdSe (001) <110> surface at $\psi = 7°$ and $E_0=3$ keV, which were scattered from the surface atomic rows(a) and from the bottom of the surface semichannel (b).

Conclusion

We have studied the energy distributions and characteristic trajectories of scattered Ar^+ ions with the CdSe(001)<110> surface at the angles of incidence $\psi=3^0,5^0,7^0$ and at the initial energy $E_0=3$ and 5 keV. It is shown, that the energy spectrum contains intense peaks of scattered ions from the surface atomic rows and from the bottom of the semichannel. The calculated characteristic trajectories of scattered ions from the surface atomic rows are shaped in such a way that the incident and reflected parts are almost parallel. And, as the angle of incidence increases, this parallelism is not observed. And the trajectories of ions scattered from the bottom of the semichannel make it possible to determine the depth of ion penetration to the surface.

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APPROXIMATION OF m-CONVEX FUNCTIONS INFINITELY SMOOTH FUNCTIONS

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Annotatsiya. Ushbu maqolada biz $\mathbb{C}^n$ kompleks fazosida m-qavariq funksiyalar va m-subgarmonik funksiyalar o‘rtasidagi bog‘liqlikdan foydalanib, m -qavariq funksiyalarning yaqinlashishini o‘rganamiz. Asosiy natija $D \subset \mathbb{R}^n$ domenida aniqlangan har qanday $u(x)$ m-qavariq funksiya cheksiz silliq, monoton ravishda kamayib boruvchi m -qavariq funksiyalar ketma-ketligi bilan yaqinlashtirilishi mumkinligini tasdiqlovchi teoremadir. Yaqinlashish mos keladigan m-subgarmonik funksiyaga o‘tish va standart yadroni qo‘llash orqali olinadi. Bundan tashqari, biz $m \geq \frac{n}{2} + 1$ domenning har bir nuqtasida uzluksiz bo‘lgan m-qavariq funksiyaga misol keltiramiz.

Kalit so‘zlar: *m-qavariq funksiyalar, m-subharmonik funksiyalar, m-qavariq funksiyalarning yaqinlashishi, Gessian.*

Аннотация. В данной работе мы исследуем аппроксимацию m-выпуклых функций с использованием связи между m-выпуклыми функциями и m-субгармоническими функциями в комплексном пространстве $\mathbb{C}^n$. Основной результат — теорема, устанавливающая, что любая $u(x)$ m-выпуклая функция, определенная на области $D \subset \mathbb{R}^n$, может быть аппроксимирована последовательностью бесконечно гладких, монотонно убывающих m-выпуклых функций. Аппроксимация получается путем перехода к соответствующей m-субгармонической функции и применения стандартного ядра. Кроме того, мы приводим пример m-выпуклой функции, которая разрывна в каждой точке области для $m \geq \frac{n}{2} + 1$.

Ключевые слова: *m-выпуклые функции, m-субгармонические функции, аппроксимация m-выпуклых функций, Гессиан.*

Abstract. In this paper, we investigate the approximation of m-convex functions using the relationship between m-convex functions and m-subharmonic functions in the complex space $\mathbb{C}^n$. The main result is a theorem establishing that any $u(x)$ m-convex function defined on a domain $D \subset \mathbb{R}^n$ can be approximated by a sequence of infinitely smooth, monotonically decreasing m-convex

functions. The approximation is obtained by passing to the corresponding m - subharmonic function and applying the standard kernel. Furthermore, we give an example of an m-convex function that is discontinuous at every point of the domain for $m \geq \frac{n}{2} + 1$.

Keywords: *m-convex functions, m-subharmonic functions, Approximation of m-convex functions, Hessian.*

Introduction

m-convex functions are the real analogue of $\mathbb{R}^n$ strongly m-subharmonic functions in complex space $\mathbb{C}^n$. In the paper a number of properties of m-convex functions were indicated, in particular a very useful connection was established between m-convex and strongly m-subharmonic functions [1-13]. In this paper, we demonstrate a connection-based m-convex functions with strongly m-subharmonic functions, approximation of arbitrary $u(x)$ m-convex functions are a decreasing sequence of infinitely smooth functions $u_j(x) \in m - cv \cap C^\infty, u_j(x) \downarrow u(x)$.

1. Let us recall that the definitions strongly m-subharmonic (sh_m) and m-convex $(m - cv)$ functions. m-convex $(m - cv)$ function is a real analogue in $\mathbb{R}^n$ strongly m-subharmonic (sh_m) functions in a complex space $\mathbb{C}^n$. As we know sh_m −functions have now become the subject of research by many mathematicians (Blocki Z., Dinew S., and Kolodzei S. [3-5], Lu S.H.C. [6], Lu H.C., and Nguyen V.D. [8], Sadullaev A. and his disciples [1-2] and others).

Definition 1. A twice smooth function $u(z) \in C^2(D), D \subset \mathbb{C}^n$, is called strongly m-subharmonic $(1 \leq m \leq n)$ if at each point of the domain D

$$sh_m(D) = \{u \in C^2 : (dd^c u)^s \wedge \beta^{n-s} \geq 0, s = 1,2,\dots,n-m+1\} \qquad (1)$$

where $\beta = dd^c\|z\|^2$ −is a standard volume form in $\mathbb{C}^n$.

Operators $(dd^c u)^s \wedge \beta^{n-s}$ are closely related to the Hessians. After a suitable unitary coordinate transformation, the hermitian quadratic form $dd^c u = \frac{i}{2}\sum_{k,t} \frac{\partial^2 u}{\partial z_k \partial \bar{z}_t} dz_k \wedge d\bar{z}_t$ is reduced to the diagonal form $dd^c u = \frac{i}{2}[\lambda_1 dz_1 \wedge d\bar{z}_1 + \dots + \lambda_n dz_n \wedge d\bar{z}_n]$, where $\lambda_1, \dots, \lambda_n$ −the eigenvalues of the Hermitian matrix $\left(\frac{\partial^2 u}{\partial z_k \partial \bar{z}_t}\right)$, which are real $\lambda = (\lambda_1, \dots, \lambda_n) \in \mathbb{R}^n$.

Therefore, it is easy to see that

$$\left(dd^c u\right)^s \wedge \beta^{n-s} = s!(n-s)!H^s(u)\beta^n,$$

where is the Hessian $H^s(u) = \sum_{1 \leq j_1 < \dots < j_s \leq n} \lambda_{j_1} \dots \lambda_{j_s}$ −of the vector $\lambda = \lambda(u) \in \mathbb{R}^n$dimension s.

Therefore, a twice smooth function $u(z) \in C^2(D), D \subset \mathbb{C}^n$, is strongly m-subharmonic if at each point $o \in D$it satisfies the following inequalities:

$$H^s(u) \geq 0, \ s = 1,2,\dots,n-m+1.$$

Strongly m-subharmonic functions are also introduced in the class of upper semicontinuous locally integrable functions $u(x) \in L^1_{loc}(D)$.

Definition 2. A function $u \in L^1_{loc}(D)$ is called sh_m in a domain $D \subset \mathbb{C}^n$, if it is upper semicontinuous and for any twice smooth sh_m functions $w_1,...,w_{n-m}$ the current of the form $dd^c u \wedge dd^c w_1 \wedge ... \wedge dd^c w_{n-m} \wedge \beta^{m-1}$, defined as

$$\left[dd^c u \wedge dd^c w_1 \wedge ... \wedge dd^c w_{n-m} \wedge \beta^{m-1}\right](\omega) =$$

$$= \int u dd^c w_1 \wedge ... \wedge dd^c w_{n-m} \wedge \beta^{m-1} \wedge dd^c \omega, \quad \omega \in F^{0,0}$$

positive definite,

$$\int u dd^c w_1 \wedge ... \wedge dd^c w_{n-m} \wedge \beta^{m-1} \wedge dd^c \omega \geq 0 \quad \forall \omega \in F^{0,0},\ \omega \geq 0.$$

Let $D \subset \mathbb{R}^n$ and $u(x) \in C^2(D)$. The matrix $\left(\frac{\partial^2 u}{\partial x_k \partial x_t}\right)$ is symmetric, $\frac{\partial^2 u}{\partial x_k \partial x_t} = \frac{\partial^2 u}{\partial x_t \partial x_k}$. Therefore, after a suitable orthonormal transformation it is transformed into a diagonal form,

$$\left(\frac{\partial^2 u}{\partial x_k \partial x_t}\right) \to \begin{pmatrix} \lambda_1 & 0 & ... & 0 \\ 0 & \lambda_2 & ... & 0 \\ ... & ... & ... & ... \\ 0 & 0 & ... & \lambda_n \end{pmatrix},$$

where $\lambda_j = \lambda_j(x) \in \mathbb{R} -$ are the eigenvalues of the matrix $\left(\frac{\partial^2 u}{\partial x_k \partial x_t}\right)$. Let $H^s(u) = H^s(\lambda) = \sum_{1 \leq j_1 < ... < j_s \leq n} \lambda_{j_1} ... \lambda_{j_s}$ – the Hessian of the dimension s of the eigenvalue vector be $\lambda = (\lambda_1, \lambda_2, ..., \lambda_n)$.

Definition 3. A twice smooth function $u \in C^2(D)$ is called *m-convex* in $D \subset \mathbb{R}^n$, $u \in m - cv(D)$, if its vector of eigenvalues $\lambda = \lambda(x) = (\lambda_1(x), \lambda_2(x), ..., \lambda_n(x))$ satisfies the conditions

$$m - cv \cap C^2(D) = \left\{H^s(\lambda(x)) \geq 0, \forall x \in D,\ s = 1,...,n-m+1\right\}. \qquad (2)$$

When $m = 1$ the class of m-convex functions coincides with the class convex functions, and when $m = n$ it coincides with the class of subharmonic functions, which are known to be well studied. The class of m-convex $(m - cv)$ functions was considered in a series works of N. Trudinger, N. Ivochkin, X. Wang and others (see [7-12]) .

The following important statements are due to Trudinger-Wang [10]

Theorem 2. *An upper semi-continuous function $u(x)$ is $m - cv(D)$ if and only if for any domain $G \subset\subset D$ there exists a sequence $u_j(x) \in C^2(G) \cap m - cv(G)$: $u_j(x) \downarrow u(x)$.*

This fact can also be taken as a convenient definition $m - cv(D)$ of functions.

Definition 4. An upper *semi-continuous function* $u(x)$ *is called* m*-convex,* $u(x)\in m-cv(D)$, *if for any domain* $G\subset\subset D$ *there exists* $u_j(x)\in C^2(G)\cap m-cv(G): u_j(x)\downarrow u(x)$.

There is a very useful connection between convex functions and strongly m-subharmonic sh_m functions for using the well-known properties of function sh_m. For this purpose, we embed the real space $\mathbb{R}_x^n$ into the corresponding complex space $\mathbb{C}_z^n$, $\mathbb{R}_x^n\subset\mathbb{C}_z^n=\mathbb{R}_x^n+i\mathbb{R}_y^n(z=x+iy)$, as a real $n-$dimensional subspace.

Theorem 3. (see [13]) *A twice smooth function* $u(x)\in C^2(D), D\subset\mathbb{R}_x^n$ *is* $m-cv$ *in* D *if and only if a function* $u^c(z)=u^c(x+iy)=u(x)$ *that does not depend on variables* $y\in\mathbb{R}_y^n$, *is* sh_m *function in the domain* $D\times\mathbb{R}_y^n$.

Theorem 3 allows us to give a convenient definition $m-cv$ of functions in the class of semicontinuous functions

Definition 5. *An upper semi-continuous function* $u(x)$ *in domain* $D\subset\mathbb{R}_x^n$ *is called* m*-convex in* $D, u\in m-cv(D)$, if *the function* $u^c(z)$ *is* m*-subharmonic,* $u^c(z)\in sh_m(D\times i\mathbb{R}_y^n)$.

Note the following properties of $m-cv$ functions

1. If $u_j(x)\in m-cv(D), j=1,2,\dots,J, J\in\mathbb{N}, D\subset\mathbb{R}^n$, where $D\subset\mathbb{R}^n$, then for any non-negative $a_1\geq 0$, $a_2\geq 0,...,a_J\geq 0$ sum

$$a_1u_1(x)+a_2u_2(x)+...+a_Ju_J(x)\in m-cv(D).$$

2. If $\gamma(t)-$ convex, a function that is decreasing in the parameter t and $u(x)\in m-cv(D)$, then $\gamma\circ u(x)\in m-cv(D)$.

3. The limit of a decreasing or uniformly convergent sequence of $m-cv$ functions is again a $m-cv$ function, i.e. if $u_j(x)\in m-cv(D)$, $j=1,2,...$, $u_j(x)\downarrow u(x)$, or $u_j(x)\Gamma\ u(x)$, then $u(x)\in m-cv(D)$.

4. The maximum of a finite number of $m-cv$ functions is again $m-cv$ function, i.e. if $u_j(x)\in m-cv(D)$, $j=1,2,...,J$, $J\in\mathbb{N}, D\subset\mathbb{R}^n$ that $\max\{u_1(x),u_2(x),...,u_J(x)\}\in m-cv(D)$.

5. If the family $u_\alpha(x)\in m-cv(D), \alpha\in\Lambda$ locally uniformly bounded above, then the regularization $u^*(x)=\overline{\lim_{y\to x}}u(y)$ is a $m-cv$ function, $u^*(x)\in m-cv(D)$.

6. If $u(x)\in m-cv(D)$, then for any hyperplane $\Pi\subset\mathbb{R}^n$ the restriction $u|_\Pi$ is a $m-cv$ function, i.e. if $u(x)\in m-cv(D)$, then $u(x)|_\Pi\in m-cv(D\cap\Pi)$.

Note that property 6 makes sense only for $m<n$.

The following corollary establishes a connection between $m-cv$ functions and the classical subharmonic functions.

Corollary 1. *If* $u\in m-cv(D)$, *then for any plane of dimension* m, $\Pi\subset\mathbb{R}^n, dim_{\mathbb{R}}\Pi=m$, *the restriction* $u|_\Pi$ *is a sh function,* $u|_\Pi\in m-cv(D)=sh(D)$.

2. Approximation $m-cv$ **functions.**

In this section we demonstrate, based on the connection between $m-cv$ and sh_m – functions (Theorem 2), the approximation of an arbitrary $u(x)\in m-cv$ function by a decreasing sequence of infinitely smooth functions $u_j(x)\in m-cv\cap C^\infty$, $u_j(x)\downarrow u(x)$.

1) Example a $m-cv$ function that is discontinuous at all points of the domain. Aleksandrov $m=1$ and his students proved that a convex function $u(x)\in 1-cv(D)$ is always Lipschitz continuous, $u(x)\in Lip(D)$. Trudinger and Wong [9] proved a generalization of this remarkable result, that any m-convex function $u(x)$ under condition $m<\frac{n}{2}+1$ is Hölder continuous with exponent $\alpha=2-\frac{n}{n-m+1}$, $u(x)\in Lip_\alpha(D)$. Below we construct an example of a $m-cv$ function (Theorem 2) that is discontinuous at each point in the domain. An example of a fundamental $m-cv$ function

$$\chi_m(x,0)=\begin{cases}|x|^{2-\frac{n}{n-m+1}} & if \quad m<\dfrac{n}{2}+1\\ \ln|x| & if \quad m=\dfrac{n}{2}+1\\ -|x|^{2-\frac{n}{n-m+1}} & if \quad m>\dfrac{n}{2}+1\end{cases} \tag{2.5}$$

shows that there $m\geq\frac{n}{2}+1$ is discontinuous $m-cv$ functions. $m-cv(\mathbb{R}^n)$ function $\chi_m(x,0)$ has a pole at the point $x=0$.

Theorem 2. *For $m\geq\frac{n}{2}+1$ there is a $m-cv(\mathbb{R}^n)$ function $u(x)\not\equiv-\infty$ such that $u(x)$ it is discontinuous at each point in space $\mathbb{R}^n$.*

Proof. Let us use the fundamental $m-cv$ function

$$\chi_m(x,\xi)=\begin{cases}|x-\xi|^{2-\frac{n}{n-m+1}} & if \quad m<\dfrac{n}{2}+1\\ \ln|x-\xi| & if \quad m=\dfrac{n}{2}+1.\\ -|x-\xi|^{2-\frac{n}{n-m+1}} & if \quad m>\dfrac{n}{2}+1\end{cases}$$

It has a pole at the point $x=\xi$. Let be $\{x^j\}$ the numbered set of all points with rational coordinates and $p\in\mathbb{R}^n$ a fixed irrational point. Let us $u(x)=\sum_{j=1}^{\infty}\varepsilon_j\frac{\ln|x-x_j^j|}{j+|x^j|}$ set $m=\frac{n}{2}+1$ and $u(x)=-\sum_{j=1}^{\infty}\frac{\varepsilon_j}{|x-x^j|^{2-\frac{n}{n-m+1}}}$, for $m>\frac{n}{2}+1$, where $\varepsilon_j>0$, $j=1,2,\ldots$, are chosen so that $u(p)=-1$. Then, for any compact set $K\Subset\mathbb{R}^n$ the terms of the second row are negative for all $j\geq1$ and those of the first row are negative starting from some

number $j \geq j_0(K)$. Consequently, the terms of the series are negative at least starting from some number $j \geq j_0(K)$. Hence, the partial sums decrease and the function $u(x)$ is a m-convex function in $\mathbb{R}^n$. Moreover, since $u(p) = -1$, it is not identically equal to $-\infty$. It follows from this that it is not equal to $-\infty$ almost everywhere in $\mathbb{R}^n$ and has a discontinuity at each point $x^0 \in \mathbb{R}^n$, since $u(x) = -\infty$ on an everywhere dense set $\{x^j\}$.

2) Approximation. The following approximation takes place theorem

Theorem 2.3. *For any m-convex function $u(x) \in m-cv(D)$ in the domain $D \cap \mathbb{R}^n$ there exists an exhaustion $D_1 \subset D_2 \subset ...$, $D = \bigcup_j D_j$, and a sequence of infinitely smooth, monotonically decreasing functions $u_j(x) \in m-cv(D_j) \bigcap C^\infty(D_j)$ such that $u_j(x) \downarrow u(x)$ $\forall x \in D$.*

Proof. Using Theorem 2.1, we embed the space $\mathbb{R}_x^n$ in the complex space $\mathbb{C}_z^n$, $\mathbb{R}_x^n \subset \mathbb{C}_z^n = \mathbb{R}_x^n + i\mathbb{R}_y^n$ $(z = x + iy)$, let us build a lift $u^c(z) = u^c(x+iy) = u(x) \in sh_m(D \times i\mathbb{R}_y^n)$.

We take into $\mathbb{R}_x^n$ the standard kernel $K_\delta(x) = \frac{1}{\delta^n} K\left(\frac{x}{\delta}\right) \geq 0$, $\delta > 0$, where

1) $K(x) = K(|x|)$;
2) $K(x) \in C^\infty(\mathbb{R}^n)$;
3) $\operatorname{supp} K = B(0,1)$;
4) $\int_{\mathbb{R}^n} K(x)\,dx = \int_{B(0,1)} K(x)\,dx = 1$.

Let us $K(z) = K(x+iy) = K(x)$. Fix a unit parallelepiped $\Pi \subset \mathbb{R}_y^n$. We take the convolution

$$u_\delta^c(z) = \int_{D_x \times i\Pi_y} u^c(z+w) K_\delta(z)dx = \int_{\mathbb{R}_x^n \times i\Pi_y} u^c(z+w) K_\delta(z)dx.$$

The first integral gives us a $sh_m -$ function, and the second integral is infinitely smooth. Since $u^c(z) = u^c(x+iy) = u(x)$, $K(z) = K(x+iy) = K(x)$, then the integral $\int_{D_x \times i\Pi_y} u^c(z+w) K_\delta(z)dx$ moreover, it does not depend on y. Therefore,

$$u_\delta^c(z) = u_\delta(x) = \int_{D_x \times i\Pi_y} u^c(z+w) K_\delta(z)dxdy = \int_{D_x} u(x-\xi) K_\delta(x)dx$$

and $u_\delta(x)$ is a m-convex $C^\infty -$function in the domain $D_\delta = \{x \in D : \operatorname{dist}(x, \partial D) > \delta\}$. Moreover, since the sequence $u_\delta^c(z)$ monotonically decreases and converges to $u^c(z)$, then $\delta \downarrow 0$, the sequence $u_\delta(x)$ is also monotonically decreasing and converges to the given function $u(x)$. Now, to complete the proof of the theorem, it is suffices to take $\delta = \frac{1}{j}$.

Conclusion

In this paper, we investigate the class of m-convex functions as an important generalization of convex and subharmonic functions and establish their close

relationship with the class of strongly m-subharmonic functions in complex space. Using this embedding, we have been able to extend the well-developed theory of m-subharmonic functions to the real case and obtain effective approximation results.

The main result of the paper is the proof of an approximation theorem, according to which any m-convex function in a domain $D \subset \mathbb{R}^n$ can be represented as the pointwise limit of a decreasing sequence of infinitely smoot m-convex functions on exhaustive subdomains. This approximation is constructed using regularization with a standard smoothing kernel after passing to the corresponding m-subharmonic function in complex space.

Furthermore, the paper provides an example of a m-convex function that is discontinuous at all points in the domain for $m \geq \frac{n}{2} + 1$, highlighting the fundamental difference in the behavior of m-convex functions from classical convex functions and demonstrating the essential dependence of regularity on the parameter m. The obtained results expand the theory of m-convex functions and can be used in further studies of Hessian equations, potential theory, and nonlinear problems in mathematical physics.

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FIRST-PRINCIPLES MODELING OF STRUCTURAL AND ELECTRONIC PROPERTIES OF $(Ge_2)_{1-x}(InP)_x$ ALLOYS

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Annotatsiya. Ushbu ishda $(Ge_2)_{1-x}(InP)_x$ qattiq eritmalarining to‘liq tarkib oralig‘idagi ($0 \le x \le 1$) strukturaviy va elektron xususiyatlarining birinchi tamoyilli tadqiqoti keltirilgan. Hisob-kitoblar zichlik funktsional nazariyasi doirasida barcha elektronli FHI-maqsadlar kodidan foydalangan holda, strukturaviy optimallashtirish uchun r2SCAN va spin-orbita bog‘lanish effektlarini o‘z ichiga olgan aniq polosali bo‘shliqni baholash uchun HSE06 yordamida amalga oshirildi. Natijalar shuni ko‘rsatadiki, panjara parametrlari Vegard qonuniga muvofiq tarkib bilan ortib boradi. Polosali struktura kuchli tarkibga bog‘liqlikni namoyon etadi, polosali bo‘shliqning kamayishi va oxir-oqibat polosali oraliq konsentratsiyalarda ($x \approx 0.5$) polosali ustma-ust tushishi kuzatiladi. Bu effektlar elektron holat gibridlanishiga bog‘liq. Topilmalar ushbu qotishmalarning sozlanishi mumkin bo‘lgan optoelektronik qo‘llanmalar uchun potentsialini ta’kidlaydi.

Kalit so‘zlar: *(Ge2)1-x(InP)x qotishmalari; zichlik funktsional nazariyasi (DFT); FHI-aims; meta-GGA; taqiqlangan zona muhandisligi*

Аннотация. В данной работе представлено исследование структурных и электронных свойств твердых растворов $(Ge_2)_{1-x}(InP)_x$ в полном диапазоне составов ($0 \le x \le 1$) на основе первых принципов. Расчеты проводились в рамках теории функционала плотности с использованием полноэлектронного кода FHI-aims, с r2SCAN для структурной оптимизации и HSE06 для точной оценки ширины запрещенной зоны, включая эффекты спин-орбитальной связи. Результаты показывают, что параметры решетки увеличиваются с составом в соответствии с законом Вегарда. Зонная структура демонстрирует сильную зависимость от состава, с уменьшением

ширины запрещенной зоны и последующим перекрытием зон при промежуточных концентрациях (x ≈ 0,5). Эти эффекты объясняются гибридизацией электронных состояний. Полученные результаты подчеркивают потенциал этих сплавов для настраиваемых оптоэлектронных применений.

Ключевые слова: *сплавы $(Ge_2)_{1}$-x(InP)x; теория функционала плотности (DFT); FHI-aims; мета-GGA; инженерия ширины зоны*

Abstract. This work presents a first-principles study of the structural and electronic properties of $(Ge_2)_{1-x}(InP)_x$ solid solutions across the full composition range ($0 \leq x \leq 1$). Calculations were performed within density functional theory using the all-electron FHI-aims code, with r2SCAN for structural optimization and HSE06 for accurate band gap evaluation, including spin–orbit coupling effects. The results show that lattice parameters increase with composition following Vegard's law. The band structure exhibits strong composition dependence, with band gap reduction and eventual band overlap at intermediate concentrations (x ≈ 0.5). These effects are attributed to electronic state hybridization. The findings highlight the potential of these alloys for tunable optoelectronic applications.

Keywords: *$(Ge_2)_{1-x}(InP)_x$ alloys; density functional theory (DFT); FHI-aims; meta-GGA; band gap engineering*

Introduction

The incorporation of optoelectronic capabilities into the well-established silicon technology platform remains a key challenge in contemporary semiconductor physics and device engineering. Silicon provides significant technological and economic benefits, such as low production cost, availability of large-area wafers, and a highly advanced fabrication ecosystem. Nevertheless, its indirect band gap and relatively low optical efficiency limit its applicability in active photonic devices.

To address these shortcomings, considerable research efforts have focused on integrating silicon with III–V semiconductor materials, which exhibit superior electronic and optical properties, making them highly suitable for light-emitting, sensing, and high-speed optoelectronic applications [1, 2].

Literature Review

Since the 1980s, the heteroepitaxial growth of III–V semiconductors on silicon substrates has been активно investigated as a pathway toward monolithic integration of electronic and photonic functionalities within a single technological platform. The rapid development of silicon photonics in recent years has further stimulated interest in III–V/Si hybrid systems, particularly those based on GaAs and InP, due to the increasing demand for silicon-compatible light sources and integrated photonic devices [3–5].

However, despite substantial progress, issues such as lattice mismatch, differences in thermal expansion coefficients, and defect generation continue to limit the efficiency and long-term stability of many heteroepitaxial structures. These limitations drive the

search for alternative material systems that can offer improved structural compatibility with silicon while retaining desirable optoelectronic properties.

In this regard, IV–III–V alloy systems emerge as a promising yet relatively малоизученная class of materials. The incorporation of III–V components into group-IV matrices opens up opportunities for band-gap tuning and controllable optical responses, while maintaining partial технологическая совместимость with silicon-based platforms. Among these materials, $(Ge_2)_{1-x}(InP)_x$ solid solutions are of particular interest, as they combine a group-IV host material with InP, a well-established III–V semiconductor широко применяемый в оптоэлектронике [6, 7]. Experimental studies have already confirmed the possibility of synthesizing $(Ge_2)_{1-x}(InP)_x$ alloys and have reported their structural and electrophysical characteristics [8-10]. Nevertheless, a comprehensive theoretical description of the influence of composition on their electronic structure and optical behavior across a wide concentration range remains insufficient.

First-principles methods based on density functional theory (DFT) offer a reliable and powerful approach for establishing quantitative relationships between composition and physical properties in semiconductor alloys. Although DFT has been extensively applied to traditional III–V and IV–IV systems, detailed theoretical studies of Ge–InP mixed alloys are still limited. In particular, the evolution of band structure features, dielectric response, and optical parameters over the entire compositional range has not yet been systematically addressed [11, 12].

In this work, this gap is addressed through a systematic first-principles investigation of the structural and electronic properties of $(Ge_2)_{1-x}(InP)_x$ solid solutions in the full composition range ($0 \leq x \leq 1$). Special emphasis is placed on composition-driven modifications of the band structure, the possibility of semiconductor–semimetal transitions, and the tunability of optical properties relevant to silicon-compatible photonic technologies. By establishing quantitative relationships for lattice parameters, electronic behavior, and dielectric characteristics, this study aims to provide a solid theoretical basis for band-gap engineering in Ge–InP-based alloys and to support their application in next-generation photonic integrated circuits.

Research Methodology

All calculations were performed within a periodic boundary framework using the conventional cubic germanium (Ge) unit cell as the host material. To systematically investigate the structural and electronic properties of the $(Ge_2)_{1-x}(InP)_x$ solid solutions, substitutional configurations were constructed for concentrations corresponding to x = 0, 0.25, 0.5, 0.75, and 1. Periodic boundary conditions were applied in all three spatial directions throughout the study.

The computational investigation was carried out using the strictly all-electron FHI-aims code [13], which employs numeric atom-centered orbitals (NAOs) and treats both core and valence electrons explicitly without the use of pseudopotentials. Structural relaxations were performed using the r2SCAN meta-generalized gradient approximation (meta-GGA) exchange-correlation functional [14], chosen for its accuracy in capturing the structural properties of semiconductor solid solutions. Scalar

relativistic effects were incorporated via the zeroth-order regular approximation (ZORA) [15].

It is well established that standard local and semi-local functionals tend to severely underestimate fundamental band gaps in semiconductors. Therefore, to obtain highly accurate electronic band structures, single-point calculations were subsequently performed on the optimized geometries using the HSE06 screened hybrid exchange-correlation functional [16, 17]. The exact exchange mixing parameter was set to $\alpha = 0.30$, with a screening parameter of $\omega = 0.11$ bohr^{-1}. To manage the computational expense associated with the exact exchange, the "LVL_fast" resolution of identity (RI) method was employed. Furthermore, given the presence of heavy elements (In), spin-orbit coupling (SOC) was included perturbatively using a non-self-consistent approach.

The explicitly treated valence electron configurations were Ge: $3d^{10}\,4s^2\,4p^2$, In: $4d^{10}\,5s^2\,5p^1$, and P: $3s^2\,3p^3$.

High numerical accuracy settings were enforced across all calculations to ensure reliable results. For the basis sets, "tight" defaults were utilized, supplemented by additional highly localized basis functions (up to "Second tier" g-functions for Ge). Geometry optimizations were executed until the maximum residual atomic forces were minimized to strictly below $5 * 10^{-4}\ eV/Å$, and total unit cell parameters were fully relaxed. The Brillouin zone was sampled using a dense 12×12×12 Monkhorst-Pack [18] k-point mesh. For the electronic band structure analysis, a high-density k-path along the high-symmetry directions (Γ - X - M - Γ - R - X) was utilized.

Analysis and Results

Ge-doped InP-based supercells were constructed using an InP supercell. Doping was introduced by substituting two Ge atoms for In–P pairs (Figure 1). Structural relaxation was performed using variable-cell (vc-relax) calculations, which allowed for simultaneous relaxation of the lattice parameters and atomic positions. These calculations utilized converged and optimized computational parameters obtained for pure Ge and InP, without further modifications, to ensure numerical consistency across all systems.

The values of the lattice constants for the different compositions of the alloy determined after full relaxation were as follows:

x=0 (Ge): a=5.674377 Å, b=5.674679 Å, c=5.674379 Å;
x=0.25: a=5.749185 Å, b=5.749187 Å, c=5.749187 Å;
x=0.5: a=5.773657 Å, b=5.773661 Å, c=5.877951 Å;
x=0.75: a=5.852070 Å, b=5.852072 Å, c=5.852072 Å;
x=1 (InP): a=5.903694 Å, b=5.903695 Å, c=5.903695 Å.

It can be seen that in the case of pure substances, the lattice constants, which have symmetry in all directions, are practically unchanged. Here, in the composition at x=0.5 there is a significant stretching along the s axis, which can be seen as a change in symmetry from cubic to tetragonal or orthorhombic.

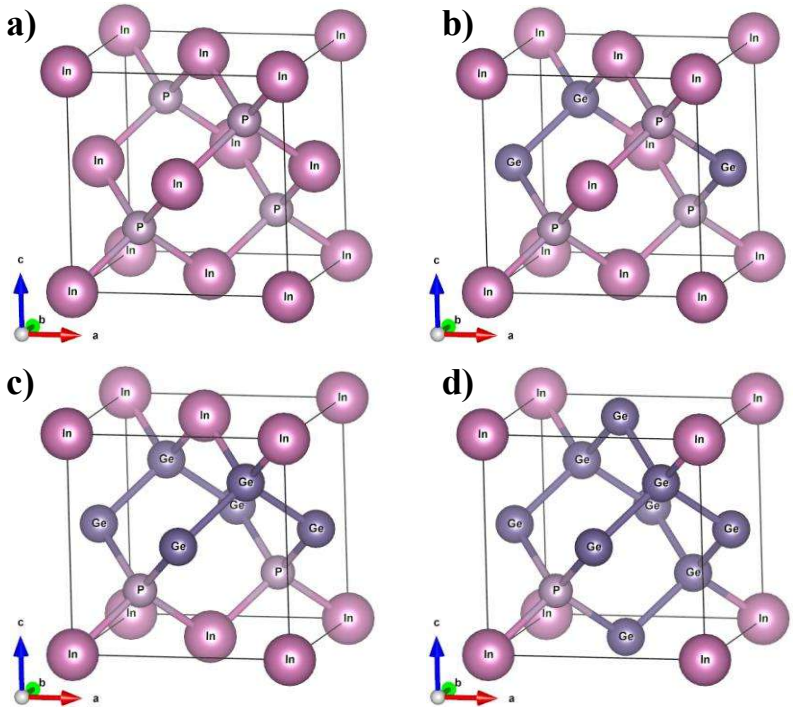

Figure 1. a) Optimized conventional unit cell of the InP crystal, b) Relaxed crystal structure of the $(Ge_2)_{1-x}(InP)_x$ solid solution at x = 0.75, c) Relaxed crystal structure of the $(Ge_2)_{1-x}(InP)_x$ solid solution at x = 0.5, d) Relaxed crystal structure of the $(Ge_2)_{1-x}(InP)_x$ solid solution at x = 0.25.

It can be seen from the results that with increasing x (as InP atoms are introduced instead of Ge atoms), the lattice parameters increase systematically from 5.67 Å to 5.90 Å. According to Vegard's law, such a linear or close to linear increase is typical for solid alloys. Especially in the composition with x=0.5, the asymmetry (along the c axis) is clearly visible, which is associated with the local stresses created by the atoms. As shown in Figure 2, the lattice parameter varies with composition according to Vegard's law and is in good agreement with experimental data [7].

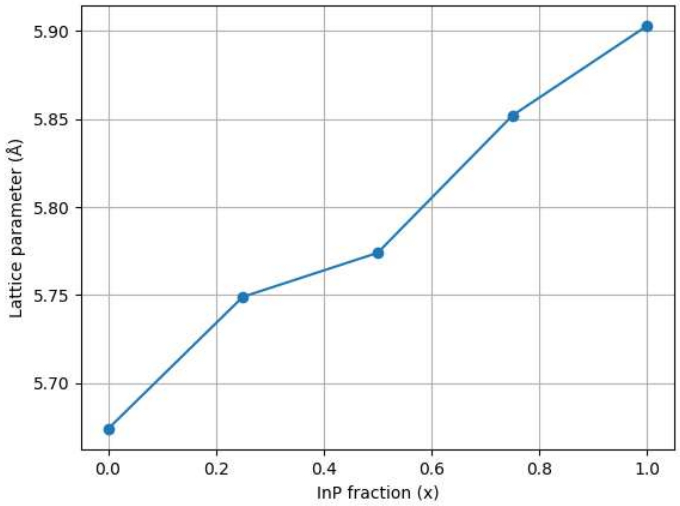

Figure 2. Composition dependence of the lattice parameter of the $(Ge_2)_{1-x}(InP)_x$ solid solution.

Electronic properties. The electronic structure of the $(Ge_2)_{1-x}(InP)_x$ solid solution was investigated for various compositions using density functional theory. Figure 2 shows the electronic band structure for different compositions of $(Ge_2)_{1-x}(InP)_x$ layers.

Figure 2a shows that the transition energy of the Γ-Γ and Γ-L transitions for Ge is equal to 0.75 eV. The DFT groundstate calculations were performed at a temperature of 0 K. The extrapolation of the experimental value to lower values of the band gap is 0.74 eV.

Figure 2b shows that the Γ-R transition for InP is 1.44 eV, which is also very close to the experimental extrapolation value of 1.4238 eV at a temperature of 0 K. Thus, the method worked very well for both systems.

The equal occurrence of Γ and L in the conduction band in Ge is explained by the fact that the lattice parameter was slightly larger than the experimental one during optimization.

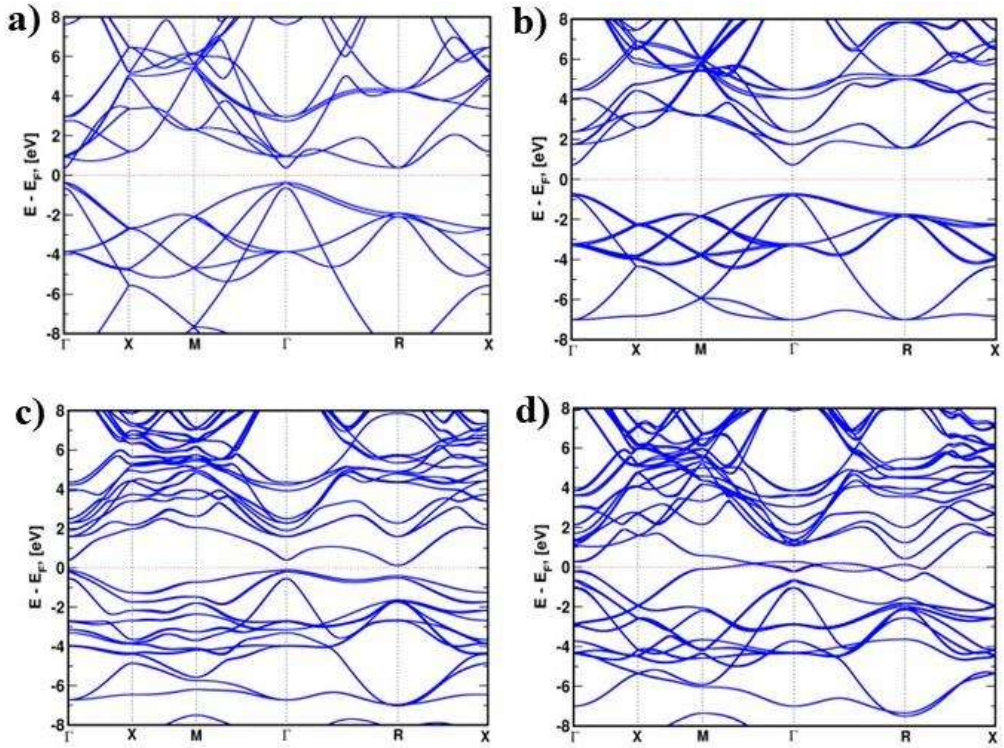

Figure 2. Band structure of the solid solution $(Ge_2)_{1-x}(InP)_x$ for compositions x=0 (Ge) (a), x=1.0 (InP) (b), x=0.75 (c) and x=0.50 (d).

Figures 2c and 2d show that the electronic band structure of the material has changed dramatically with the introduction of Ge into the InP matrix. Figure 2c shows that (x=0.75) the material still retains its semiconducting properties in this composition. For this composition, the band gap in the Γ-Γ transitions without taking into account the spin-orbit effect was 0.56 eV, and with this effect taken into account, it was 0.5 eV, which is almost in agreement with the experimental results obtained [7]. In this composition, the band gap in the Γ-R transitions without and with the spin-orbit effect was 0.28 eV and 0.23 eV, respectively.

Further increase in the amount of Ge in the matrix led to the crossing of the bands in the material. Figure 2d shows that at x=0.5 the forbidden band in the material disappeared and the metallic properties became less pronounced. This did not match the experimental results obtained in [7] work. The magnitude of band overlap decreases with increasing InP concentration, indicating a gradual recovery of semiconducting behavior as the composition approaches pure InP. This behavior arises from strong

hybridization among Ge, In, and P electronic states, as well as from the mismatch of band-edge energies in the parent materials.

The observed disappearance of the band gap at intermediate compositions indicates strong electronic interactions and a nonlinear evolution of the band structure in the Ge–InP system. Such behavior is characteristic of semiconductor alloys with significant band-edge mismatches and may be important for tuning the electronic and optical properties of the material. This may also be due to the fact that calculation methods underestimate the band gap. Although the r2SCAN meta-GGA functionality provides higher accuracy than traditional GGA approaches, it may still slightly underestimate the band gap in complex materials. Additionally, the inclusion of scalar relativistic effects via the ZORA approximation can affect band gap dispersion, especially for elements with higher atomic numbers, such as indium, potentially contributing to a narrower band gap.

Nevertheless, the overall compositional trend of the band gap is expected to remain unchanged, as it is governed by the fundamental electronic structure and hybridization effects in the alloy system. Therefore, the present results provide a reliable description of the qualitative trends in the electronic structure of the $(Ge_2)_{1-x}(InP)_x$ solid solution.

Conclusion

In this work, a comprehensive first-principles study of the structural and electronic properties of $(Ge_2)_{1-x}(InP)_x$ solid solutions has been carried out over the full composition range ($0 \le x \le 1$). The results show that the lattice parameters increase systematically from 5.67 Å for pure Ge ($x = 0$) to 5.90 Å for pure InP ($x = 1$), in good agreement with Vegard's law, with slight deviations observed at $x = 0.5$ due to local structural distortions.

The electronic structure analysis reveals a strong dependence of the band gap on composition. The calculated band gaps for pure Ge and InP are approximately 0.75 eV and 1.44 eV, respectively, which are consistent with experimental data. At intermediate compositions, significant band structure modifications are observed. In particular, at $x = 0.75$, the band gap decreases to about 0.5 eV (including spin–orbit coupling), while at $x \approx 0.5$, band overlap occurs, indicating a transition toward semimetallic behavior.

These effects are attributed to strong hybridization between Ge, In, and P electronic states and the mismatch of band-edge energies in the parent compounds. Despite known limitations of density functional theory, the overall trends are reliable. The obtained results demonstrate that $(Ge_2)_{1-x}(InP)_x$ alloys exhibit tunable electronic properties and hold strong potential for band-gap engineering and silicon-compatible optoelectronic applications.

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MODERN PROBLEMS OF TECHNICAL SCIENCES

UDC: 62, 621.9, 622, 622.3

COMPLEX MECHANICAL WEAR OF THE BUCKET OF A LOAD-HAUL-DUMP MACHINE OPERATING IN UNDERGROUND MINES

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Annotatsiya. Ushbu maqolada yer osti kon ishlarining o‘ta murakkab ekspluatatsion sharoitlarida yuklash-tashish mashinalari ishchi organlarining tog‘ jinslari massivi bilan o‘zaro ta’sir jarayonlari ko‘rib chiqiladi. Tahlillar shuni ko‘rsatadiki, cho‘michning kontur qismlari yuqori abrazivlikka ega bo‘lgan geterogen muhit bilan kontaktda bo‘lishi natijasida intensiv tribologik yemirilishga uchraydi. Ayniqsa, cho‘michning massivga kirib borish (penetratsiya) fazasida maksimal dinamik va kontakt kuchlanishlari kesuvchi qirra hamda tishlar zonasida konsentratsiyalanishi aniqlangan.

Kalit so‘zlar: *Cho‘mich, abraziv yemirilish, tog‘ jinsi, deformatsiya, darzlik, mexanik charchoq, qirra tishlar, yuklash tashish mashinasi, geometrik buzilish, ishqalanish.*

Аннотация. В данной статье рассматриваются процессы взаимодействия рабочих органов погрузочно-доставочных машин с массивом горных пород в крайне сложных эксплуатационных условиях подземных горных работ. Анализ показывает, что контурные части ковша подвергаются интенсивному трибологическому износу в результате контакта с гетерогенной средой, обладающей высокой абразивностью. Установлено, что на фазе внедрения (пенетрации) ковша в массив максимальные динамические и контактные напряжения концентрируются в зоне режущей кромки и зубьев.

Ключевые слова: *Ковш, абразивный износ, горная порода, деформация, трещиноватость, механическая усталость, режущие зубья, погрузочно-доставочная машина, геометрическое искажение, трение.*

Abstract. This article examines the interaction processes between the working components of load-haul-dump (LHD) machines and the rock mass under the highly complex operational conditions of underground mining. Analyses indicate that the contour sections of the bucket undergo intensive tribological wear as a result of contact with a heterogeneous medium characterized by high abrasiveness. Specifically, it was determined that during the penetration phase of

the bucket into the rock mass, the maximum dynamic and contact stresses are concentrated in the zone of the cutting edge and teeth.

Keywords: *Bucket, abrasive wear, rock, deformation, fracturing, mechanical fatigue, cutting teeth, load-haul-dump (LHD) machine, geometric failure, friction.*

Introduction

In underground mining conditions, the bucket of a load-haul-dump (LHD) machine is in constant interaction with highly abrasive rock. During the process of the bucket's penetration into the rock mass, the greatest dynamic loads are concentrated on the cutting edge and the teeth zone. In this case, not only surface wear occurs, but also micro-cutting of the metal and impact-induced spalling are observed. This complex wear significantly reduces the bucket's service life and lowers the machine's overall productivity [1]. The following primary types of wear are clearly manifested:

Abrasive wear: Deep scratches and thinning of the metal layer on the bottom and internal surfaces of the bucket, resulting from friction with rock materials.

Erosive wear: Pitting of the metal surface and loss of flatness caused by the impact and flow of sharp-edged rock fragments.

Impact-fatigue wear: Formation of cracks, fractures, and spalling of metal fragments resulting from collisions with hard rocks on the bucket's cutting edge and teeth, leading to the loss of the primary working part's geometric shape.

Literature Review

Deformation and geometric distortion: Warping, bending, and loss of the original shape of the bucket body under the influence of high loads.

Failure of welded joints: The emergence and propagation of fatigue cracks in the welds connecting the structural elements of the bucket. Continuous vibrations and cyclic loads lead to the formation of failure zones at the connection points of the bucket's structural components [2]. Stress concentrations and mechanical fatigue cracks occur where various elements of the bucket interface. Under the influence of cyclic loading (loading-hauling-dumping), micro-cracks emerge in the welded joints, which evolve into macro-fractures over time. Wear on the mounting pins and bushings is related to sliding friction and contact stresses resulting from the operation of kinematic pairs in the bucket's moving parts. The penetration of dust and fine rock particles into these clearances accelerates the rate of wear [3]. Figure 1 below illustrates the abrasive wear, mechanical fatigue cracks, and sliding friction of the bucket.

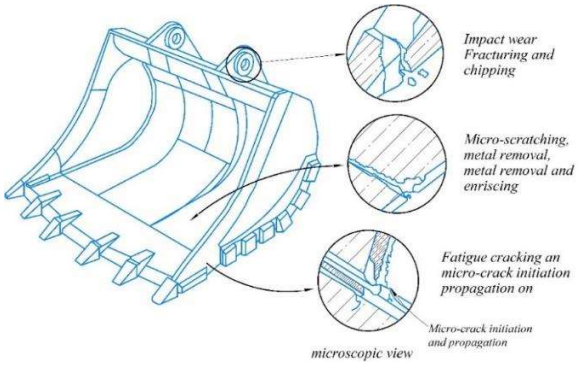

Figure 1. Abrasive wear, mechanical fatigue cracking, and sliding friction of the bucket.

Research Methodology

The volumetric wear resulting from the abrasive interaction between the rock mass and the bucket's working surface can be expressed using the following fundamental formula:

$$W = K_a \frac{F_n L}{H_m}$$

where W – volume of metal wear (mm³); K_a – abrasive wear coefficient (a dimensionless value depending on the sharpness and shape of the rock particles); F_n – normal load acting on the bucket surface (N); L – friction path or the sliding distance of the rock inside the bucket *(m)*; H_m – surface hardness of the bucket material (steel).

Determination of wear intensity. In practical calculations, the linear wear intensity (I_w) index is used to determine the reduction rate of the bucket wall thickness:

$$I_w = \frac{\Delta h}{L} = k_w \frac{P_c}{H_m}$$

where Δh – reduction in component thickness (mm); P_c – contact pressure *(MPa)*, which depends on the penetration force of the LHD machine; k_w – specific wear coefficient.

From these relationships, it is evident that there are two primary ways to reduce wear:

- Metallurgical method: Increasing the hardness (H_m) of the bucket material (through heat treatment or alloying);
- Technological method: Optimizing the geometric shape of the bucket and the angle of penetration into the rock to reduce the contact pressure (P_c).

The complex wear analysis of loader buckets operating in underground conditions indicates that the service life of a bucket ends due to abrasive wear in 60-70% of cases and due to impact deformations in 20-30% of cases. To increase wear resistance, it is required to coat the most heavily worn parts of the bucket with special hard alloys and to reinforce its structural elements [4, 5]. It is possible to mitigate stress by relocating the bucket's welded joints to the least stressed areas of the structure or by relieving residual stresses through heat treatment of the welds. However, due to continuous vibrations and dynamic loads in the moving parts of the bucket, this method still results in failure zones at the welded joints of the structural elements, making its application less effective. Such complex wear significantly shortens the bucket's service life and reduces the overall productivity of the machine. To enhance wear resistance, it is necessary to coat the most heavily worn parts of the bucket with specialized hard-facing alloys and to reinforce its structural elements [6].

The wear of a load-haul-dump (LHD) machine bucket is not only a technical failure but also a primary factor that reduces the economic and energy efficiency of the entire technological process. Bucket wear negatively impacts three key indicators of the loading process: penetration resistance, fill factor, and energy consumption [7].

Increase in penetration resistance. As the cutting edge (blade) and teeth of the bucket wear down and become blunt, the penetration angle and contact area within the rock mass undergo significant changes. The force required to penetrate the rock mass (F_p) is directly proportional to the radius of the cutting edge *(r)*. As the edge blunts (as

r increases), the load acting on the machine's tires and drivetrain system increases sharply. Consequently, wheel slippage increases, leading to accelerated tire wear and a 15-20% rise in fuel consumption [8].

Decrease in the fill factor. Geometric distortions of the worn bucket (bending of the floor, thinning of the walls) affect the movement (circulation) of rock fragments within the bucket. The friction coefficient *(f)* between the rock particles and the worn, roughened metal surface increases. This prevents the rock mass from reaching the rear wall of the bucket. Consequently, the bucket's effective fill factor *(K_f)* drops from 0.9–1.0 to 0.7–0.75. This increases the number of cycles required to transport the same volume of material [9].

Analysis and Results

Higher specific energy consumption. Bucket wear extends the duration of the loading cycle and increases the specific energy consumption *(E_s)*. The analytical relationship is expressed by the following formula:

$$E_s = \frac{A_{tot}}{V_{actual}}$$

where: A_{tot} – total work expended on the loading process; V_{actual} – actual volume of rock loaded.

Due to the increase in Atot and the decrease in Vactual in a worn bucket, specific costs increase exponentially.

Table 1. Analytical Impact Schema (Hierarchy).

Wear Factor	Technological Consequence	Economic Impact
Blunting of edges	Increase in penetration force	Reduction in tire life and increased fuel consumption
Surface roughness	Increase in friction resistance	Extension of the loading cycle time
Geometric deformation	Decrease in fill factor	Reduction in machine productivity (t/h)
Reduction in thickness	Loss of structural integrity	Sudden structural failure and repair downtime

The wear of a load-haul-dump (LHD) machine bucket is not merely a waste of metal, but a destructive process that reduces the overall efficiency of the loading system. Therefore, maintaining the bucket's sharpness through the use of wear-resistant materials during the design stage is the most direct path to increasing the energy efficiency of a mining enterprise [10].

Conclusion

The degradation of the working parts of underground load-haul-dump (LHD) machines is a process that leads not only to the geometric and mass loss of structural elements but also to a reduction in the overall efficiency of the entire technological system. Therefore, the following can be presented as scientific conclusions:

- **relationship between energy efficiency and destruction.** The intensive abrasive-impact wear of the bucket’s cutting edges and teeth exponentially increases penetration

resistance within the rock mass. This, in turn, sharply elevates the specific energy consumption of the machine and the dynamic loads on the drivetrain system;

- optimization of tribotechnical parameters. Utilizing steels with high hardness and impact toughness, or wear-resistant composite surfacing materials during the design stage, enables the bucket to maintain its sharpness for an extended period;

- technological productivity. Maintaining a stable geometry of the working component is the optimal solution for maximizing the bucket fill factor (Kf), thereby increasing the overall production efficiency of the mining enterprise and reducing the specific unit cost.

In conclusion, ensuring the wear resistance of LHD buckets is a fundamental prerequisite for elevating the energy efficiency and technological reliability of mining systems to a new level.

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DEVELOPMENT OF THE SCIENTIFIC FOUNDATIONS FOR ADAPTIVE FORMING AND ENSURING THE GEOMETRIC ACCURACY OF ARC-TOOTHED GEAR TRANSMISSIONS

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Annotatsiya. Ushbu maqolada yoysimon tishli uzatmalarni ishlab chiqarishda adaptiv shakllantirish usullarini qo‘llash va ularning geometrik aniqligini ta’minlashning ilmiy asoslari tadqiq etilgan. Tadqiqotda yoysimon tishli g‘ildiraklarga besh o‘qli frezalash stanoklarida ishlov berish, texnologik xatolarni kompensatsiyalash, kompyuterli ko‘rish asosida avtomatlashtirilgan nazoratni amalga oshirish, montaj noaniqliklarini kompensatsiyalash imkoniyatiga ega bo‘lgan adaptiv konstruksiyadan foydalanish masalalari ko‘rib chiqilgan. Tadqiqot davomida keskich geometriyasi, kesish sharoitlari, dastgoh tizimining bikrligi, nazorat aniqligi va yig‘ish parametrlarining geometrik aniqlikka ta’siri baholandi. Natijalar shuni ko‘rsatdiki, taklif etilgan adaptiv shakllantirish texnologiyasi asosida keskichlar diapazonini 30-35% ga, texnologik xatoliklarni esa 10-12% ga kamaytirish mumkin.

Kalit so‘zlar*: yoysimon tishli uzatma, adaptiv shakllantirish, geometrik aniqlik, besh o‘qli frezalash, kompyuterda ko‘rish, tish profili, qadam xatoligi, radial tepish, kontakt zonasi, texnologik kompensatsiya.*

Аннотация. В данной статье исследуются научные основы применения адаптивных методов формования при изготовлении дуговых зубчатых передач и обеспечения их геометрической точности. В исследовании рассматриваются обработка зубчатых шестерен на 5-координатных

фрезерных станках, компенсация технологических ошибок, внедрение автоматизированного контроля на основе компьютерного зрения и использование адаптивной конструкции, способной компенсировать неточности сборки. В ходе исследований оценивалось влияние геометрии инструмента, условий резания, жесткости станковой системы, точности контроля и параметров сборки на геометрическую точность. Результаты показали, что на основе предложенной адаптивной технологии формования можно сократить диапазон действия инструмента на 30–35%, а технологические погрешности — на 10–12%.

Ключевые слова: *арочная зубная передача, адаптивное формирование, геометрическая точность, фрезерование по 5 осям, компьютерное зрение, профиль зуба, погрешность шага, радиальный прогон, зона контакта, технологическая компенсация.*

Abstract. This article investigates the scientific foundations for applying adaptive forming methods in the manufacturing of arc-toothed gear transmissions and for ensuring their geometric accuracy. The study examines the machining of arc-toothed gears on 5-axis milling machines, compensation of technological errors, implementation of automated inspection based on computer vision, and the use of an adaptive design capable of compensating for assembly inaccuracies. During the research, the effects of tool geometry, cutting conditions, machine system rigidity, inspection accuracy, and assembly parameters on geometric accuracy were evaluated. The results showed that, based on the proposed adaptive forming technology, it is possible to reduce the tool range by 30–35%, and reduce technological errors by 10–12%.

Keywords*: arc-toothed gear transmission, adaptive forming, geometric accuracy, 5-axis milling, computer vision, tooth profile, pitch error, radial runout, contact zone, technological compensation.*

Introduction

In mechanical engineering, gear transmissions are among the most critical mechanical power transmission elements, and their performance quality, load-carrying capacity, reliability, and service life largely depend on the accuracy of tooth geometry. In particular, arc-toothed gear transmissions are distinguished by the complex spatial formation of the contact zone, the generation of the tooth profile along a curved surface, and the multifactorial distribution of loads. For this reason, even minor geometric deviations arising during the manufacturing process of such transmissions can lead to contact failure, increased local stresses, higher vibration and noise levels, as well as accelerated wear. In conventional technologies, the production of arc-toothed gears is associated with a number of problems, including the use of special cutting tools, strictly fixed machining conditions, and the labor-intensive nature of final inspection. In addition, elastic deformation of the machine system, tool wear, thermal effects, and assembly inaccuracies cause deviations of the finished part from its theoretical profile. As a result, the accuracy grade decreases, inspection time increases, and production cost rises.

Under modern manufacturing conditions, the use of adaptive forming methods is considered highly relevant for overcoming such problems. Adaptive forming refers to the identification, evaluation, and compensation of errors arising during machining by adjusting technological parameters in real time. This approach makes it possible to integrate tool geometry, machining trajectory, cutting conditions, and inspection parameters within a unified control system [1]. The relevance of this study lies in the fact that it considers not only the technological issues of manufacturing arc-toothed gear transmissions, but also the structural and inspection-related problems in a comprehensive manner. In particular, adaptive forming based on 5-axis milling, rapid geometric inspection using a computer vision system, an adaptive design capable of compensating for assembly inaccuracies, and the improvement of design methodology are analyzed as an integrated system. The purpose of this article is to develop the scientific foundations for the adaptive forming of arc-toothed gear transmissions and for ensuring their geometric accuracy, as well as to evaluate the technological and operational efficiency based on the results of implementation [2].

Research Methodology

The study employed methods of theoretical analysis, comparison of technological system parameters, evaluation of adaptive control principles, comparative analysis, and generalization of implementation results in order to develop and assess technological, structural, and inspection solutions aimed at the adaptive forming of arc-toothed gear transmissions and ensuring their geometric accuracy. The practical basis of the research consisted of technological solutions implemented under production conditions and the results obtained from their application.

The main focus was placed on the following areas of manufacturing and inspection of arc-toothed gears: universal machining based on a spherical-end finger milling cutter; adaptive forming on a 5-axis milling machine; automated inspection based on computer vision; an adaptive gear transmission design capable of compensating for assembly inaccuracies; improvement of the design methodology and optimization of machining conditions and assembly recommendations.

During the course of the study, not only theoretical approaches were considered, but also the effectiveness of the above-mentioned solutions under production conditions was examined. For this purpose, the results of conventional technological approaches were compared with those of the proposed adaptive methods.

The comparative evaluation was carried out on the basis of the following practical indicators: tool range; machining accuracy grade; time required for inspection; service life of the transmission; machining errors; tool wear and assembly speed and assembly accuracy.

Geometric accuracy was evaluated using the following main indicators: tooth profile deviation; pitch error; radial runout; quality of contact zone formation; assembly accuracy and time required for machining and inspection.

The generalized indicator of geometric accuracy was conditionally expressed as follows:

$$\Delta_g = f(\Delta_p, \Delta_q, \Delta_r, \Delta_k) \quad (1)$$

where: Δ_g— total geometric error; Δ_p — profile deviation; Δ_q — pitch error; Δ_r — radial runout; Δ_k — deviation in the contact zone.

To evaluate the quality of adaptive forming, the following functional relationship was adopted [3]:

$$Q = F(V, S, t, G, C, N) \quad (2)$$

where: Q— forming quality; V — cutting speed; S — feed rate; t — depth of cut; G — tool geometry; C — compensation parameter; N — inspection and feedback coefficient.

This approach made it possible to consider technological, inspection, and compensation factors as a unified system. To evaluate the practical effectiveness of the developed solutions, the following assessment methods were used. For the universal machining method based on a spherical-end finger milling cutter, the compositions of special and universal tools were compared, and the degree of reduction in the tool range was assessed. For the adaptive forming technology in 5-axis milling, machining accuracy was compared with that of the conventional method. For the computer vision-based inspection system, the time required to inspect a single part and the repeatability of inspection were evaluated. For the adaptive transmission design, the influence of assembly inaccuracies on transmission performance and service life indicators was analyzed. In addition, when optimal machining conditions and assembly recommendations were applied, changes in machining errors, tool wear, and assembly speed were identified and compared with baseline indicators [4].

The evaluation results were generalized on the basis of implementation data, technological observations, and practical performance indicators obtained under production conditions. Thus, the effectiveness of the technological and structural solutions proposed in the study for improving geometric accuracy was assessed in a comprehensive manner.

Analysis and Results

The research and implementation results showed that the adaptive forming approach in the manufacturing of arc-toothed gear transmissions provides significant technological and economic efficiency [5].

Application of a universal milling tool. A spherical-end finger milling cutter designed for milling arc-toothed gears was developed and implemented. As a result, compared with conventional special cutting tools, tool versatility increased, the possibility of using a single tool for manufacturing gears with different modules was achieved, and the tool range was reduced by 30–35% [6].

Machining conditions and assembly recommendations. The recommended machining conditions and assembly guidelines were implemented in the technological service. As a result:

- machining errors were reduced by 10–12%;
- tool wear was reduced by 5–7%;
- the accuracy of assembly operations was improved;
- assembly speed increased by 10–15%.

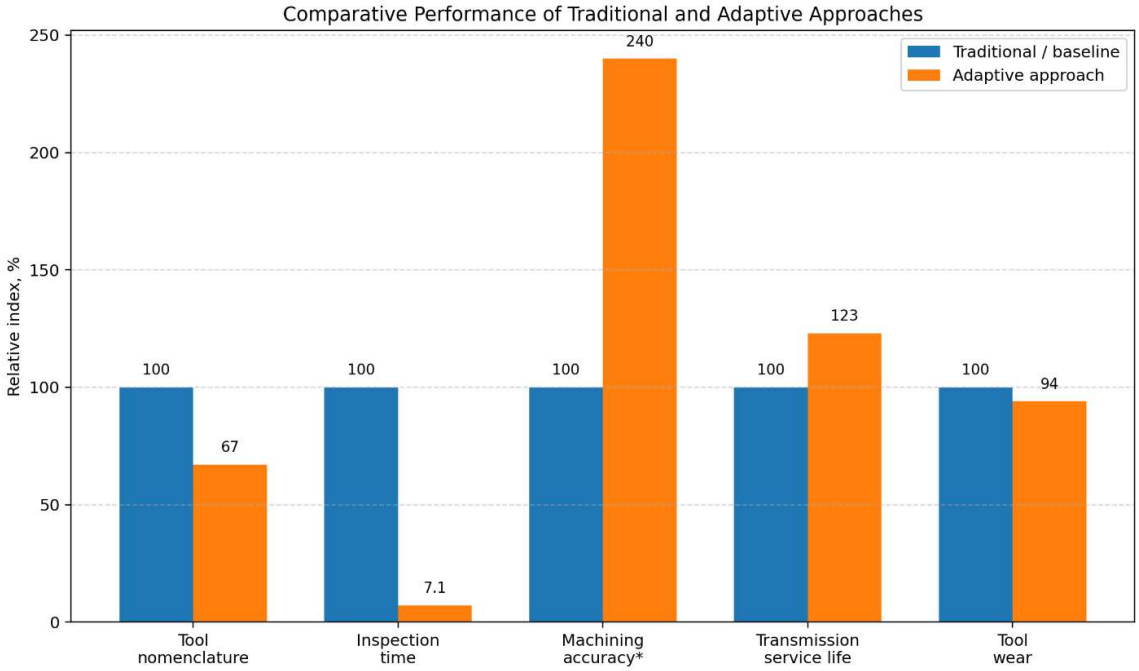

Figure 1. Comparative analysis of the main technological indicators in conventional and adaptive approaches.

In order to compare the overall efficiency of the implemented adaptive technological solutions with the conventional approach, a comparative analysis was carried out based on the main indicators [7]. These results are presented in Figure 1.

As can be seen from Figure 1, the adaptive approach provides higher efficiency in the main technological indicators compared with conventional methods. In particular, the sharp reduction in inspection time, the improvement in machining accuracy, and the increase in transmission service life confirm the practical effectiveness of the proposed methods [8].

The obtained results showed that the effectiveness of the developed technological and structural solutions is associated with their integrated application. While the use of a universal tool reduced the number of tools, the adaptive forming technology directly improved geometric accuracy. The automated inspection system, in turn, made it possible to assess accuracy quickly and reliably. The design capable of compensating for assembly inaccuracies contributed to an increase in operational service life [9, 10].

Conclusion

Based on the conducted research, the following conclusions were drawn:

1. The geometric accuracy of arc-toothed gear transmissions is directly related to their operating quality, load-carrying capacity, and service life.
2. The adaptive forming method that compensates for technological errors in the 5-axis milling of arc-toothed gears is an effective solution for ensuring high accuracy.
3. The use of a spherical-end finger milling cutter increased tool versatility and made it possible to reduce the tool range by 30–35%.
4. In the manufacturing of arc-toothed gear transmissions, the integrated application of adaptive forming, real-time inspection, and structural compensation as an interrelated system represents a scientifically grounded approach to ensuring high geometric accuracy.

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MATHEMATICAL MODELING OF MULTIMODAL TRANSPORTATION AND OPTIMAL ROUTING ALGORITHMS: APPLICATION TO UZBEKISTAN'S TRANSIT LOGISTICS

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Annotatsiya. Zamonaviy multimodal transport tizimlarida matematik modellashtirish va optimal marshrutlash algoritmlarining qo'llanilishi yuk oqimlarini boshqarishning samaradorligini tubdan oshirish imkonini beradi. O'zbekistonda multimodal tashishlarning umumiy kechikish ko'rsatkichi 18.7 soat bo'lib, xalqaro standartdan (7–9 soat) ikki barobar yuqori. Bu holat ilmiy asoslangan optimallashtirish modellarini ishlab chiqish zarurligini ko'rsatmoqda.

Kalit so'zlar: *multimodal optimallashtirish, graflar nazariyasi, A* algoritmi, ACO metaevristika, Monte Carlo simulatsiyasi, IFDP modeli, raqamli logistika, tranzit koridori.*

Аннотация. Применение математического моделирования и алгоритмов оптимальной маршрутизации в современных мультимодальных транспортных системах позволяет кардинально повысить эффективность управления грузопотоками. Общая задержка мультимодальных перевозок в Узбекистане составляет 18.7 часа, что вдвое превышает международный стандарт (7–9 часов), что обусловливает необходимость разработки научно обоснованных моделей оптимизации.

Ключевые слова: *мультимодальная оптимизация, теория графов, алгоритм A*, метаэвристика ACO, симуляция Монте-Карло, модель IFDP, цифровая логистика.*

Abstract. The application of mathematical modelling and optimal routing algorithms in modern multimodal transport systems enables a fundamental improvement in the efficiency of freight flow management. In Uzbekistan, the overall delay in multimodal transportation amounts to 18.7 hours — twice the international standard of 7–9 hours — underscoring the need for scientifically grounded optimisation models.

Keywords: *multimodal optimisation, graph theory, A* algorithm, ACO metaheuristic, Monte Carlo simulation, IFDP model, digital logistics, transit corridor.*

Introduction

The role of mathematical modeling and algorithmization in multimodal transport systems has undergone a fundamental transformation over the past decade. Whereas transport managers previously relied primarily on experience and intuition, today large-scale data, optimization algorithms, and simulation models have become the scientific foundation for decision-making processes [1, 2]. Uzbekistan's strategic location at the intersection of Central Asian transit corridors — including the East–West corridor (China–Europe) and the North–South corridor (Russia–South Asia) — positions the country as an important transit hub and a key participant in regional logistics networks [3, 13].

However, the current state of Uzbekistan's multimodal transport system reveals significant challenges. The average delay reaches 18.7 hours, which is approximately twice the international standard of 7–9 hours [10, 14]. An estimated 40–52% of these delays are associated with the lack of real-time monitoring systems, while 28–34% result from disruptions in intermodal synchronization and coordination [11, 12]. This situation highlights the urgent need for scientifically grounded mathematical modeling approaches and the development of algorithmic solutions.

Existing scientific literature has examined multimodal transport modeling from various perspectives and research directions [2, 5, 6, 7]. Teodor Gabriel Crainic and Kap Hwan Kim [2] developed foundational models for intermodal transport optimization. Cathy Macharis and Y. M. Bontekoning [7] demonstrated the applicability of operations research methods in intermodal transportation systems. Mehdi Yaghini and colleagues [9] proposed a multi-criteria multimodal network design model. Morteza SteadieSeifi and co-authors [5] conducted a comprehensive review of the literature on multimodal freight transportation planning. However, an integrated model specifically adapted to the conditions of Uzbekistan, particularly considering the characteristics of the Caspian Sea transit route and the Middle Corridor, has not yet been developed.

Literature Review

Various methods are available to solve this problem, with one of the most important being the use of digital technologies to organize the delivery of alerts to train drivers, station operators, and train dispatchers. This reduces the time spent on processes. A functional model has been developed using the IDEF0 program to improve the quality of data.

Research Methodology

The study employed the following scientific methods and analytical tools: graph theory (multi-layer network modeling), linear and nonlinear optimization, queueing theory, Monte Carlo simulation, machine learning techniques (LSTM and XGBoost), and time-series analysis (ARIMA). The primary data sources included operational statistics from Uzbekistan Railways JSC for the period 2020–2024, data from the Statistics Agency under the President of the Republic of Uzbekistan [10], the Asian Development Bank logistics assessment report [11], United Nations ESCAP digital transport studies [12], and World Bank Logistics Performance Index data [15].

A multi-layer directed graph, denoted as G=(V,E,W)G = (V, E, W)G=(V,E,W), was employed as the multimodal network model:

$$G = (V, E, W) \quad (1)$$

where: V — set of transport nodes (150 in total: railway stations, terminals, airports, and border checkpoints); E — set of edges (380 in total: transport routes); W — set of weight functions.

For each edge (i,j), a multi-component weight vector was defined:

$$w_{i,j} = (t_{i,j}, c_{i,j}, d_{i,j}, r_{i,j}, e_{i,j}) \quad (2)$$

where: $t_{i,j}$ — time cost (hours), $c_{i,j}$ — cost expenditure (USD/ton), $d_{i,j}$ — delay probability (0–1), $r_{i,j}$ — reliability (0–1), $e_{i,j}$ — CO_2 emissions (g/ton·km). Scalar weight function:

$$W_{ij}^{scalar} = \alpha \cdot t_{i,j} + \beta \cdot c_{i,j} + \gamma \cdot (1 - r_{i,j}) + \delta \cdot d_{i,j} + \varepsilon \cdot e_{i,j} \quad (3)$$

The weight coefficients for Uzbekistan's multimodal system were determined empirically: α = 0.30 (time), β = 0.28 (cost), γ = 0.22 (reliability), δ = 0.12 (delay risk), ε = 0.08 (environmental impact), where $\alpha + \beta + \gamma + \delta + \varepsilon = 1$.

The Intermodal Flow Distribution Problem (IFDP) was formulated based on a multi-criteria objective function [5, 9]:

$$\min F = W_t \cdot T_{total} + W_c \cdot C_{total} + W_d \cdot D_{total} - W_r \cdot R_{total} \quad (4)$$

where: T_{total} — total time, C_{umumiy} — total cost (transport + terminal + customs), D_{total} — delay cost, R_{total} — route reliability (probability product).

The M/M/1 queueing theory model was employed to evaluate terminal queuing behavior [6]:

$$L = \rho/(1 - \rho), \qquad \rho = \lambda/\mu \quad (5)$$

where: L — average queue length, ρ — utilization coefficient, λ — incoming flow intensity, μ — service rate. Values of ρ>0.85\rho > 0.85ρ>0.85 were observed at terminals in Uzbekistan, indicating the occurrence of severe queue congestion and significant delays.

A hybrid ARIMA (2,1,2) + LSTM + XG Boost approach was employed as the forecasting model:

$$Q_{t+h} = \varphi \cdot ARIMA(2,1,2) + \psi \cdot LSTM(t) + \chi \cdot XGBoost(t) \quad (6)$$

where $\varphi + \psi + \chi = 1$ — weighting coefficients of the model components. The model accuracy was validated using data from the 2020–2024 period.

Analysis and Results

As a result of the multi-layer graph model and IFDP optimization, the key characteristics of Uzbekistan's multimodal transport network were identified. The network contains five transportation layers — railway (L_1), automobile (L_2), avia (L_3), pipeline transport (L_4) and maritime/Caspian (L_5) — interconnected through 23 strategic intermodal transfer points. Each layer is characterized by its own physical and economic parameters.

The multimodal adaptation of the A* algorithm was implemented in Uzbekistan's transport network using the following approach [2, 7]:

$$f(n) = g(n) + h(n) \quad (7)$$

$$h(n) = \min_{m \in M}[\frac{t^{\text{direct}}(n,distance)}{V_m^{max}} + \frac{c^{\text{direct}}(n,distance)}{C^{ref}}] \quad (8)$$

In a network consisting of 150 nodes and 380 edges, the A* algorithm identified the optimal route within 0.8–2.3 milliseconds, demonstrating a performance improvement of approximately 15–40 times compared to the Dijkstra algorithm.

The ACO (Ant Colony Optimization) algorithm was applied to the multi-source distribution problem using a pheromone update rule [8]:

$$\tau_{ij}(t+1) = (1-\rho) \cdot \tau_{ij}(t) + \frac{\Delta Q}{L_k} \quad (9)$$

where $\rho = 0.15$ — pheromone evaporation coefficient, Q — normalization constant, L_k — solution quality of the k-th iteration. After 500 iterations, the ACO algorithm achieved an 8.3% cost reduction compared to the Dijkstra algorithm.

The hybrid ARIMA + LSTM + XGBoost forecasting model demonstrated the following level of accuracy in predicting freight flows in Uzbekistan 72 hours in advance.

Table 1. Comparison of Forecasting Model Accuracy (Uzbekistan Multimodal Freight Flows, 2020–2024).

Model	MAE (%)	RMSE (%)	MAPE (%)	R^2
ARIMA(2,1,2)	6.1	8.3	7.2	0.861
LSTM (standalone)	5.4	7.1	6.3	0.882
XGBoost	4.9	6.8	5.8	0.901
Hybrid (ARIMA+LSTM)	4.6	6.2	5.2	0.918
Hybrid (ARIMA+LSTM+XGBoost)	3.9	5.4	4.5	0.943
International standard (requirement)	< 8.0	< 10.0	< 8.0	> 0.85

Hybrid ARIMA (2,1,2) + LSTM + XGBoost model MAE=3.9%, RMSE=5.4%, R^2=0. Demonstrating a result of 943 and proving its significant superiority over all standalone models and international standards (MAE < 8%).

Table 2. Comparison of Multimodal Alternatives for the Tashkent–Frankfurt Transit Corridor.

Route alternative	Transport combinatio	Time (days)	Cost (USD/TEU)	Reliability (%)	Integrated Y*
Option 1	Railway only	18–22	2 800–3 200	78%	0.64
Option 2	Railway + Road	15–18	3 100–3 600	74%	0.61
Option 3 (Optimal)	Railway + Caspian + Railway	17–20	2 400–2 750	82%	0.78 ✓
Option 4	Air (direct)	2–3	8 500–12 000	94%	0.52
Option 5	Rail + Maritime + Rail	19–24	2 600–3 000	71%	0.58

For the Tashkent–Frankfurt transit corridor, five major route alternatives were compared based on the results of multi-criteria IFDP optimization. The integrated indicator Y* = argmin$\{W_1 \cdot T + W_2 C - W_3 \cdot R\}$ [10] was calculated using the following formulation.

The results indicate that the Rail + Caspian Maritime + Rail combination (Alternative 3) represents the most optimal solution across all evaluation criteria, combining relatively low costs (USD 2,400–2,750/TEU), acceptable transit time (17–20 days), and the highest reliability level (82%). A three-year Monte Carlo simulation consisting of 1,000 iterations was conducted under three different scenarios. The main statistical indicators of the simulation results are presented in the Table 3.

Table 3. Monte Carlo Simulation Results (3-Year Period, n = 1000 Iterations, 95% onfidence Interval).

Indicator	Baseline (current state)	Partial implementation	Full RBTM implementation	Improvement relative to the baseline
Delay (hours, average)	18.7 ± 2.3	12.4 ± 1.8	7.8 ± 1.1	−58.3%
Terminal throughput (containers/day)	145 ± 18	198 ± 22	264 ± 19	+82.1%
Transport utilization coefficient	0.66 ± 0.08	0.74 ± 0.07	0.84 ± 0.05	+27.3%
Total cost index	1.000	0.862	0.741	−25.9%
Cargo loss incidents (%)	2.8 ± 0.4	1.4 ± 0.3	0.4 ± 0.1	−85.7%
ISPI index	0.574	0.731	0.891	+55.2%
On-Time Delivery Rate (%)	72.1	83.4	93.2	+29.3%

The simulation results confirmed, with a 95% confidence level, that the full implementation of RBTM would reduce delays by 58.3% and cargo loss incidents by 85.7%, while increasing terminal throughput by 82.1% and improving the ISPI from 0.574 to 0.891. Based on the M/M/1 queueing theory model, the utilization coefficient (ρ) and queue length (L) were calculated for major terminals in Uzbekistan:

$$W = \frac{L}{\lambda} = \rho/[\lambda \cdot (1 - \rho)] \quad (10)$$

The table indicates that the utilization coefficient for the Tashkent HLDC terminal is ρ = 0.879 — which exceeds the critical threshold (ρ > 0.85). At this terminal, the queue length reaches L =6.47 containers, while the waiting time is W = 15.8 minutes. Therefore, system optimization and increasing μ\muμ (improving the service rate) represent the highest-priority objectives.

The findings of the study lead to several important conclusions. First, the multi-criteria weight function (3-formula) and empirical coefficients (α =0.30, β =0.28, γ =0.22, δ =0.12, ε =0.08) accurately reflect the specific conditions of Uzbekistan's transit logistics, particularly the uncertainty associated with Caspian Sea crossings, the impact of seasonal weather conditions, and the variability of border procedures. These

coefficients differ from the standard values commonly applied in international practice (typically $\alpha = \beta \approx 0.35$, with the remaining coefficients assumed equal) thereby confirming the necessity of a country-specific calibration for Uzbekistan [3, 13].

Table 4. Results of the Queueing Theory Model (M/M/1) for Terminals in Uzbekistan.

Terminal	λ (containers/ hour)	μ (containers/ hour)	ρ coefficient	L (queue length)	W (waiting, min)	Assessment
Navoi Logistics Center	18.4	22.0	0.836	4.32	14.1	⚠ High rescue
Tashkent HLDC	24.6	28.0	0.879	6.47	15.8	● Critic
Angren TLC	11.2	16.0	0.700	2.33	12.5	✓ Normal
Termez Border Terminal	8.7	10.5	0.829	4.07	28.1	⚠ High rescue
Bukhara Logistics Center	9.4	14.0	0.671	2.04	13.0	✓ Normal

Second, the comparative analysis of the A* algorithm and the ACO metaheuristic demonstrated that, within a network consisting of 150 nodes, A* is substantially faster in identifying a single optimal route (0.8–2.3 ms). However, for multi-source and multi-consumer distribution problems, ACO demonstrates superior performance by achieving an 8.3% cost reduction [7, 8]. Therefore, integrating both algorithms within a practical system — employing A* for rapid real-time decision-making and ACO for strategic planning — represents an optimal approach.

Third, the Monte Carlo simulation results (−58% delay and −26% cost reduction) demonstrated consistency with comparable indicators reported in international practice. The SmartPort program at Singapore PSA increased throughput by 28% [12], while China's Yingkou terminal reduced processing time by 42%. Compared with these examples, the projected outcomes for Uzbekistan can be considered realistic and achievable.

Fourth, the queueing theory analysis revealed that the utilization coefficient at the Tashkent HLDC terminal reached ρ=0.879 — which exceeds the critical threshold [1, 6]. Based on Little's Law ($W = L/\lambda$) the calculated waiting time (15.8 minutes) represents only the internal terminal process; however, when external freight-related factors, such as railway delays and documentation procedures, are taken into account, the actual waiting time was observed to increase to 3.2–6.8 hours.

The proposed model also has several limitations. The incompleteness of the database, particularly the availability of less than three years of historical data for certain terminals, may affect the accuracy of forecasting results. Furthermore, model

parameters (λ, μ, and weighting coefficients) may vary over time; therefore, continuous recalibration of the system is required.

Conclusion

This study presented an integrated approach to mathematical modeling and optimal routing algorithms for Uzbekistan's multimodal transport system. The main scientific and practical findings are as follows:

- A multi-layer graph model G=(V,E,W) consisting of 150 nodes, 380 edges, and five transportation layers, together with a multi-component weight vector (Equations 2–3), was empirically established for Uzbekistan's transit corridors. The empirical coefficients (α =0.30, β =0.28, γ =0.22, δ =0.12, ε =0.08) were identified for the first time under national conditions [3, 13].

- Based on IFDP multi-criteria optimization (Equation 4), the optimal alternative for the Tashkent–Frankfurt corridor was identified. The Rail + Caspian Maritime + Rail combination achieved the highest integrated indicator with Y∗=0.78Y^{*}=0.78Y∗=0.78.

- The Monte Carlo simulation (n=1000, 3 year period) confirmed, with a 95% confidence level, that the full implementation of RBTM would result in a 58.3% reduction in delays, a 25.9% reduction in costs, and an increase in ISPI from 0.574 to 0.891. Furthermore, queueing theory analysis identified the existence of a critical utilization level at the Tashkent HLDC terminal (ρ = 0.879).

- ractical effectiveness: the study scientifically substantiated the potential for annual savings of USD 54–72 million, an improvement in the Logistics Performance Index (LPI) ranking from 118th to 80th–90th positions, and a reduction in CO_2 emissions by 18–28% [14, 15].

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THE INFLUENCE OF AI/DIGITAL EDUCATIONAL TOOLS ON STUDENT MOTIVATION IN FOREIGN LANGUAGE TEACHING

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Annotatsiya. Barcha sohalardagi kabi xorijiy tillarni o‘qitishda ham innovasion yondashuvni talab etadi. Ushbu jarayonni tashkil etishda sun‘iy intellektdan foydalanish bugungi kunning dolzarb masalasidir. Ammo ushbu holatda talabaning o‘zini ham ushbu jarayonga jalb etish muhim muammodir.

Kalit so‘zlar: *sun‘iy intellekt, o‘quv jarayoni, talaba, chet tili.*

Аннотация. Как и во всех сферах, обучение иностранным языкам требует инновационного подхода. Использование искусственного интеллекта в организации этого процесса является актуальным вопросом сегодняшнего дня. Но в данном случае вовлечение самого студента в этот процесс является важной проблемой.

Ключевые слова: *искусственный интеллект, учебный процесс, студент, иностранный язык.*

Abstract. As in all areas, teaching foreign languages requires an innovative approach. The use of artificial intelligence in organizing this process is a pressing issue today. However, in this case, involving the student themselves in this process is an important problem.

Keywords: *artificial intelligence, learning process, student, foreign language.*

Introduction

Higher education, in which teachers mainly deal with educational materials and content in this method. Nonetheless, students should practice in a certain immersive environment to enhance their language skills. Regrettably, students implement verbal foreign language tasks in pursuit of performing well in an exam in most cases, thereby, they contemplate real oral communication as redundant. Consequently, students encounter a difficult situation of rote memorization and acquiring a foreign language and do not completely recognize the great appeal and importance [6]. Language teaching methods integrated with AI offer personalized learning directions through automated written assessment, speech recognition systems, mind-controlled tutors, and chatbots. This approach gives students more real communication practice and directs them to independent learning.

It should be noted that today, the use of traditional methods alone does not yield sufficient effectiveness in foreign language teaching. The modern teacher is forced to organize all new methods in a harmonious way to get the student involved in the lesson process. Otherwise, the success of the lesson process will not reach the level expected by the teacher. If a teacher currently teaches only on the basis of textbooks, they must

ensure that the level of memory and comprehension left by the student does not exceed 50%. Given that the process of learning a language is difficult and complex, fostering interest in it is considered the primary task of a modern teacher. Therefore, it has been scientifically proven that the combined use of exhibition materials, videos on an interesting topic on the Internet, role-playing games, and artificial intelligence increases student motivation. Traditional teaching does not allow for the consideration of students' individual characteristics; it is known that some students memorize well by listening, while others prefer visual communication. Organizing the lesson process using artificial intelligence is an important and modern tool for engaging them in the lesson by assigning worthy tasks to each of them and involving them in role-playing games, developing their individual positions accordingly. In traditional lessons, it has been found that the teacher recounted the lesson "dryly" or the student was limited to simply telling him the material he memorized, which, as proven by scientists, does not remain in long-term memory and turns the student into a passive participant [4].

Literature Review

In a multicenter study conducted by Stockwell A. (2020), it was confirmed that the use of electronic visual materials in the language learning process increases the student's personal motivation, provides the opportunity to apply the studied material in practice, and preserves it in the students' long-term memory. The promotion of artificial intelligence in this process increases student activity, personal motivation, and a sense of direct involvement in the process. These tools integrate conventional listening technique and storytelling with multimedia, which conveys the process of material built on a certain theme through digital media based on a target and a specific contemplation. Not only does information technology application improve the variety of emotions, experiences, methods, and techniques, but also boosts determination during the process of imparting language skills [9].

Hargis W., 2022 found that due to the development in technology, influenced by innovation and variety, how learners grasp text has also altered: conventional written texts are being substituted by electronic documents which sparks several senses [15].

Also, Long, J., et al. (2022) emphasizes the importance of using audio materials, various interactive methods, and videos in foreign language learning among students. The use of programs developed on the basis of these interactive methods helps to organize and ensure the educational process to make the lesson processes interesting [1].

Analysis and Results

The growth of digitalization in education has led to an increase in the use of digital tools, which are essential in teaching foreign languages. Since foreign languages require four basic language skills (listening, speaking, reading, and writing), teachers must use different materials and adapt them to these skills [1].

The rise in digitalization in education has led to the increased use of digital tools that have a role in foreign language teaching. As four fundamental language skills (listening, speaking, reading, and writing) are required in foreign languages, teachers should use various materials and adapt them according to these skills. From this point of view, digitalization helps to save teachers’ time and effort in the process of creating

material. From the student point of view, it is believed that interest in digital materials, especially among young people, has a more positive impact on learning [14].

Increasing the effectiveness of foreign language teaching by promoting digitalization in education is linked to several factors. In this regard, it is important to develop skills in a foreign language (speaking, writing, reading, listening) and to master the provided materials. It has been confirmed that developing students' speech through the use of digital technologies increases the efficiency of the educational process due to their increased interest in language acquisition [1,13]. This approach covers three important dimensions in teaching English:

1. Communication with AI (using language through dialogues with AI);
2. Working with AI (creating, editing, and analyzing text using AI);
3. Thinking about AI (critical assessment and reflection on the results of AI).

The main advantage of this method would be that students have an option to use English not only with grammar drills or related exercises, but also in the real-life scenarios and practical tasks. As a result, the process of language learning goes beyond artificial exercises and becomes a meaningful and contextual activity [9, 12, 15].

A key advantage of digital tools for learning and providing instruction is their user-friendliness. As these technologies are intuitive and easy to navigate for most students, they can excel in a short span of time [4, 6, 9]. They also provide new opportunities for dynamic classrooms, assignments, and assessment. Students find that their ideas are taken shape instantaneously, organize projects in an easy way, and this allures them in the creative process [8,11,16].

On the other hand, foreign language education already has a relatively perfect system. Artificial intelligence owns the ability to process large, different real-world data with high speed. Thereby, conducting it in a deep analysis of the application of AI technology models in foreign language learning environment and deeply integrating new software into the educational procedure is vital [3, 7, 10, 17].

In a quasi-experiment conducted by Simon Suh (2025), 34 students were measured before (pre-test) and after (post-test) working with AI-based language learning platforms (such as Duolingo and Santa) [19]. The study analyzed the following indicators: student activity, academic achievements, and satisfaction with learning. The results showed that when working with AI tutors:

1. Increased student activity (increased engagement in learning);
2. Improved academic performance (increased student skills and scores);
3. Student satisfaction.

These differences were determined by comparing the results of the pre-test and post-test. These empirical results provide several important pedagogical conclusions on the application of artificial intelligence in English lessons in higher education:

1. Increasing personalization and activity. AI-based tutors provide students with exercises and feedback tailored to their individual needs. This increases the active involvement of students in the educational process and enhances their activity - these are often the shortcomings of traditional teaching methods. Empirical results show that students' interactive learning experiences increase their motivation and the effectiveness of learning.

2. Improvement of academic performance. Pre-test and post-test comparisons show that learning supported by AI has a positive impact on students' academic performance. This helps reinforce basic English language skills, such as grammar, vocabulary, and communication skills. At the same time, this result enhances language learning through contextual and interactive practice, unlike the approach based on easy memorization.

3. Student satisfaction and learning experience. Students who worked with AI tutors typically expressed high satisfaction with the learning process. This result leads to the recognition of the language learning process as “interesting” and “personally useful,” which, in turn, strengthens a positive attitude towards language learning. This aspect is directly related to the motivation for language learning.

4. The necessity to use of artificial intelligence (AI) for pedagogical purposes. Empirical findings also indicate that simply deploying AI tools does not automatically produce optimal results. it is essential that their use is pedagogically directed and structurally and methodologically aligned. A teaching system supported by AI will not be entirely independent of the instructor; rather, the instructor must supervise and guide the effective use of AI tools [2, 12, 18].

Conclusion

In conclusion, the use of artificial intelligence in English language teaching in the higher education system of Uzbekistan not only increases the effectiveness of language learning, but also forms a modern, student-centered, and digital model of education that develops competencies. With the help of AI tools, learners’ individual needs can be met, inner motivation is strengthened, and communication skills are bred; simultaneously, teachers are afforded opportunities to guide instruction that are more engaging, creative, and target-oriented.

At the same time, the success of AI integration will depend on the digital literacy of teachers, the availability of lesson planning and methodological manuals, as well as the technical infrastructure of universities. Therefore, to expand English language education based on AI in Uzbekistan, it is necessary to conduct training for teachers, introduce elements of AI into existing educational programs, and carry out systematic work to strengthen digital infrastructure in universities.

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PHILOSOPHICAL ANALYSIS OF SUFISM IN THE TEACHINGS OF KHOREZM SCHOLARS

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Annotatsiya. Maqolada Xorazmlik so‘fiylar — Najmiddin Kubro, Mahmud az-Zamaxshariy va shayx Adina Eshonning ilmiy hamda ma’naviy-intellektual faoliyati tadqiq etiladi. Ularning tasavvuf ta’limoti rivojiga qo‘shgan hissasi, shuningdek, asarlarining mintaqa tarixiy-falsafiy va madaniy merosidagi ahamiyati tahlil qilinadi. Ayniqsa, shaxsning ma’naviy kamoloti va ruhiy tarbiyasiga oid qarashlariga alohida e’tibor qaratilgan.

Kalit so‘zlar: *tasavvuf, ma’naviy-axloqiy tarbiya, mutafakkir, olim, axloq, shaxs shakllanishi, gunoh va tavba, yaxshilik va yomonlik, taqdir, rizq.*

Аннотация. В статье анализируется научная и духовно-интеллектуальная деятельность хорезмийских суфиев — Наджмиддин Кубро, Махмуд аз-Замахшари и шейха Адина Эшон. Выявляется их вклад в развитие суфийской мысли, а также определяется значение их трудов в контексте историко-философского и культурного наследия региона. Особое внимание уделяется анализу концепций нравственного совершенствования личности и духовного воспитания, разработанных данными мыслителями.

Ключевые слова: *суфизм, духовно-нравственное воспитание, мыслитель, учёный, нравственность, формирование личности, грех и покаяние, добро и зло, судьба, пропитание, ризк.*

Abstract. The article examines the scientific, spiritual and intellectual activities of the Khorezm Sufis - Najmiddin Kubro, Mahmud az-Zamakshari and Sheikh Adina Eshan. Their contribution to the development of Sufi teaching, as well as the significance of his works in the historical, philosophical and cultural heritage of the region are analyzed. Particular attention is paid to the views of the individual regarding the spiritual maturity and spiritual education of the individual.

Keywords: *Sufism, spiritual and moral education, thinker, scholar, ethics, personality formation, sin and repentance, good and evil, destiny, sustenance (rizq).*

Introduction

Abu Rayhan Beruni writes in his work “Monuments of Ancient Peoples”: “The Khorezm people kept history from the time people began to settle in Khorezm”. It is not by chance that we began our article with such phrases. Khorezm is such a great land that various manifestations of social development have been observed in this oasis, and great thinkers, scientists, and great religious figures have emerged who have

contributed to these achievements. Najmiddin Kubro, a major Sufi scholar, ranks among the Az-Zamakhsharis. The most remarkable feature of the achievements of independent Uzbekistan in the sphere of science is that our modern scientists are conducting scientific research that has long been done to enrich our history, and as a result, new historical names are manifested in their creativity. Among them is Sheikh Adina Eshon, one of the Philosophers of Khwarezm. In our scientific research, the activities and work of this great philosophical scientist are covered at the expense of research [8].

The progressive Middle Ages played a huge role in the history of our country. It was during this period that the most universal period of development of our history, the renaissance, took place. In the spheres of science, fiction, culture of religion, a number of scientists engaged in their activities and left the world with rare masterpieces of science. We all know the history of the Mongol invasion and the subsequent period of crisis, which came after the light in the history of our homeland. One of the great thinkers who continued his scientific work during such difficult times, Najmiddin Kubro, became known in the world of religion as a companion, a sharp thinker, and the founder of the Sufi sect [4]. Najmiddin Kubro (1145–1221) was a major Khorezmian scholar [1] who left a deep mark on the development of Sufism in the 13th century.

Sheikh Najmiddin Kubro-the founder of the “Kubrawi” doctrine, Ahmad ibn Umar Abuljanob Najmiddin al-Kubro Al-Khivakiy, was born in Khiva Castle. His childhood was spent in constant study of religious and secular sciences. Sheikh Najmiddin Kubro's disciples numbered more than four hundred, including: Majididdin Baghdadi, Sa'diddin Hamawi, Ayn uz-Zamin Jamoliddin Gaili, Bobo Kamol Jandi, Najmiddin Rozi ad-Doya, Radiduddin Ali Lolo, Fariduddin Attor, Bahouddin Walad (Jaloliddin Rumi's father) Safiddin Sa'id al-Boxarzi, Badriddin Firdavsi as-Samarqandi, Ahmad al-Gurpani, Nuriddin Abdurahman Al - Isfarani, Ruknidin Alouddavla, as-Simnani, Ali Hamadani, Ibn Shahabiddin and other great field poets and preachers studied. In this way, he gained fame with recognition of his school throughout the East as “Shaykhi Valitarosh” – a magnificent teacher who raised and raised Saints [7].

As for the nickname “Valiytarosh”, the meaning of this word means a guardian. After all, the divine ability of Najmiddin Kubro was so great that whoever had their eyes on at the moment when inspiration struck in their hearts, would achieve the rank of Governor. Najmiddin Kubro left his homeland Khwarezm in his sixteen to seventeen years of age to travel through the countries of Iran, Egypt, Iraq in an attempt to strengthen his education. His heart, thirsty for knowledge, does not leave him alone, and when he hears the voice of any named scientist, he immediately sets out, whether on foot or on a horse, or on a camel, spending weeks, and sometimes months, finding someone he was looking for, and learning from him diligently. If he was not satisfied with his studies, he would ask his teacher for permission and set off again [7].

Another scholar, Az-Zamakhshari, who has a special place in the exaltation of teachings such as Islamic culture, mysticism in khwarezm. The work “Al-Kashshof,” in which the great scholar acquired great achaemenism in the world of science, is a popular interpretation written on the Holy Quran. Great scholar's full name was Abul Qasim Mahmud ibn Umar ibn Muhammad (Ahmad in some sources), who was born

on Wednesday 27 of the month of Rajab (29 March 1075 CE), the 467th of Ah, In Zamakhshar, one of the large villages of Khwarezm" [3].

The full name of the work is "Al-Kashshof an haqoiq it-tanziyl va uyun «il-aqoviyl fi vujuh it-ta'viyl" [1] ("opening the eyes of the closed truths in the Quran and the narratives by interpreting it") and is read with great interest. "Al-Kashshof" was highly praised by Az-Zamahshari himself, who even wrote of his work: Indeed, there are many interpretations in the world, However, there is no such thing as "Al-Kashshof" among them. If you seek guidance, recite "Al-Kashshof" again, if ignorance is a disease, "Al-Kashshof" is a cure for it [9].

Looking back at the history of the writing of "Al-Kashshof", Az-Zamakhshari diligently studies the many works devoted to Qur'anic exegesis and approaches them both positively and critically during his research. This is how the world-famous work "Al-Kashshof" was created [1]. Historical accounts note-that the work was written in Mecca, one of the sacred territories, and this is not in vain, that is, the Ruler of Mecca Abul-Hasan Ali ibn Hamza ibn Wahhos As-Sulaymaniyah was benevolent. The work "Al-Kashshof" was born on the basis of numerous sources on description, Hadith, fiqh, ilm al-Qiraat, and other sciences.

The work "Al-Kashshof" is highly regarded as a masterpiece, as evidenced by the abundance of manuscript copies, the presence of commentaries related to the work, and the fact that they are being published.

The full name of this scientist, which found fame under the name of Odina Eshon, is Abul-Muzaffar ibn Sayyid Muzaffar al-Husayniy al-Khwarazmi al-Karwaki. His real name was Sayyid Odina Muhammad [2]. From an early age, Odina Eshon is influenced by her mysticism. After completing his studies at the madrasa, the young man tries to learn from a scholar. However, in the Islamic world of the East, having failed to find such a bright scholar, he begins to engage independently. Adina Eshon is distinguished from the Uvaysi (who met the spirit of the Messenger). Throughout his life, Odina Eshon tirelessly read Rumi's "Masnaviyi va Ma'naviy" and was able to fully study its secrets and symbolic hints. Having reached perfection in Sufism and rising to the highest level of the field, Odina Eshon is determined to explain the most subtle points of the work "Masnaviyi va Ma'naviy" [3].

A major scholar named Adina Eshon al-Khwarazmi (died 1801), who contributed to the development of our culture and spirituality living in Khwarezm, worked tirelessly towards the education of a perfect person.) about his life and work, the son of Latifjan Haji Bahauddin, who was from his family, did some significant work [2].

Literature Review

A little touch on the life and work of Sheikh Najmiddin Kubro, "Safinat ul-Aziz" by Doroshukuh, "Riyaz ul-orifin" by Rizokulikhan Hidayat, "Khazarat ul-asfiyo" by Mawlawi Ghulam Sarwar Sahib Lohuri, "Tuhfat ul-asfiyo" by Haji Khalifa, "Tuhfat ul-fuqaro," "Nafohat ul-uns" by Abdurahman Jami, "Tazkirat ush-shuaro by Davleteshah Samarkandi, "Tarixi Guzida" by Hamdullah Qazwini, "Majolis ul-ushshaq" by Husayn Boyqara, "Tabatoti Nasiriy" by Mavlono Minhojiddin [12:403], "Mu'jam" by Ibn Yakut, "Nasoyim ul-lovab" by Alisher Navai, much valuable information on the life and biography of the great thinker mentioned. Haji Khalifa

(death of the 1658) in almost five chapters in the tazkiras entitled “Tuhfat ul-fuqaro”, hazrat Najmiddin Kubro is mentioned with respect and lists the number of Arabic works as eight [8].

There are many scientific works on the life history of Az-Zamakhshari. Among them are Ibn Khollikon's “Vafoyot al-a’yon, Ibn Al-Anbari's “Nuzhadul-Alf Fi tabaqotil udabo”, Yaqut Al-Hamawi’s “Mo’jam al-udabo”, Al-Yofiy’s “Mir’ot ul-jinon”, Ibn Al-Jawzi’s “Al-Muntazam ”, Jalaliddin Suyuti’s “ Bug’yotul vuot ”, Ibn Al-Kifti’s “Inbah al-ruwot”, and works by other arab authors. Summing up the evidential information brought by the same authors, it is possible to get a certain idea of Zamakhshari’s family, his youth years.

The study and publication of the scientific heritage of Adina Eshon will undoubtedly help to open a new page of our history. Latifjan Haji, the author of “The story of Shaykh Adina Eshon”, mentions that Bahauddin’s son used mostly manuscript books in the preparation of this book. In particular, “The history of saints in Khwarezm”, a book of 630 sheets, contains a complete account of Sheikh Adina Eshon. As for the treatises “Mir’ot ul-obidiyn” [5]. and “Tavbat ut-toyibiyn” by Odina Eshon, these two treatises are written in Persian and are dedicated to articulating the general rules of Shari’ah and Tariqat. For example, the book “Mir’ot ul-obidiyn” describes the rules for the recitation of prayer and the rules for its wholeheartedly fulfilling. “Tavbat ut-toyibiyin” describes ways to avoid sins and to regret it even if sin is committed, and to return from it [9].

Analysis and Results

Our grandfather Najmiddin Kubro emphasized human virtues in his Sufi ideas. In particular, the doctrine embodied such high-status qualities as human valor and purity, heroism and self-sacrifice, physical-spiritual power, moral exaltation, patriotism. Sheikh Najmiddin Kubro, based on his life experiences, made specific conclusions that if signs of evil appear in a person, he can be decorated with the best manners and beautiful qualities if he acquires knowledge and uses reason: “I saw that the one who was able to educate himself and refrain from lust is the strongest person...”

In his work, Fakhruddin as-Safiy, author of “Rashahot ayn ul-Hayat”, refers to the hidden interpretation of Najmiddin Kubro’s teaching, relying on the thoughts of hazrati Abdurahman Jami, and Shaykh Kubro suggests that the process of prayer is closely related to the process of human respiration “Scholar Makhdumi Nuriddin Abdurahmon al-Jomi says that Shaykh Abul Jannob Najmiddin al-Kubro’s power Spirit of God, as he wrote in his treatise” “Fawotix al-jamol” animal respiration occurs due to one natural necessity [2]. Human beings, in fact, breathe in the same necessity, but it is in the process of breathing that a person ideologically mentions the blessed name of God.

The German Orientalist Karl Brockelman reports that there are about a hundred manuscripts of “Al-Kashshof” and more than twenty commentaries and margins written on it in various manuscript funds around the world, which is evidence of the great fame and importance of the work of Az-Zamakhshari. An autograph copy of “Al-Kashshof” copied by Az-Zamakhshari (528 Ah, 1134 CE) is kept in Tehran library [6]. Adina Eshon’s Persian-language treatise “Miftoh ul-asror” (key of Secrets), “Risolai Odina Eshon” [2]., and the Arabic-language treatise “Sharxi kalimoti ba’zi ahli suluk”

(commentary on the words of some people of religion), written by her disciple, have come down to us [2].

The identification and removal of the person of Adina Eshon to the world of science was carried out by the first president of our country I.A. Karimov's statement that "Imam Bukhari, Imam Termiziy, Khodja Bahouddin Naqshband, Khodja Ahmad Yassawi, al-Khwarazmi, Beruniy, Ibn-Sino, Amir Temur, Mirzo Ulugbek, Zahiriddin Muhammad Babur and many other great ancestors have added a tremendous mass to the development of our national culture, have become the national pride of our people".

Conclusion

In conclusion, it is worth noting that the poet Sheikh Najmiddin Kubro, a mature exponent of the world of mysticism, left in his scientific approaches the Association of masterpieces ideas for the growing younger generation heritage. These include improving manners, friendly relations in our youth, finding and strengthening universal qualities such as honesty, purity, truthfulness, fairness, while fostering a sense of hatred for vices such as disgrace, arrogance, enmity, envy, betrayal, falsehood, oppression, fissfulness. Az-Zamakhshari's rich scientific and Literary Heritage has been studied in Eastern and Western countries and translated into several foreign languages. But what is sad is that none of Az-Zamakhshari's Works has yet been fully translated into Uzbek. For this reason, the translation of scholar 's works into the languages of our peoples, the transformation of this heritage into the wealth of the general public, should be one of the urgent tasks facing our scientists. The study of the heritage of Sheikh Adina Eshon is of great importance in the study of the literature and history of mysticism.

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METHODS FOR DEVELOPING THE DIDACTIC COMPETENCE OF FUTURE HISTORY TEACHERS THROUGH USING PERIODICAL PRESS PUBLICATIONS

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Annotatsiya. Maqolada davriy matbuot nashrlaridan foydalanish orqali bo‘lajak tarix o‘qituvchilarining didaktik kompetentsiyasini rivojlantirish usullari o‘rganiladi. Gazeta va jurnal materiallari jamoatchilik fikri, rasmiy ma’lumotlar, mualliflik pozitsiyasi va ma’lum bir davrning xususiyatlarini aks ettiruvchi tarixiy manbalar sifatida tahlil qilinadi. Tadqiqot manba-kontekst tahlili, qiyosiy o‘qish, muammoli seminarlar, didaktik vazifalarni loyihalash, mikro-o‘qitish va refleksiv sharhlarni kasbiy tayyorgarlikning samarali usullari sifatida asoslaydi.

Kalit so‘zlar: *bo‘lajak tarix o‘qituvchisi, didaktik kompetentsiya, davriy matbuot, gazeta, jurnal, tarixiy manba, usul, tarixiy tafakkur, manba tahlili, mikro-o‘qitish.*

Аннотация. В статье рассматриваются методы развития дидактической компетенции будущих учителей истории посредством использования публикаций периодической прессы. Газетные и журнальные материалы анализируются как исторические источники, отражающие общественное мнение, официальную информацию, позицию автора и особенности конкретного периода. Исследование обосновывает эффективность таких методов профессиональной подготовки, как анализ контекста источника, сравнительное чтение, проблемно-ориентированные семинары, разработка дидактических заданий, микропреподавание и рефлексивный комментарий.

Ключевые слова: *будущий учитель истории, дидактическая компетенция, периодическая пресса, газета, журнал, исторический источник, метод, историческое мышление, анализ источников, микропреподавание*

Abstract. The article examines methods for developing the didactic competence of future history teachers through the use of periodical press publications. Newspaper and magazine materials are analyzed as historical sources that reflect public opinion, official information, authorial position, and the features of a specific period. The study substantiates source-context analysis, comparative reading, problem-based seminars, didactic task design, micro-teaching, and reflective commentary as effective methods for professional training.

Keywords: *future history teacher, didactic competence, periodical press, newspaper, magazine, historical source, method, historical thinking, source analysis, micro-teaching*

Introduction

The integration of periodical press materials into the preparation of prospective history teachers significantly expands the capacity to structure lesson content on empirical, source-based, and analytical foundations. Newspapers and journals reflect the political discourses, social challenges, economic conditions, cultural dynamics, intellectual climate, and official information flows of a given historical period. Incorporating such materials into history instruction enables learners to differentiate between factual accounts, historical interpretations, authorial positions, and period-specific contexts. Consequently, pre-service teachers learn to analyze newspaper texts not merely as informational sources but as historical documents, to design didactic tasks aligned with instructional objectives, and to guide students toward evidence-based historical reasoning.

Didactic competence is defined by the ability to select and transform historical knowledge, adapt explanations to learners' cognitive and developmental levels, design purpose-driven lessons, and assess educational outcomes. A lesson model grounded in periodical sources strengthens pre-service teachers' pedagogical reasoning. Journalistic articles, reportage sketches, interviews, news briefs, editorials, advertisements, photographic documentation, and statistical data each reveal distinct strata of historical events. During the source selection process, student teachers must account for the material's provenance, the author's perspective, the publication's editorial stance, its temporal and spatial situatedness, and its intended rhetorical impact on the target audience.

R.B. Bain [1] argues that history education should be organized as an inquiry-driven cognitive activity centered on questioning, evidentiary analysis, problem-solving, and research, rather than as a passive reception of information. This approach is particularly critical when working with periodical materials. Newspaper and journal texts prompt learners to interrogate sources, cross-verify information against alternative evidence, and recognize the interplay between authorial interpretation and historical context. This process cultivates a pedagogical culture in which future history teachers design lessons as research-oriented inquiries rather than as transmissions of predetermined content.

B.A. VanSledright [2] emphasizes that assessing historical thinking requires evaluating a source's origin, reliability, contextual framing, and conditions for evidentiary use. Engaging with periodical publications enables student teachers to apply these criteria in practical pedagogical settings. Although newspaper data may appear as ready-made facts at first glance, in historical instruction they function as sources that demand questioning, comparative analysis, and contextual interpretation. VanSledright's framework fosters pre-service teachers' capacity for didactic decision-making, source adaptation to instructional tasks, and the establishment of clear assessment criteria.

P. Lee and R. Ashby [3] demonstrate that students' conceptualizations of evidence, historical explanation, and historical claims develop progressively. A closely aligned theoretical perspective is advanced by S. Levesque [4], who frames historical thinking through second-order concepts such as evidence, historical significance, continuity and change, causation, and historical perspective. Periodical materials provide a highly effective medium for operationalizing these concepts in classroom instruction, as

newspaper texts preserve the contemporary voices, societal concerns, and interpretive frameworks of their time.

C. Monte-Sano [5] highlights the importance of source engagement, argumentation, evidence selection, and conclusion-drawing in constructing historical writing and evidence-based reasoning. A. Reisman [6] demonstrates that document-based history lessons develop students' capacity to "read like a historian," critically evaluate sources, and reason from evidence. J.D. Nokes [7] conceptualizes historical literacy as an integrative process encompassing textual reading, evidence identification, and historical conclusion-formulation. Collectively, these theoretical perspectives provide a robust scholarly foundation for methodological approaches aimed at developing the didactic competence of prospective history teachers through periodical press integration.

N.G. Dayri [8] and M.T. Studenikin [9] have emphasized problem-based questioning, document analysis, independent reasoning, and instructional technology as critical components of history teaching methodology. The methodological legacy of these scholars remains highly relevant for integrating periodical materials into the educational process. When newspaper texts are studied as historical documents, student teachers learn to select sources aligned with didactic objectives, construct systematic questioning frameworks, scaffold learner activities progressively, and guide students toward evidence-based historical conclusions. Thus, the utilization of periodical press publications constitutes an effective, integrative pedagogical pathway that synthesizes theoretical grounding, source criticism, methodological design, and reflective practice in the development of future history teachers' didactic competence.

Research Methodology

The study employed pedagogical analysis, scholarly literature review, source-critical analysis, comparative reading, didactic modeling, classroom observation, expert evaluation, and synthesis. Pedagogical analysis was directed toward identifying opportunities for integrating periodical press materials into history instruction. A systematic review of scholarly literature facilitated the synthesis of theoretical perspectives on historical thinking, source literacy, document-based instruction, historical writing, and didactic competence. Source-critical analysis enabled the systematic differentiation of newspaper and journal materials according to authorship, publication date, socio-historical context, target audience, and historiographical value.

Engagement with periodical publications was structured within a three-stage methodological framework. In the first stage, student teachers completed practical tasks involving source selection, compilation of a source documentation form (source passport), and contextualization within the relevant historical period. The second stage entailed a multidimensional analysis of newspaper or journal content, examining thematic substance, linguistic features, authorial stance, core thesis, evidentiary basis, and interpretive frameworks. In the third stage, participants designed instructional objectives, a systematic sequence of questions and tasks, problem-based scenarios, assessment rubrics, and reflective exercises based on the selected materials. This sequential approach effectively bridged theoretical knowledge with applied pedagogical practice.

The methodological component prioritized source-context analysis, comparative reading, problem-based seminars, didactic task design grounded in press materials, micro-teaching, and reflective commentary. Source-context analysis enabled student teachers to interpret newspaper texts in relation to contemporary historical conditions. Comparative reading focused on juxtaposing how the same event was portrayed across different publications. Problem-based seminars cultivated students' competencies in formulating inquiry questions and constructing evidence-based responses. Micro-teaching provided a simulated pedagogical environment for prospective teachers to test instructional decisions under conditions approximating real classroom dynamics.

Table 1. Consolidated summary of methodological approaches grounded in periodical press materials for history teacher education.

Method	Instructional Task	Required Student Action	Competency Indicator	Assessment Evidence
Source-context analysis	Contextualize press materials within their historical period	Compiles a source documentation form, identifying publication date, authorship, intended audience, and core idea	Source selection and historical contextualization	Source documentation form with concise analytical commentary
Comparative reading	Compare narrative interpretations of a single event across multiple publications	Juxtaposes two to three source texts using a comparative matrix, delineating convergent and divergent interpretive framings	Differentiation of evidence, historical interpretation, and authorial stance	Comparative analysis matrix with evidence-based conclusion
Problem-based seminar	Facilitate inquiry-based questioning and structured debate using periodical sources	Formulates a problem-based inquiry question derived from textual analysis and substantiates group responses with evidentiary reasoning	Formulation of inquiry questions and facilitation of academic discourse	Seminar discussion protocol with oral defense of interpretations
Instructional task design	Transform journalistic texts into instructional tasks aligned with lesson objectives	Designs text-based instructional tasks (e.g., guided questions, graphic organizers, structured tables, analytical essays, or assessment items) aligned with learning objectives	Instructional design and selection of assessment criteria	Instructional task portfolio with expert rubric evaluation
Micro-teaching and reflective commentary	Implement and evaluate the designed task within a simulated classroom context	Delivers a 10–12 minute micro-teaching session, analyzes learner responses, and implements	Reflective practice and pedagogical decision-making	Micro-teaching observation form with reflective journal entry

As a pilot empirical study, the didactic preparedness of 36 student teachers working with periodical press materials was examined. Assessment was conducted across five indicators: source selection, historical contextualization, comparative reading, instructional task design, and reflective commentary following micro-teaching. Each indicator was evaluated using a five-point rubric. To synthesize the findings, a Periodical Press Development Index (DMI) based on the geometric mean was adopted. The geometric mean was specifically selected to prevent high scores in certain indicators from masking underdeveloped competencies in others, thereby ensuring a more balanced competency profile.

Formula for the Periodical Press Index.

$$DMI = \sqrt[5]{M_t \times S_t \times Q_t \times L_d \times R_t} \times 20 \quad \Delta DMI = DMI_{yak} - DMI_{bos}$$

In the equation, *DMI* denotes the Didactic-Methodological Development Index for engagement with periodical press materials. The variables represent the following assessment indicators: M_t (source selection), S_t (historical contextualization), Q_t (comparative reading), L_d (instructional task design), and R_t (reflective analysis). Each indicator is scored on a scale from 1 to 5. The final index is expressed as a percentage. ΔDMI represents the differential between baseline and post-intervention scores, quantifying developmental progress over the training period.

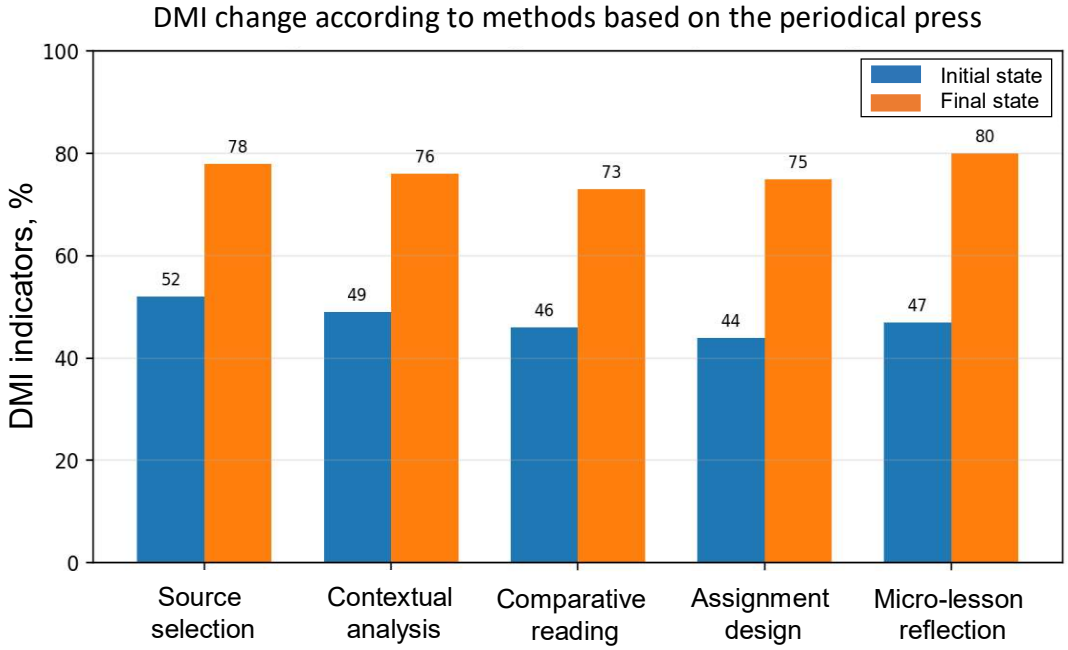

Figure 1. Histogram depicting competency development across periodical press-based methodological approaches in history teacher education.

Histogram based on a pilot study sample (n = 36), illustrating baseline and post-intervention competency levels across five periodical press-based methodological approaches. The most pronounced gains were observed in micro-teaching with reflective commentary, instructional task design, and source-context analysis.

Analysis and Results

Analysis of the findings demonstrates that methodological approaches grounded in periodical press materials effectively foster the development of prospective history teachers' didactic competence through concrete, observable pedagogical actions. At

baseline, student teachers predominantly approached newspaper or journal texts as straightforward repositories of historical information. By the post-intervention stage, however, participants demonstrated increased attention to critical source evaluation criteria, including publication date, authorship, intended audience, socio-political context, and the distinction between evaluative commentary and evidentiary content within the text. The source-context analysis indicator rose from 52% to 78%, reflecting students' enhanced understanding of systematic criteria for selecting periodical materials for instructional purposes.

The comparative reading methodology enabled student teachers to examine how a single historical event was represented across diverse periodical publications. Throughout the instructional sequence, participants learned to attribute inter-publication differences not merely to textual length or stylistic variation, but to authorial stance, editorial orientation, evaluative framing of events, and historically situated perspectives. The comparative reading indicator increased from 46% to 73%. Student teachers' written analyses subsequently demonstrated strengthened capacities for evidence-based reasoning, explanatory differentiation among sources, and epistemologically cautious engagement with historical narratives.

Performance on instructional task design improved from 44% to 75%. Initially, student teachers predominantly generated comprehension-oriented questions requiring literal retrieval of information from press texts. By the final stage, participants designed cognitively demanding tasks requiring causal analysis, critical evaluation of authorial claims, comparative source interrogation, integration with historical maps or data tables, and composition of concise analytical essays. This shift indicates substantial development in the methodological design dimension of didactic competence.

The micro-teaching and reflective commentary methodology yielded the most substantial gains. Baseline performance stood at 47%, rising to 80% post-intervention. Student teachers practiced designing and delivering brief instructional segments (10–12 minutes) based on newspaper materials, including formulating probing questions, scaffolding learner responses, facilitating structured discussion, guiding evidence-based historical conclusions, and conducting self-evaluative analysis of their pedagogical decisions. Reflective commentary enabled participants to identify instructional strengths and areas for refinement, thereby informing iterative pedagogical improvement.

Collectively, integration of periodical press materials activated cognitive, methodological, communicative, and reflective dimensions of didactic competence in an integrated manner. Newspaper and journal texts connected students' historical knowledge to source-critical analysis, transformed methodological planning into actionable instructional tasks, intensified pedagogical discourse through micro-teaching, and cultivated self-assessment capacities through structured reflection. Across all methodological approaches, illustrative DMI calculations based on the pilot sample demonstrated consistent, statistically meaningful growth

The development of prospective history teachers' didactic competence through periodical press integration rests upon several interrelated methodological conditions. First, press materials must be selected and framed explicitly as historical sources. Merely incorporating a newspaper excerpt into a lesson does not, in itself, yield

pedagogical value. Methodological efficacy is maximized when selected materials are coherently aligned with lesson objectives, learner developmental levels, historical contextualization, formative aims, and task design. Student teachers must be equipped to interrogate press texts with attention to authorship, historical moment, ideological positioning, target audience, and evidentiary selection.

R.B. Bain's [1] inquiry-based framework for history education supports the organization of periodical press-based lessons around generative questioning. When press materials serve as the entry point for instruction, learners do not passively receive a predetermined narrative; rather, they actively interrogate the source. For instance, comparing two newspaper articles addressing the same historical event prompts learners to recognize divergent representational strategies. The prospective teacher then leverages this observation to formulate a problem-based inquiry question, facilitate structured group discussion, and guide students toward evidence-based historical conclusions.

B.A. VanSledright [2] emphasizes that assessing historical thinking requires moving beyond factual recall toward source-based reasoning. Similarly, evaluating student teachers' didactic competence through periodical press tasks should prioritize their capacity to analyze source reliability, authorial perspective, contextual framing, and pedagogical applicability—not merely to summarize content. Didactic preparedness advances when student teachers can articulate how a source's provenance and rhetorical features inform its instructional utility.

P. Lee and R. Ashby [3] demonstrate that learners' conceptions of historical evidence develop progressively toward greater sophistication. As student teachers gain proficiency in working with periodical materials, they must anticipate and scaffold analogous developmental trajectories in their future pupils. Instructional sequences should therefore progress from information-retrieval tasks toward contextual analysis, comparative interpretation, and ultimately, independent historical argumentation. S. Levesque's [4] second-order concepts—historical significance, causation, continuity and change—are rendered particularly accessible through the concrete, contemporaneous voices preserved in press materials.

C. Monte-Sano [5] underscores the importance of source engagement and argument construction in developing evidence-based historical writing. Assigning concise analytical essays grounded in periodical sources helps prospective teachers learn to structure the pedagogical relationships among inquiry questions, evidentiary support, interpretive explanation, and historical conclusions. A. Reisman [6] demonstrates that document-based history lessons cultivate students' capacity to "read like a historian." When newspaper articles are treated as historical documents, learners systematically examine authorship, temporal situatedness, evidentiary basis, linguistic choices, and rhetorical purpose. J.D. Nokes [7] similarly argues that historical literacy develops through integrative engagement with textual and evidentiary reasoning.

N.G. Dayri [8] emphasizes problem-based scenarios and the cultivation of active, independent reasoning in history instruction. M.T. Studenikin [9] advocates for the deliberate integration of contemporary methods and technologies with learner-centered activity. When periodical press materials are employed in alignment with these principles, prospective teachers evolve beyond the role of textual deliverer toward that

of facilitator: orchestrating critical analysis, formulating precise inquiry questions, scaffolding evidentiary discrimination, and guiding evidence-based conclusion formation.

Discussion findings indicate that periodical press-based methodologies achieve optimal efficacy not as isolated techniques, but as an interconnected didactic system. Source-context analysis ensures rigorous material selection. Comparative reading cultivates interpretive differentiation. Problem-based seminars develop discursive and evidentiary competencies. Instructional task design bridges theory and classroom practice. Micro-teaching with reflective commentary consolidates professional identity and iterative pedagogical reasoning.

Conclusion

Integrating periodical press materials into the preparation of prospective history teachers synthesizes historical knowledge, source-critical analysis, methodological design, pedagogical communication, and reflective assessment within a unified instructional activity. Newspaper and journal texts enable student teachers to examine historical events through multiple lenses: temporal context, authorial positioning, public discourse, and evidentiary interpretation. This approach establishes a foundation for organizing instruction not as knowledge transmission, but as an inquiry-driven process centered on source interrogation, generative questioning, collaborative discussion, and evidence-based conclusion.

Empirical findings confirm that source-context analysis, comparative reading, problem-based seminars, instructional task design, micro-teaching, and reflective commentary constitute an effective methodological framework for integrating periodical press into history education. These approaches collectively develop student teachers' capacities to: select and evaluate historical evidence; adapt textual materials to pedagogical objectives; design cognitively demanding tasks for learners; critically appraise source reliability; pilot instructional segments in simulated contexts; and engage in systematic self-evaluation of pedagogical practice.

For higher pedagogical education, it is recommended that periodical press materials be employed not merely as supplementary resources, but as primary sources that enrich lesson content, activate historical thinking, and scaffold methodological decision-making. When positioned in this manner, press materials empower prospective teachers to utilize journalistic texts as instruments for historical evidentiary reasoning, problem-based inquiry, comparative analysis, structured debate, and reflective assessment—thereby strengthening the foundational competencies required for effective, inquiry-oriented history instruction.

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FORMING THE DIGITAL CULTURE OF STUDENTS IN THE PROCESS OF USING AI

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Annotatsiya. Ushbu maqolada oliy ta’lim tizimida sun’iy intellekt texnologiyalaridan foydalangan holda savodxonlikning nazariy asoslari, pedagogik ahamiyati va rivojlanish mexanizmlari har tomonlama tahlil qilinadi. Shuningdek, SI savodxonligining tuzilishi ilmiy asosda tavsiflangan. Maqolada akademik halollikni mustahkamlash, axborot xavfsizligini ta’minlash va ongli va mas’uliyatli foydalanish madaniyatini shakllantirishning ahamiyati asoslab berilgan.

Kalit so‘zlar: *raqamli ta’lim, sun’iy intellekt, oliy ta’lim, raqamli transformatsiya, moslashuvchan ta’lim.*

Аннотация. В данной статье комплексно анализируются теоретические основы, педагогическая значимость и механизмы развития грамотности использования технологий искусственного интеллекта в системе высшего образования. Также на научной основе раскрывается структурное содержание ИИ-грамотности. В статье обосновывается актуальность укрепления академической добросовестности, обеспечения информационной безопасности и формирования культуры осознанного и ответственного использования технологий ИИ.

Ключевые слова: *искусственный интеллект, высшее образование, цифровая трансформация, адаптивное обучение.*

Abstract. This article comprehensively analyzes the theoretical foundations, pedagogical importance and development mechanisms of literacy using artificial

intelligence technologies in the higher education system. Also, the structure of SI literacy is described on a scientific basis. The importance of strengthening academic honesty, ensuring information security, and forming a culture of conscious and responsible use is justified in the article.

Keywords: *digital education, artificial intelligence, higher education, digital transformation, adaptive education.*

Introduction

Today, digital technologies are developing rapidly and are being widely implemented in all spheres of society worldwide. In particular, the application of artificial intelligence (AI) technologies to the educational process creates wide opportunities for improving individual education, increasing the interest and activity of students, and easing the workload of teachers [1-3]. The integration of artificial intelligence into the higher education system increases the possibility of providing personal orientation, interactivity and flexibility of education, developing adaptive teaching models, providing individual recommendations and feedback, creating modern educational platforms, and modeling real communicative situations. In developed countries such as the USA, Germany, Canada and China, digitization of the educational process based on artificial intelligence and the use of interactive methods have become an important component of modern education [4].

Literature Review

Improving the quality and effectiveness of education in educational institutions around the world, as well as implementing student-centered pedagogical approaches, is becoming an urgent issue. The global recommendation for artificial intelligence ethics, adopted by UNESCO in 2021, specifically states the need to use artificial intelligence capabilities wisely and efficiently, reduce possible risks, and ensure inclusive and sustainable development of Education [5]. These principles are especially important in teaching computer graphics and web design, as modern educational approaches require a deep consideration of the individual characteristics, potential, and needs of students. Artificial intelligence technologies help teachers organize targeted and effective teaching tailored to these individual needs.

However, along with the widespread use of AI tools in the educational process, a number of ethical and legal issues are also increasing. In particular, issues of copyright, academic integrity, plagiarism, personal data security, and the impartiality of AI results are becoming increasingly relevant. Therefore, developing students' skills in adhering to ethical standards and developing digital culture in the process of using AI tools is an important task of higher education.

Research Methodology

The theoretical and methodological foundations of the informatization of education, as well as the issues related to the formation of cognitive and digital competencies in the context of artificial intelligence, have been extensively explored by leading scholars in the field of AI and digital education.

Analysis and Results

In particular, the works of Stuart Russell, Peter Norvig, Geoffrey Hinton, Yann LeCun, Yoshua Bengio, Andrew Ng, Fei-Fei Li, Sebastian Thrun, Demis Hassabis, and Ian Goodfellow focus on the integration of artificial intelligence and digital technologies into education. Their research highlights the development of students' digital culture, computational thinking, and information literacy, as well as the enhancement of intellectual, analytical, and critical thinking skills within AI-enhanced learning environments.

Moreover, contemporary studies emphasize that the effective use of AI in education requires not only technical competence but also a well-developed digital culture, including ethical awareness, responsibility, and critical evaluation of AI-generated content. Scholars argue that AI-driven educational environments promote personalized learning, adaptive instruction, and data-informed decision-making, which significantly improve learning outcomes and student engagement. At the same time, they underline the importance of fostering students' ability to interact with AI tools consciously, generate meaningful prompts, interpret results critically, and verify the reliability of digital information.

In addition, recent research highlights emerging challenges such as algorithmic bias, over-reliance on AI systems, and the risk of diminishing independent thinking skills. Therefore, integrating AI into education should be accompanied by the development of ethical guidelines, academic integrity policies, and digital literacy frameworks that ensure the responsible and transparent use of AI technologies. In this context, forming students' digital culture becomes a key pedagogical objective, enabling them to function effectively and responsibly in a rapidly evolving digital and AI-driven society.

The use of AI technologies in higher education is being studied from a didactic, organizational, and educational perspective. It is argued that AI tools allow individualization of the educational process, improving the effectiveness of teaching, developing visual thinking, and encouraging a creative approach [3]. However, the intensification of this process is also causing ethical dilemmas in the academic environment. In particular, the issue of academic integrity is one of the most pressing issues when working with AI tools. New forms of plagiarism, such as presenting results generated by an AI under one's own name and outsourcing assignments entirely to an AI, negatively impact the quality of education and the fairness of assessment [1, 4]. Copyright and intellectual property issues are also relevant, with discussions about the authorship of content created by AI, its legality, and the culture of citing sources [2].

AI literacy is the ability of an individual to understand, evaluate, and use AI technologies effectively and responsibly. AI tools allow for individualization of the learning process. However, to use them effectively, students and teachers must have the skills to create the right prompts, check results, verify sources, and avoid plagiarism. Improper use of AI tools can lead to plagiarism, academic fraud, and a decline in independent thinking. Research also raises the issue of existing algorithmic deviations (bias) on AI platforms. AI systems often rely on certain data sets, which can lead to the reinforcement of stereotypes, biases, or specific cultural perspectives.

The rapid introduction of artificial intelligence tools into the educational process, and in particular their widespread use in computer graphics and web design, raises a

number of complex ethical and legal issues. The authorship of visual content created through the use of AI technologies, ensuring academic integrity, personal data security, and the risks associated with the production of manipulative content require special attention in the educational process.

1. Copyright and intellectual property issues: Images and designs generated using AI tools raise copyright issues. Because the issue of intellectual ownership of a product created by an AI is interpreted differently in current scientific and practical discussions. As a result, the question “Who owns the image generated by an AI?” is emerging as one of the most pressing issues in the modern digital learning environment. It is also important to educate students about Creative Commons licenses, respect copyright when using visual content, and develop a culture of proper attribution. This process serves to protect intellectual property and strengthen digital culture.

2. Academic integrity and plagiarism: While using AI tools to complete graphic design assignments can increase the efficiency of the learning process, it also increases the risk of violating academic integrity principles. In particular, cases where students directly present images or design elements generated by AI without creatively reworking them create new forms of plagiarism. In such a situation, it is necessary to clearly define the normative-moral limit between “using AI help” and “getting ready-made work through AI”. Therefore, higher education institutions are required to develop assessment criteria for the transparency of work performed using AI, i.e., the use of AI to indicate (disclosure), document prompts, and determine creative contribution.

3. Personal data security and privacy: During the use of AI platforms, students may enter personal data, photos, biometric data, and educational materials into online AI systems. This poses certain risks from a digital security and privacy perspective, potentially leading to the processing or dissemination of personal data by third parties. Therefore, introducing students to information security rules when using AI tools, developing personal data protection skills, and forming digital hygiene principles in the educational process is one of the most important methodological tasks.

4. The risk of deepfakes and visual manipulation: The development of generative AI technologies has expanded the ability to create highly realistic but fake visual content. In particular, deepfake technologies artificially alter a person's face, voice, or movement in images and videos, increasing the risk of spreading misinformation and manipulating public opinion. In such circumstances, it is important to develop students' media literacy, that is, the skills to critically evaluate visual materials, identify fake content, and verify information sources. Digital culture represents a person's ability to behave in a digital environment, work with information, respect intellectual property, follow information security rules, and adhere to ethical standards in digital communication.

The formation of digital culture in students can be achieved through the following methodological approaches.

1. It is necessary for the teacher to introduce a “Code of Ethics for AI” into the educational process, which is appropriate for the subject of computer graphics, and to set limits on the use of AI; the procedure for citing sources; the requirement to document prompts and workflow; and strict restrictions on plagiarism.

2. The portfolio and process documentation method requires the student to submit a portfolio based on not only the final result, but also sketches; prompts; processing stages; and original design elements. This method provides effective results in ensuring academic integrity.

3. Through Case-study and debate techniques, discussions can be organized on the basis of real-life ethical situations in the course of the lesson.

4. It is necessary to update the assessment criteria, i.e., to apply new assessment criteria in the context of using AI technologies. This includes originality of idea; creative approach; adherence to design rules; ability to analyze and improve the AI result; and ethical requirements (source, honesty, safety).

Conclusion

In addition, it is important to emphasize that the formation of students' digital culture in the context of artificial intelligence should be considered as a continuous and systematic pedagogical process. It requires not only the integration of AI tools into the educational environment but also the development of a holistic educational strategy aimed at fostering responsible, ethical, and critical use of these technologies.

Furthermore, higher education institutions should promote interdisciplinary approaches that combine technological knowledge with ethical, legal, and social aspects of AI. This will enable students to better understand the broader implications of AI technologies and apply them in a balanced and informed manner.

Special attention should also be paid to developing students' self-regulation, digital responsibility, and lifelong learning skills, as these competencies are essential for adapting to rapidly changing technological environments. In this regard, educators play a crucial role not only as knowledge providers but also as facilitators who guide students in navigating complex digital ecosystems.

Ultimately, the effective formation of digital culture through the use of artificial intelligence contributes to preparing competitive, creative, and socially responsible specialists who are capable of making informed decisions and acting ethically in the digital society.

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LEXICAL-SEMANTIC ANALYSIS OF THE CONCEPT MONEY IN ENGLISH, UZBEK AND RUSSIAN LANGUAGES

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Annotatsiya. Ushbu maqola ingliz, o‘zbek va rus tillarida “pul” konseptining leksik-semantik xususiyatlarini qiyosiy-tipologik jihatdan o‘rganishga bag‘ishlangan. Maqolada mazkur konseptning uchta tilda nominatsiya birliklari, frazeologik iboralar, maqol va matallar, semantik maydon hamda madaniy konnotatsiyalar tahlil qilinadi. Shuningdek, har bir tilda ustun bo‘lgan kontseptual metaforalar ham alohida ko‘rib chiqiladi. Tadqiqot natijalari shuni ko‘rsatadiki, “pul” konsepti uchala tilda ham universal va til-madaniyatga xos xususiyatlarni o‘z ichiga oladi: ingliz tilidagi birliklar ko‘proq pragmatik va iqtisodiy yo‘nalganlikni aks ettirsa, o‘zbek tilidagi birliklar etik va ijtimoiy munosabatlar bilan uzviy bog‘liqdir, rus tilida esa davlat va shaxsiy mol-mulk o‘rtasidagi farqlash alohida kuchli ifodalangan. Olingan natijalar madaniyatlararo muloqot, tarjimashunoslik va xorijiy tillarni o‘qitish metodikasi uchun amaliy ahamiyatga ega.

Kalit so‘zlar: *konsept, pul, leksik-semantik tahlil, lingvokulturologiya, ingliz tili, o‘zbek tili, rus tili, nominatsiya birliklari, konnotatsiya, frazeologiya, kontseptual metafora.*

Аннотация. Настоящая статья посвящена сравнительно-типологическому исследованию лексико-семантических характеристик концепта “деньги” в английском, узбекском и русском языках. В работе анализируются номинативные единицы данного концепта, фразеологические обороты, пословицы и поговорки, семантические поля, концептуальные метафоры, а также культурные коннотации. Исследование показывает, что концепт “деньги” включает как универсальные, так и лингвокультурные составляющие: английский язык отличается прагматической и экономической направленностью номинативных единиц, узбекский богат единицами, связанными с этико-социальными отношениями, тогда как в русском языке особо выражено противопоставление государственных и личных финансовых ресурсов.

Ключевые слова: *концепт, деньги, лексико-семантический анализ, лингвокультурология, английский язык, узбекский язык, русский язык, номинативные единицы, коннотация, фразеология, концептуальная метафора.*

Abstract. This article is devoted to the comparative-typological study of lexical-semantic features of the concept “money” in English, Uzbek, and Russian. The

paper analyses nomination units, phraseological expressions, proverbs and sayings, semantic fields, conceptual metaphors, and cultural connotations of this concept across three languages. The findings demonstrate that the concept "money" encompasses both universal and language-culture-specific features: English exhibits a predominantly pragmatic and economic orientation in its nomination units, Uzbek is rich in units associated with ethico-social relations, while Russian shows a marked distinction between state and personal financial resources. The results have practical implications for cross-cultural communication, translation studies, and foreign language pedagogy.

Keywords: *concept, money, lexical-semantic analysis, linguoculturology, English language, Uzbek language, Russian language, nomination units, connotation, phraseology, conceptual metaphor.*

Introduction

In today's era of globalization, comparative linguistic analysis of culturally significant concepts has become one of the central tasks of modern linguistics. Language is not merely a means of communication — it is simultaneously a repository of cultural knowledge, a reflection of national mentality, and a mirror of societal values. In this context, concepts that are universally present in all human cultures yet encoded differently across languages offer particularly valuable material for cross-linguistic investigation [1, 14].

The concept of 'money' represents one of the most fundamental and universally recognized economic and social phenomena, deeply embedded in the cultural and linguistic consciousness of every nation. While the material essence of money — as a medium of exchange, unit of account, and store of value — is universal, its linguistic representation and cultural connotations vary significantly across languages and cultures [2, 43]. The way a language names, categorizes, and evaluates monetary phenomena reveals deep-seated cultural attitudes toward wealth, fairness, labour, and social relations.

The relevance of this research is further confirmed by the growing attention in modern linguistics to economic discourse and financial terminology as bearers of cultural identity. In the context of expanding economic ties between English-speaking nations, Uzbekistan, and Russian-speaking regions, understanding how the concept of money is linguistically framed across these cultures has direct practical significance for intercultural business communication, professional translation, and foreign language education [3, 19; 5, 17]. The rapid penetration of English financial terminology into Uzbek and Russian in recent decades makes the comparative dimension of this study particularly timely.

English, Uzbek, and Russian — representing three distinct linguistic and cultural traditions: Germanic-Anglo-Saxon, Turkic-Central Asian, and Slavic respectively — offer a rich comparative framework for studying how the concept 'money' is lexically encoded, semantically organized, and culturally perceived. The choice of these three languages is further motivated by their typological diversity and the sustained cultural-historical contacts between the peoples who speak them, particularly the century-long

Uzbek-Russian bilingual experience and the more recent penetration of English economic vocabulary into both [4, 28].

It should also be noted that the three cultures represented by these languages correspond to three distinct orientations in cross-cultural psychology: the individualist-capitalist tradition of English-speaking cultures, the collectivist-Islamic tradition of Uzbek culture, and the historically collectivist-state-centred tradition of Russian culture. Each of these orientations generates a different set of conceptual emphases, metaphorical mappings, and evaluative connotations around money, making the comparative analysis particularly productive from both linguistic and cultural perspectives [8, 52].

The purpose of this article is to conduct a comparative lexical-semantic analysis of the concept “money” / “pul” / “деньги” in English, Uzbek, and Russian, identifying nomination units, semantic field structure, phraseological expressions, conceptual metaphors, and cultural connotations characteristic of each linguistic system.

Literature Review

The theoretical foundations of this research rest on the achievements of cognitive linguistics, linguoculturology, and conceptual analysis. The concept as a fundamental unit of the mental lexicon and cognitive structure of language has been extensively explored in both Western and post-Soviet linguistic traditions, yielding a rich body of methodological tools applicable to the present study.

The framework of conceptual metaphor analysis developed by G. Lakoff and M. Johnson [1, 187] demonstrated that abstract economic concepts, including money, are structured through systematic metaphorical mappings rooted in embodied experience. Their research established that expressions such as “time is money” are not merely rhetorical figures but reflect deep cognitive structures shaping economic conceptualization. Z. Kövecses further developed this framework, demonstrating how metaphorical source domains systematically structure abstract target domains across different languages and cultures, including economic ones [9, 67].

G. Fauconnier and M. Turner’s theory of conceptual integration, or “conceptual blending” [16, 78], provides an additional analytical lens for the phraseological material: many idioms about money involve blending between a literal source domain (water, seeds, tools, dirt) and the target domain of money, creating emergent conceptual structures that are culture-specific. This framework helps explain why superficially similar metaphors (e.g., MONEY IS WATER) can generate different idiomatic expressions and cultural evaluations in English, Uzbek, and Russian.

In Russian linguistics, Yu.S. Stepanov’s foundational work on cultural constants [2, 43] established the methodological principle that culturally significant concepts possess a historical, cultural, and etymological “layering” that must all be taken into account in full analysis. V.A. Maslova’s contributions to linguoculturology [3, 35] provided a systematic description of the relationship between language and national character. The semantic-cognitive methodology developed by Z.D. Popova and I.A. Sternin [4, 28] — distinguishing between the conceptual core, near periphery, and far periphery of a concept — provides the primary analytical framework for the structural

dimension of this research. V.N. Telia's study of Russian phraseology [11, 45] provides the theoretical grounding for the analysis of idiomatic material.

In Uzbek linguistics, the study of national linguistic-cultural concepts was advanced by Sh.S. Safarov [5, 89], who established systematic frameworks for analyzing Uzbek conceptual structures and the role of cognitive processes in language use. The comprehensive treatment of Uzbek lexical semantics by N.M. Mahmudov [6, 156] documented the semantic organization of key concept fields, while F.R. Qodirov's targeted analysis of economic vocabulary [7, 77] provides the most directly relevant Uzbek-language reference for the financial domain.

A key theoretical contribution to understanding cross-cultural differences in economic attitudes comes from G. Hofstede's research on cultural dimensions [8, 127], which provides the comparative framework for observed differences between individualist and collectivist cultural orientations toward wealth. A. Wierzbicka's cross-cultural semantic methodology based on universal semantic primitives [10, 312] provides grounds for distinguishing universal from culture-specific components of the concept. V.I. Karasik's approach to the analysis of language personality and cultural concepts [12, 117] complements the linguocultural dimension of the analysis by linking lexical choices to broader discourse practices.

A brief methodological note is required regarding the lexicographic materials. Dictionary definitions represent institutionally sanctioned, diachronically accumulated conceptualizations and therefore best capture the prototypical and established zones of a concept. To partially compensate for the underrepresentation of colloquial and emerging registers in dictionaries, informal and slang vocabulary was additionally documented from language corpora and supplementary sources. Phraseological units and proverbs were cross-checked across multiple phraseological dictionaries in all three languages to ensure representativeness.

Research Methodology

The methodology of this research combines: (1) conceptual analysis — identification and structural description of the concept's layers; (2) continuous sampling from lexicographic sources; (3) comparative-contrastive analysis across three languages; (4) componential analysis of the semantic structure of lexical units; (5) linguocultural analysis of connotations and pragmatic associations; (6) cognitive-metaphorical analysis of conceptual metaphors. The research material was drawn from explanatory dictionaries of English [13], Russian [14], and Uzbek [15], as well as phraseological dictionaries and collections of proverbs in all three languages.

Analysis and Results

The analysis proceeds through five stages: etymology and core nomination units, semantic field structure, phraseological and idiomatic material, proverbial and cultural connotation analysis, and comparative conceptual metaphor analysis.

Etymology and core nomination units. The etymology of the core lexical items reveals distinct cultural-historical pathways. The English word money derives from Latin moneta — a title of the goddess Juno, in whose temple Roman coins were minted — thereby encoding a foundational historical connection between religious authority, state power, and economic production [13, 1145]. This etymological origin reflects the

institutionalized, officially sanctioned nature of currency in the Western cultural tradition, situating money within a framework of civic and political order from its earliest nominal history.

The Uzbek pul carries Turkic-Persian roots and entered the language via the commercial networks of the Silk Road, originally denoting small coins of low denomination used in everyday bazaar transactions. This etymological background encodes a conception of money grounded in practical commercial exchange rather than in abstract accumulation or institutional authority, reflecting the mercantile character of Central Asian urban culture and the historical role of the region as a crossroads of trade routes. The word's association with small-denomination coins further reinforces a cultural emphasis on everyday sufficiency rather than large-scale accumulation [15, 487].

The Russian деньги (a grammatical plural with no standard singular form in contemporary usage) derives from the Tatar tenge — itself a unit of currency — demonstrating the profound influence of the Golden Horde period on Russian economic vocabulary [14, 389]. The obligatory plural form is linguistically significant: money is conceptually encoded as an inherently aggregate, collective entity in Russian, rather than as a countable abstract unit, a feature that distinguishes it sharply from both English money (singular possible) and Uzbek pul (singular standard).

The derivational productivity of money-related vocabulary further illuminates cultural priorities. English demonstrates high derivational activity in the financial domain through suffixation (monetize, financialize, capitalize, bankroll) and compounding (moneymaker, moneylender, money-laundering), reflecting a culture in which financial activity is widely elaborated and professionally specialized. Uzbek derivational patterns in this domain are more conservative, with borrowings from Arabic-Persian (kapital, moliya, daromad, bank) playing a larger role than native derivational morphology, suggesting that the elaborated conceptualization of financial activity was historically linked to external influences through trade and scholarship. Russian financial vocabulary shows extensive borrowing from French and Dutch in the Imperial period (финансы, биржа, кредит) and from English in the post-Soviet period (брокер, дефолт, рейтинг), encoding two distinct historical waves of economic modernization [2, 267].

The informal and slang registers reveal additional cross-cultural differences of cultural significance. In English, the sheer diversity of slang terms for money (over 200 documented expressions including dough, bread, loot, greenbacks, moolah, scratch, wad, stack, cheese, quid, tenner) reflects both the cultural centrality of money and the characteristically playful, creative relationship of English speakers with financial vocabulary [13, 1146]. This lexical exuberance has no parallel in Uzbek or Russian, where slang money vocabulary is more limited. Russian slang shows a characteristic pattern of ironic diminutives (деньжата, монетка) alongside post-Soviet anglicisms (бакс, грин) that entered the language during the economic transformation of the 1990s, encoding a specific historical rupture in attitudes toward money.

Semantic field structure. Comparative analysis of semantic field organization reveals that while all three languages share a universal conceptual core — money as medium of exchange and measure of value — the peripheral zones are structured

according to different cultural schemata [4, 135]. Following Popova and Sternin's methodology, we distinguish between the core, near periphery, and far periphery of the concept in each language.

English structures its near peripheral zone predominantly around function and form. Distinctions between cash and credit, between capital and currency, between income and assets are lexically prominent and productively differentiated. The far periphery includes an elaborated semantic zone of abundance and accumulation: a fortune, a windfall, a bundle, a mint, a killing. These lexical patterns reflect a cultural orientation toward individual financial achievement and the detailed tracking of financial flows, consistent with Hofstede's identification of high individualism and high long-term orientation in Anglo-Saxon cultures [8, 164].

Uzbek organizes its near peripheral zone around ethical value and social relations. The concept haq (rightful due, one's lawful share) constitutes a culturally specific near-peripheral element that foregrounds the Islamic ethical principle of fair financial dealing, encoding the legal and moral obligation to pay fairly. The concept baraka (divine blessing manifest in prosperity) introduces a spiritual-ethical dimension entirely absent from English and Russian. The far periphery includes sufficiency-oriented terms (yetarli — enough; kamchilik — shortage; ortiqcha — excess), reflecting a cultural orientation toward adequacy and fair distribution rather than accumulation for its own sake [5, 112].

Russian organizes its near peripheral zone around source and legitimacy of ownership, producing a striking lexical distinction between state resources (казна, государственные средства) and personal wealth (состояние, богатство). The far periphery features a particularly rich emotional-affective zone, expressed through the extensive development of diminutive forms (деньжата, монетка, копеечка) encoding a mixture of tenderness, irony, and resignation toward small amounts of money that lacks precise equivalents in English or Uzbek [12, 203]. This affective zone reflects a historically specific relationship between Russian speakers and conditions of economic scarcity and uncertainty.

A particularly revealing dimension of semantic field analysis is the 'moral valence' zone — the set of associations linking money to ethical categories. In English, the moral valence zone is relatively underdeveloped: neutral terms like funds, resources, and capital carry minimal moral loading, reflecting a cultural tendency to treat money as a morally neutral instrument [10, 148]. In Uzbek, the moral valence zone is highly elaborated: terms like haq (rightful earning) contrast directly with harom (forbidden, illicitly obtained gain), encoding Islamic legal categories within the semantic field itself. In Russian, the moral valence zone reflects the influence of both Orthodox Christian tradition and Soviet-era attitudes toward private wealth: the term нажива (ill-gotten gain) and the expression наживаться на чужом горе (to profit from others' misfortune) encode a strong negative moral evaluation of speculative profit.

Phraseological units and idioms. The phraseological representation of the concept 'money' reveals deeply sedimented cultural attitudes that often encode values and beliefs not explicitly stated in dictionary definitions. In English, money-related idioms frequently reflect a pragmatic, achievement-oriented worldview: time is money (Benjamin Franklin, 1748) encodes the commodification of time central to Protestant-

capitalist work ethics [1, 204]; money talks asserts the power of wealth to influence decisions and social outcomes; to throw money at a problem reflects a cultural tendency to regard financial resources as a primary problem-solving instrument. The idiom put your money where your mouth is urges financial commitment to back stated positions, encoding a cultural valorization of financial risk-taking as proof of genuine belief. Money doesn't grow on trees encodes the foundational economic principle of scarcity. These expressions collectively build the conceptual metaphor MONEY IS POWER, in which financial capacity translates directly into social agency.

In Uzbek, phraseological units related to pul demonstrate a notably stronger ethical and relational orientation. Pulning ko'zi yo'q (money has no eyes) encodes the recognition that money is a morally neutral instrument requiring human ethical guidance — a formulation that implicitly warns against allowing money to govern moral decisions. Puling bo'lsa, do'sting ko'p (if you have money, you have many friends) reflects a pragmatic social observation about instrumental relations, expressed with a degree of ironic wariness. Aqlli odam pulni aqlli ishlatadi (a wise man spends money wisely) foregrounds financial prudence as an intellectual and moral virtue. Ko'p pul ko'p tashvish (much money, much worry) encodes the distinctly non-maximizing view that wealth brings burden rather than freedom. These expressions collectively frame money as a morally charged phenomenon that tests character and requires wise stewardship [6, 89].

Russian phraseological units reveal both pragmatic awareness and characteristic moral ambivalence. Деньги не пахнут (money has no smell), derived from Emperor Vespasian's remark about the urine tax, has been fully assimilated into folk wisdom as pragmatic acknowledgment that the origin of money does not diminish its utility — an acceptance of moral compromise that would be formulated quite differently in Uzbek. Деньги к деньгам (money goes to money) encodes the observation that wealth accumulates. Копейка рубль бережёт (a kopeck saves a ruble) emphasizes incremental thrift as a financial virtue, structurally parallel to the English "look after the pennies." Деньги — дело наживное (money is an acquirable thing) encodes a fatalistic optimism about financial recovery. However, не в деньгах счастье (happiness is not in money) — widely cited and often extended ironically — demonstrates the characteristic Russian dual-register of pragmatic acknowledgment and anti-materialist moral sentiment [11, 178].

Proverbs and cultural connotations. Analysis of proverbs confirms and deepens the findings from phraseological material, revealing additional dimensions of the culturally specific conceptualization of money. English proverbs emphasize pragmatic management and the role of individual agency in financial outcomes: "A fool and his money are soon parted" associates financial imprudence directly with personal weakness. "Look after the pennies and the pounds will look after themselves" articulates an ethos of incremental accumulation through disciplined attention to small sums. "Money is a good servant but a bad master" acknowledges the ambivalent power of wealth while asserting human agency. "A penny saved is a penny earned" frames frugality as equivalent to productive labour, which is highly characteristic of the Protestant-capitalist value system [13, 987].

Uzbek proverbs reveal a culturally specific emphasis on the transience of material wealth and the superiority of moral and social capital: Pul topish oson, pul saqlash qiyin (Earning money is easy, saving it is hard) encodes a psychological observation about the asymmetry between the effort of acquisition and the discipline of retention. Mol o'lsa yeri qolur, er o'lsa so'zi qolur (When cattle die, land remains; when a man dies, his word remains) explicitly subordinates material wealth to moral legacy, reflecting the value hierarchy of traditional Uzbek culture in which a person's word and reputation are the most durable forms of capital. Puldan qimmatroq narsa bor (There are things more valuable than money) encodes the cultural principle that non-material values — honour, family, health, faith — occupy a higher position in the value hierarchy than wealth [7, 92].

Russian proverbs maintain a distinctive tension between pragmatic realism and moral idealism that is characteristic of Russian cultural discourse more broadly. Без денег везде плохо (Without money it is bad everywhere) acknowledges the practical necessity of money with unvarnished directness that is entirely absent from comparable Uzbek proverbs. Деньги — навоз: сегодня нет, а завтра воз (Money is like manure: today there's none, tomorrow a cartful) metaphorically encodes the cyclical, unpredictable nature of financial fortune through the agricultural image of manure as simultaneously worthless and enormously productive. The prominence of fate and unpredictability in Russian money proverbs — in sharp contrast to the English emphasis on personal agency and the Uzbek emphasis on ethical stewardship — reflects a broader difference in cultural attitudes toward individual control versus collective fate [11, 221].

These findings align with Hofstede's cultural dimensions framework [8, 127]: the high individualism and moderate uncertainty avoidance in Anglo-Saxon culture correlates with a functional, management-oriented discourse around money that emphasizes personal agency; the collectivism and moderately high uncertainty avoidance of Uzbek culture generates a stronger emphasis on ethical relations, communal attitudes, and the spiritual framing of wealth; the Russian combination of collectivism and high uncertainty avoidance produces a distinctive dual register of pragmatic realism and anti-materialist moral sentiment. Wierzbicka's observation [10, 394] that lexical and phraseological differences between languages reflect genuine conceptual differences in how cultures structure reality receives strong empirical confirmation in the domain of the money concept.

Conclusion

The comparative lexical-semantic analysis of the concept 'money' / 'pul' / 'деньги' in English, Uzbek, and Russian has yielded the following principal findings.

First, all three languages share a universal conceptual core — money as medium of exchange and measure of economic value — confirming the existence of pan-human cognitive universals that transcend specific linguistic and cultural boundaries, consistent with the theoretical predictions of semantic primitives theory [10, 394]. This universal core manifests in the basic denotative definitions provided by dictionaries in all three languages and in the shared communicative function of money-related vocabulary.

Second, the peripheral semantic zones of the concept reveal significant culture-specific differentiation corresponding to distinct cultural orientations. English demonstrates a pragmatic-functional orientation with extensive lexical differentiation by form, scale, and source of monetary value, and a highly developed zone of abundance terminology. Uzbek exhibits a rich ethico-relational periphery connecting money to concepts of rightful compensation, social harmony, and spiritual blessing, with an elaborated moral valence zone distinguishing 'lawful' from 'forbidden' financial gain. Russian shows a distinctive emphasis on the source and legitimacy of ownership, a tension between collective and individual wealth, and an emotional-affective dimension expressed through productive diminutive forms and fatalistic idioms.

Third, the phraseological, proverbial, and conceptual-metaphorical material confirms and extends these findings. English phraseology constructs money as a pragmatic instrument of individual agency that can be converted into power and time. Uzbek frames money as a morally charged phenomenon requiring ethical stewardship, framing wealth as a seed to be cultivated and a test to be passed. Russian maintains a characteristic dual register of pragmatic realism and anti-materialist moral sentiment, with a distinctive tolerance for moral ambiguity about the origins of money.

These findings have practical implications for several applied domains. In cross-cultural business communication, awareness of the conceptual frames associated with money in each culture can help prevent misunderstandings rooted in different assumptions about the ethics of profit, the legitimacy of wealth, and the appropriate attitude toward financial discussion. In professional translation, the culture-specific connotations of money-related phraseology require careful attention to avoid the misleading literalism that occurs when idioms are translated without their conceptual context. In foreign language pedagogy, the conceptual and cultural dimensions of financial vocabulary should be made explicit rather than treated as merely lexical content, as Safarov [5, 201] argues is essential for the development of genuine communicative competence.

Future research might productively extend this analysis in several directions: diachronic investigation of how the money concept has shifted under the influence of digitalization and cryptocurrency discourse in each language; corpus-based quantitative analysis of the relative frequency of different metaphorical frames in financial journalism across the three languages; and extension of the comparative framework to additional Turkic languages and to other post-Soviet linguistic cultures.

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CURRENT TASKS OF FORMING AN IDEAL LEADER MODEL

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Annotatsiya. Ushbu maqolada zamonaviy liderni shakllantirish va uning ijtimoiy imidjini yaxshilash uchun mamlakatda ushbu sohada to‘plangan katta tajribaga tayanishning o‘zi yetarli emasligi, ideal lider modelini shakllantirish, yetakchilik qobiliyatiga ega yosh, istiqbolli mutaxassislarni izlash, ularga yetakchilik madaniyatini o‘rgatish va ularning yetakchilik qobiliyatlarini oshirish zarurligi ta’kidlangan. Shuning uchun, ushbu vazifalarni aniqlamasdan va ularning tizimli yechimini ta’minlamasdan turib, mamlakat taraqqiyoti va vatan manfaatlariga xizmat qiladigan zamonaviy liderni topishning iloji yo‘qligi ilmiy tahlil qilingan.

Kalit so‘zlar: *professional mobillik, ijtimoiy mobillik, zamonaviy lider, rahbarning ijtimoiy qiyofasi, ideal lider, demokratik boshqaruv usullari, zaxira kadrlar nomenklaturasi, “ustoz-shogird” tizimi, “yosh lider,” “kasbiy ko'nikmalar,” intellektual, axloqiy, huquqiy, siyosiy va boshqa xususiyatlar va fazilatlar.*

Аннотация. В данной статье подчеркивается, что для формирования современного лидера и улучшения его общественного имиджа недостаточно опираться на значительный опыт, накопленный в этой области в стране, необходимо сформировать идеальную модель лидера, искать молодых, перспективных специалистов с лидерскими качествами, обучать их культуре лидерства и совершенствовать их лидерские навыки. Таким образом, научно анализируется, что без определения этих задач и обеспечения их систематического решения невозможно найти современного лидера, который служил бы развитию страны и интересам Родины.

Ключевые слова: *профессиональная мобильность, социальная мобильность, современный лидер, социальный образ лидера, идеальный лидер, демократические методы управления, номенклатура резервного персонала, система “наставник-ученик,” молодой лидер,” “профессиональные навыки,” интеллектуальные, моральные, правовые, политические и другие характеристики и качества.*

Abstract. This article emphasizes that in order to form a modern leader and improve his social image, it is not enough to rely on the significant experience accumulated in this field in the country, it is necessary to form an ideal leader model, search for young, promising specialists with leadership skills, teach them leadership culture, and improve their leadership skills. Therefore, it is

scientifically analyzed that without identifying these tasks and ensuring their systematic solution, it is impossible to find a modern leader who would serve the development of the country and the interests of the Motherland.

Keywords: *professional mobility, social mobility, modern leader, social image of the leader, ideal leader, democratic management methods, nomenclature of reserve personnel, "mentor-student" system, "young leader," "professional skills," intellectual, moral, legal, political and other characteristics and qualities.*

Introduction

To form a modern leader and raise his social image, it is not enough to rely on the significant experience accumulated in this area in the country, of course. At the same time, it is also necessary to identify urgent tasks that need to be solved in the near future, and to determine measures for their implementation in practice. Without identifying these tasks and ensuring their systematic solution, it is impossible to find a modern leader who will serve the development of the country and the interests of the Motherland.

Based on the analysis, we believe that the urgent tasks in Uzbekistan in terms of raising the social image of a modern and ideal leader should be the following:

To raise the social image of a modern leader, it is necessary to form an ideal leader model and make it a reference point and beacon for efforts in this regard. The ideal leader model refers to a set of knowledge and skills, character and virtues, talents and abilities necessary to manage a company or organization. Scientific considerations and ideas about it have not yet appeared. In the history of socio-philosophical thought, many significant ideas have been put forward in this regard. For example, the great thinker Abu Nasr Al-Farabi believes that a leader should naturally embody 12 qualities and virtues: 1) health; 2) prudence; 3) strong memory; 4) intelligence; 5) eloquence; 6) striving for enlightenment; 7) restraint of the ego; 8) love of truth; 9) generosity; 10) not chasing after wealth and worldly things; 11) justice; 12) determination and courage. We can find similar ideas in the works of Confucius, Al-Mawardi, Ibn al-Azraq, Al-Ghazali, Nizamul-Mulk, Amir Temur, Alisher Navoi and others. Similar ideas and considerations are also contained in the heritage of many prominent representatives of Western philosophy.

Literature Review

Today, the scientific ideas of specialists about the ideal leader model are characterized by their diversity. In particular, the Russian scientist A. Kitov, who has specially studied this aspect of the problem, imagines the ideal leader model as a composition consisting of four parts (managerial abilities, political qualities, professional qualities, organizational qualities). Each part, in turn, includes a number of elements.

The First President of our country, Islam Karimov, also thought a lot about the main characteristics of a modern leader and the ways to form these characteristics. His many speeches contain significant thoughts on this issue. In particular, in his speech at the IX session of the Oliy Majlis of the Republic of Uzbekistan, where the Law of the Republic of Uzbekistan "On Education" and the "National Program for Personnel

Training" were adopted, he emphasized: "The achievement of our great goals and noble intentions, the renewal of our society, the development and prospects of our life, the implementation of reforms, the fate of the results of our plans - all this is, first of all, closely related to the problem of training highly qualified, intelligent specialists who meet the requirements of the time."[2] The ideal model of such a leader, according to Islam Karimov, should embody talent, research, possession of modern knowledge, patriotism, loyalty to the country, dedication, skill, independent worldview, faith and belief, and similar characteristics.

Research Metodology

This study employs a qualitative, theoretical-analytical methodology grounded in socio-philosophical and pedagogical approaches to leadership formation. The research integrates a comparative review of classical and contemporary leadership models, including works by Al-Farabi, Confucius, A. Kitov, and policy documents from Uzbekistan, using hermeneutical methods for interpretation. A systemic-functional approach is applied to identify urgent tasks for developing an "ideal leader model" within the Uzbek context, analyzing existing mechanisms such as reserve nomenclature and certification processes to diagnose deficiencies. Foreign experiences from developed countries are examined through comparative analysis to incorporate universal values. The methodology concludes with a practical-oriented synthesis, translating theoretical findings into actionable measures—improving selection mechanisms, ensuring professional mobility, and modernizing leader training monitoring—thus bridging the gap between theoretical models and social reality.

Analysis and Results

Scientific ideas about the ideal leader model are not just a set of ideas of theoretical importance. On the contrary, the creation of this model makes it possible to fulfill a number of practical tasks. In particular, without its formation, it is impossible to give purpose, content and orientation to the work of training modern leaders in the country. The existence of such a model would allow us to determine specific tasks for the upbringing of modern leaders, to describe in detail the knowledge and abilities, character and virtues, qualifications and skills that need to be formed, and to accurately identify shortcomings in the spiritual image of a specific leader. This model serves as a theoretical and methodological basis for the formation of a leader who can serve the development of the Motherland, the prosperity of the country, national interests, and subordinate his activities to the interests of society as a whole.

To form an ideal leader model, it is necessary, first of all, to conduct scientific research on this topic. Philosophers, political scientists, and educators of our country have carried out and are carrying out many scientific research works on the leader and leadership activities. However, most of them provide general considerations about the spiritual image of the leader, analyze various problems related to leadership activities. Of course, the facts and arguments presented in these sources, as well as the conclusions drawn, are of great scientific, theoretical and practical importance. At the same time, it would be expedient to clearly describe the ideal leader model. This task can only be carried out within the framework of special scientific research. Such

scientific research can only be carried out on the basis of orders from competent organizations.

Secondly, in order to avoid national isolation in the formation of an ideal leadership model and, based on it, in raising the social image of a modern leader, it is advisable to study and analyze world experience on the subject, especially the achievements of developed countries and influential corporations and companies operating in them. The study of foreign experience would allow raising the social image of a leader not only on the basis of national, but also universal values. This research work also requires a certain social order from the government.

1. In order to raise the social image of a modern leader, it is necessary to further improve the mechanism for selecting, educating and improving the skills of leading personnel operating in the country. The social significance of this mechanism is immeasurable. The solution to various social problems in any society directly depends on the activities of the leader and the level of formation of his social image. If a leader organizes his activities on the basis of democratic management methods, his social image is based on universal human values and humanitarian ideas, and is not disconnected from real life, he will be able to quickly grasp the causes and consequences of problems in society, the need and ways to eliminate them. The activities of a leader whose social image is riddled with various vices and shortcomings will also be ineffective. That is why it is necessary for society to have an effective mechanism for selecting, educating, and improving the skills of leadership personnel. This mechanism serves to enhance the social image of the leader.

A unique system for selecting leadership personnel was formed during the years of independence. In particular, as we noted in the previous paragraphs, there is a nomenclature of reserve personnel for all prestigious positions, and centers and training courses are operating to familiarize reserve personnel with the secrets of modern leadership. A comprehensive system is in place that allows for continuous professional development of most senior personnel.

However, it is important to remember that the effectiveness of this mechanism is not a quality that can be achieved through one-time efforts. As various aspects of social life change, this mechanism must also be continuously improved. In order to develop the mechanism for selecting, educating, and improving the skills of leaders in line with modern requirements, it is necessary, first of all, to identify and eliminate existing problems in this regard.

There are many sources, ideas, concepts and proposals in world science on the theoretical and methodological foundations of monitoring the process of forming modern leaders. They offer many ways, methods and techniques, factors and means of analyzing the effectiveness of the process of training leadership personnel in the country. Of course, the issue is approached based on the socio-political, economic and spiritual situation prevailing in different countries. However, all of them emphasize the need to determine the effectiveness of activities in the following three areas when analyzing the process of training leadership personnel [1]:

a) the effectiveness of measures taken to identify personnel with leadership abilities; any process aimed at training leadership personnel begins with the identification of capable and potential personnel. The effective organization of this process is a

prerequisite for providing society with qualified leaders. The effectiveness of measures in this area is associated with the development of clear criteria for determining leadership abilities;

b) the effectiveness of the process of training selected reserve personnel for managerial positions; this process should be aimed not only at expanding the range of knowledge related to the specialty, but also at teaching the secrets of modern management, forming the skills to use information and communication technologies, and developing the ability to adapt one's work to social needs. The effectiveness of measures in this direction depends on ensuring the consistency between the process of training reserve personnel and the functional tasks of the position that this personnel must perform;

c) the effectiveness of the process of appointing personnel trained for management to managerial positions; the failure of personnel selected using a special methodology and prepared to occupy a managerial position to remain in such a position undermines the authority of the entire management training system, as well as the nomenclature of reserves for managerial positions. To prevent this, it is necessary to strictly monitor the process of forming a clear list of vacant managerial positions and filling them, as well as the state of vertical and horizontal professional mobility of managerial personnel.

Conclusion

The conclusion is that in order to form a modern leader in our country and improve his social image, it is necessary to identify urgent tasks that need to be solved in the near future, and to determine measures for their implementation in practice. Social reality analysis shows that urgent tasks in this regard are related to the formation of an ideal leader model, improving the mechanism for selecting, educating and improving the skills of managers, searching for young specialists, implementing innovative forms of regular certification of managers, modernizing the monitoring of the process of training managers, and determining the goals and objectives of personnel policy in line with social processes. The implementation of these tasks creates a solid foundation for improving the social image of managers.

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HISTORICAL STUDIES OF THE DEVELOPMENT OF HISTORICAL EDUCATION IN THE KHORESM REGION OF UZBEKISTAN IN THE PERIOD OF INDEPENDENCE

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Annotatsiya. Mazkur matnda 1991-yildan keyingi davrda O‘zbekistonda tarix fanining rivojlanishi va tarixiy ta’limni o‘rganishdagi yangi yondashuvlar tahlil qilinadi. Mustaqillik yillarida tarixdagi “oq dog‘lar”ni qayta ko‘rib chiqish, ilmiy tadqiqotlarni kengaytirish va ob’ektivlik tamoyillariga asoslangan yangi ilmiy qarashlar shakllangani ko‘rsatib beriladi. 1990-yillarda og‘ir iqtisodiy sharoitlarga qaramay, tarix bo‘yicha dissertatsiyalar himoya qilinib, muhim monografiyalar nashr etilgani qayd etiladi. Ayniqsa, E.R. Xalikovaning 1995-yilda yozilgan dissertatsiyasi tarixiy ta’lim istoriografiyasida muhim o‘rin tutib, mafkuraviy cheklovlardan xoli holda ilmiy tahlil olib borilgan dastlabki tadqiqotlardan biri sifatida baholanadi.

Kalit so‘zlar: *Mustaqillik davri, O‘zbekiston tarixi, tarixshunoslik, tarixiy ta’lim ob’ektivlik tamoyili, mafkuraviy cheklovlar, sovet davri ta’limi, Toshkent davlat universiteti, tarix fakulteti, ilmiy kadrlar tayyorlash.*

Аннотация. В данной аннотации анализируются процессы развития исторической науки в Узбекистане после 1991 года, а также формирование новых подходов к изучению исторического образования. Показано, что в годы независимости были созданы благоприятные условия для пересмотра «белых пятен» в истории, расширения научных исследований и формирования новых научных взглядов, основанных на принципах объективности. Несмотря на сложные экономические условия 1990-х годов, успешно защищались диссертации по истории и издавались важные монографии. Особое внимание уделяется диссертации Э.Р. Халиковой (1995 г.), которая занимает важное место в историографии исторического образования и рассматривается как одно из первых исследований, свободных от идеологических ограничений и основанных на объективном научном анализе.

Ключевые слова: *Период независимости, история Узбекистана, историография, историческое образование, принцип объективности, идеологические ограничения, образование советского периода, Ташкентский государственный университет, исторический факультет, подготовка научных кадров.*

Abstract. This abstract analyzes the development of historical science in Uzbekistan after 1991, as well as the emergence of new approaches to studying historical education. It highlights that during the years of independence, favorable conditions were created for revising the “blank spots” in history, expanding

scholarly research, and forming new academic perspectives based on the principles of objectivity. Despite the difficult economic conditions of the 1990s, historical dissertations were successfully defended and significant monographs were published. Particular attention is given to the 1995 dissertation by E.R. Khalikova, which holds an important place in the historiography of historical education and is considered one of the first studies conducted free from ideological constraints and grounded in objective academic analysis.

Keywords: *Independence period, history of Uzbekistan, historiography, historical education, principle of objectivity, ideological constraints, Soviet-era education, Tashkent State University, Faculty of History, training of scientific personnel.*

Introduction

After 1991, favorable conditions emerged for studying the "blank spots" in the history of Uzbekistan, expanding and revising previous research, and developing new approaches. Despite the difficult economic conditions that arose during the transition to independent Uzbekistan, dissertations in history were successfully defended in the 1990s, and monographs were published. Among the scholars who contributed to this process are U. Aleutov, R.Sh. Akhmetshin, R.J. Bazarbaev, A.A. Mavrulov, T. Rakhmonov, M.R. Rakhmatullaev, M.N. Nurmukhamedov, I. Tursunov, J. Khasanbaev, A.X. Choriyev, K. Ergashev, and other researchers. All dissertations of this period are distinguished by a high academic level; they were carried out on the basis of the principles of objectivity and historicism and moved beyond the framework of Marxist-Leninist ideology.

During this period, a dissertation on historical education in Uzbekistan was also defended, which remains the only one of its kind in historiography to this day. This is the study written in 1995 by E.R. Khalikova, conducted on the example of the Faculty of History at Tashkent State University [1]. In her research, the author examined the experience of the faculty established in 1935, the process of the formation of its departments, the training of academic personnel, the growth in the number of students, and the reforms implemented during the transition to independence. It is worth noting that this work is one of the first dissertations on historical education that was free from the use of the works of classical Marxism-Leninism and the requirements of an ideological approach, which made it possible to provide an objective analysis of the research topic.

Literature Review

The author rightly points out that the main shortcoming of historical education at that time was excessive ideological bias, as a significant portion of study time was devoted to socio-political subjects. In addition, the subject "History of the USSR" was given priority over other disciplines: for example, the Department of the History of Uzbekistan consisted of only four teachers and was not taught at all in non-history specializations. At the same time, the faculty's teaching staff was academically strong, especially in the field of archaeology, and the requirements for students were very high. Beyond regular university classes, students participated in a scientific club, which contributed to the formation of a cohort of highly qualified young historians; the best

graduates remained at the departments as instructors, ensuring continuity between generations. Overall, the Faculty of History at Tashkent State University was a leading center for research on Central Asia; lecture courses also included topics on the history of Khorezm [2].

E.R. Khalikova's dissertation, based on archival documents from Tashkent State University, is considered a valuable scholarly work, although its focus did not include the study of school-level historical education. The dissertation does not address the interpretation of history as a foundation for the formation of patriotism and communist ideology, nor does it provide an in-depth analysis of state policy in the field of historical education. In addition, in our view, a number of important aspects relevant to the topic were not covered. However, the author did not set out to address these tasks. The aim of the dissertation was different—to demonstrate the development of the Faculty of History at one of Uzbekistan's leading universities. Therefore, the features and trends identified by E. Khalikova reflect the general state of historical scholarship and its evolution across different chronological stages. For this reason, the dissertation is regarded as a key work in the historiography of the subject.

Research Methodology

This study applies a historical-analytical methodology, using historiographical analysis and archival sources. It examines E.R. Khalikova's 1995 dissertation as a key case, reassesses Soviet ideological biases through objectivity, and compares regional developments (Khorezm, Karakalpakstan) using biographical collections and university records.

Analysis and Results

The new scholarly tradition that emerged in the 1990s continued to develop, and after 2000, a substantial body of major publications appeared. Researchers increasingly focused on the history of religious education and the role of the clergy in the intellectual and cultural development of Uzbekistan. [3]. This suggests that in the 1920s there was a cadre of highly qualified teachers in Khorezm capable of teaching history; however, they did not meet the ideological requirements imposed on educators by the Soviet authorities. In general, the history of science and education in the Republic of Uzbekistan and its individual regions has been examined in the works of scholars such as A. Adilov, K. Allambegenov, Sh. Ayapov, O. Ibragimov, O.Sh. Kanimkulov, R. Urazbaeva, K. Uteniyazov, O. Yusupov, V.N. Yagodin, and others [4]. The scope of research related to the preservation of historical knowledge in the Khorezm region has expanded: X. Yuldashev's dissertation is devoted to the formation and development of archival work in the region [5], D.K. Babojonov's monograph is devoted to the history of museums in Khiva [6], F.E. Atadjanova's article focuses on the modern reform of higher education in Khorezm and other regions [7]. A work that has generated significant scholarly interest in the study of historical education is the monograph by N.K. Nurullayeva, which is devoted to the cultural and educational ties between Karakalpakstan and Khorezm. In this work, the author demonstrates that prior to the establishment of the Faculty of History in Urgench in 1942, the training of historians was carried out in Karakalpakstan. She also provides data on the number of history teachers trained to work in schools in Khorezm.

Conclusion

Among the more important publications on this research topic are biographical collections dedicated to scholars from Khorezm. In his book *"Khorezmian Historian Scholars,"* O. Abdullaev compiled materials on prominent graduates of the Faculty of History at Urgench State University from its establishment in 1942 up to 2007. These graduates not only worked in Khorezm but were also engaged in academic and teaching activities at other higher education institutions across Uzbekistan, with some continuing their scholarly and pedagogical work to this day. In addition, Abdullaev's monograph includes information about university teachers who graduated from other institutions but later connected their careers with Khorezm. The book presents biographies of 45 historians from both the Soviet and post-Soviet periods. This publication helps to better understand the process of кадров (personnel) formation in scientific institutions and higher education establishments of the Khorezm region and serves as an invaluable source for studying historical education during the period of 1924–1991. Overall, the historiography of the period under consideration has laid the foundation for conducting a specialized study on the development of historical education in the Khorezm region.

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PATRIOTISM MANIFESTED THROUGH HEROISM (social-philosophical approach)

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Annotatsiya. Maqolada Vatanparvar, qaxramonlik alohida fenomen sifatida xalqning, millatning eng oliyjanob fazilatlari ifoda etilgan, shunday qaxramonlari bor xalq, millat o‘zida yaratishga kuch, quvvat va dadillik borligiga ishonishi asoslangan.

***Kalit so‘zlar**: Qahramonlik, vatanparvarlik, shaxs, jamiyat, xalq, millat, orzu, tilak, olijanob, vatan, millatchilik, kamtarlik*

Аннотация. В статье выражены самые благородные качества народа, нации, как отдельные явления патриотизма, героизма, обосновано вера, основанного на убеждении, что у наций есть сила и мужество, чтобы созидать.

***Ключевые слова:** Героизм, патриотизм, личность, общество, народ, нация, мечта, желание, благородный, родина, национализм, скромность.*

Abstract. The article expresses the most noble qualities of the people, the nation, as a separate phenomenon of patriotism, heroism, based on the belief that the people with such heroes have the strength, power and courage to create.

***Keywords:** Heroism, patriotism, person, society, people, nation, dream, wish, noble, homeland, patriotism, nationalism, humility*

Introduction

The aspirations of the people and the nation, their vision of social justice, find their expression in the selfless individuals who live in the interests of the Motherland. It is these people and children who, overcoming any circumstances, make bold adjustments to secure the future of the nation. The Scottish philosopher T. Carlein says that the history of humanity and society is the history of great individuals, and a people and nation with great individuals look directly to their future and development [1]. Heroism as a separate phenomenon expresses the noblest qualities of a people, a nation, a people, a nation that has such heroes believes that it has the strength, power and courage to create. That is why the era with heroes is often mentioned in the history of a people, a nation, and it is shown as an example to future generations.

Literature Review

Many works have been written about the socio-philosophical characteristics of heroism. From Herodotus, the “father of history,” to Thucydides, Plutarch, Kursi Rufus, Ibn Khaldun, Narshahi, As Samarkandi, A. Toynbee, A. Manfred, N.I. Karamzin, A.N. Gumilev, they studied the periods and topics related to the phenomenon of heroism separately [2-5]. Folk oral literature mainly includes the theme

of heroism. Gilgamesh, Odyssey, Alpomish, Gorogly, Kuntugmysh, Takhir and Zuhra, Farkhod and Shirin, even the images of Efendi and Aldar Kose were created on the basis of this theme [6, 7]. It is the value of every nation and people to sing about their heroes, their patriots, and their leaders with noble qualities. By understanding their heroes, we understand the life of the people and the nation.

Research Methodology

This study employs a qualitative socio-philosophical methodology, integrating hermeneutical analysis and comparative-historical approaches. It examines heroism as a moral phenomenon through the lens of classical and contemporary thinkers (Herodotus, Carlyle, Agzamkhodjaeva) and folk epics. The research uses conceptual analysis to deconstruct heroism, patriotism, and altruism, identifying their structural components: social ideal, developmental requirements, and educational goals. Case illustrations (e.g., pandemic medical workers, monument controversies) ground theoretical abstractions in social reality. The method prioritizes interpretive understanding over empirical measurement, seeking to clarify the ethical and cultural dimensions of heroic action within Uzbek society.

Analysis and Results

Heroism is a moral reality. It is a phenomenon associated with the human heart, spirit, spirituality, and ideal. It is not a simple phenomenon, it is a collective expression, a sum total of the noble qualities of the people and nation in the spiritual life and actions of the individual.

When studying heroism as a separate reality, phenomenon:

-the ideal of the individual and society;

-the requirements of social development;

-a social and educational goal;

-special attention is paid to factors such as the influence of national and universal values.

The ideal of the individual and society, along with strategic goals, consists of visions taken from the historical and cultural heritage. Such an ideal is formed on the basis of the integration of historical and cultural experience in the development of society. Special studies show that people often tend to seek the ideal from the past, from historical and cultural experience.

According to Doctor of Philosophy, Professor S. Agzamkhodjaeva, the ideal, as an expression of subjective reality, dreams, wishes, and visions of a happy future, has the power to project past reality into the future. Projection is the application of existing experience to the future.

Both in the ideal and in heroism, there is a call for the individual to live with noble goals. This call implies living in the interests of the people, country, homeland, and development. Heroism, the ideal it follows, requires combining personal interests with social interests, and, when necessary, abandoning personal motives. In heroism, there is always something related to the Motherland, and there is no heroism without a sense of patriotism and devotion.

We don't call someone who jumps into a well to save a cat or a lamb that has fallen into it a hero, but when this action is aimed at saving the life of a person, a baby, we call it heroism. So, heroism is self-sacrifice for a person, a nation, a homeland.

Patriotism is not just about standing at the border and blocking the enemy's path, it is about removing artificial obstacles for the prosperity of the homeland, praising the symbols of the homeland, singing the praises of nature, serving its goals, and adding honor to the honor of the homeland through hard work.

It is peaceful but selfless work, humbly respecting patriotic values, and serving the welfare of the people and nation, overcoming egoistic tendencies. Here, the ideal is manifested in ensuring the well-being of the people and nation. Therefore, the ideal must be objectified, that is, manifested in real actions.

Heroism that meets the requirements of social development is positive, but here there is a subjective, ready-made, imaginative approach to heroism. Such an approach leads to an assessment of the broad phenomenon of heroism within narrow views and schemes. For example, the decision to remove the statues of S. Rakhimov and the fourteen Shomahmudovs from the squares in Tashkent was a narrow, mental scheme of universal ideas about heroism during the era of autocratic rule into a narrow, mental scheme. Now they have been returned to their place. In social life, a negative attitude towards the value that has been formed as a phenomenon of heroism in people's minds gives rise to erroneous, noobistic ideas about social progress.

Social development has its own laws. These laws are the criteria for human behavior. They include abandoning selfish goals, not opposing one's life and actions to social upbringing and laws, proceeding from ethnocultural factors, participating in socially useful work, etc. Therefore, heroism, when it complies with these laws, turns into a sense of patriotism.

The socio-educational goal is formed by the laws of development. It is not formed by itself, mechanically, outside the requirements of the state, society and development. The existing values in social life, especially their models in the form of a harmony of national and universal values, set a special goal for education. This goal has a strategic and tactical nature. The strategic goal includes educational, upbringing, and propaganda work aimed at forming a sense of loyalty to universal values in a person.

They are associated with the formation of humanism, love of life, noble qualities in a person. Love of life, preservation of life (A. Schweitzer) comes as an eternal task of human upbringing. The social educational goal directs the phenomenon of heroism to this eternal task. Tactical education serves to implement the tasks facing society today and in the coming years. For example, today Uzbekistan is striving for innovative development in order to enter the ranks of the 50 most advanced, developed countries in the world by 2030.

This sets the task of social education to educate individuals with innovative thinking. However, this task is replaced by another task with the passage of time. This is a requirement of social life, development.

Neither strategic social education nor tactical social education rejects the nobility, altruism, and patriotism in the phenomenon of heroism, but sets a specific task for it, based on its own characteristics and requirements. A person who effectively and excellently fulfills this task is called a "hero", a "hero of our time".

Heroism involves selflessness, altruism, and even self-denial. That is why it differs from ordinary activity or labor. If we study the lives of people with the honorary title of "Heroes of Uzbekistan," we will see that they have a deep love for their profession. Since this love is aimed at the prosperity of the people, the homeland, it acquires an altruistic character. That is, "Heroes of Uzbekistan" are devotees who have devoted their entire lives and activities to the interests of their homeland.

Heroism is certainly not a phenomenon that requires official recognition. For example, during the coronavirus pandemic, medical workers who risked their own health and lives for the health of the nation are true heroes. But not all of them call a person, a person who has been officially recognized, a "hero", a "hero of our time".

Heroism involves selflessness, altruism, and even self-denial. That is why it differs from ordinary activity or labor. If we study the lives of people with the honorary title of "Heroes of Uzbekistan," we will see that they have a deep love for their profession. This love acquires an altruistic character because it is directed towards the prosperity of the people, the homeland. That is, "Heroes of Uzbekistan" are self-sacrificers who have devoted their entire lives and activities to the interests of their homeland.

Heroism, of course, is not a phenomenon that requires official recognition. For example, during the coronavirus, medical workers who risked their health and lives for the health of the nation are real heroes. But not all of them are officially recognized heroes. So, there are also heroes in life who are not officially recognized or acknowledged. The most important thing is that their activities, even their actions, are built on selflessness, altruism in the interests of the nation and the homeland.

Conclusion

This socio-philosophical analysis concludes that heroism is a moral phenomenon rooted in altruism, self-sacrifice, and deep devotion to the homeland and nation. It transcends official recognition, manifesting in everyday acts of courage—such as medical workers during the pandemic—as well as in officially honored figures. Heroism integrates national and universal values, serving both strategic educational goals (humanism, love of life) and tactical societal tasks (innovative development). The study affirms that heroes embody the noblest qualities of a people, and their recognition strengthens national identity, social cohesion, and the collective belief in a nation's capacity for progress and resilience.

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MATHEMATICAL PROCESSING OF CALIBRATION CURVE DATA FOR THE COMPLEX COMPOUND FORMED BETWEEN YTTRIUM(III) AND THE REAGENT 2,4-DINITROSO-1-HYDROXY-5-AMINONAPHTHALENE-6,8-DISULFONIC ACID, EMPLOYING THE METHOD OF LEAST SQUARES REGRESSION ANALYSIS

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Annotatsiya. Ittriy guruhining elementlari lyuminestsent materiallar ishlab chiqarishda; po‘lat va quyma temir uchun issiqlik barqarorligini oshirish uchun qotishma qo‘shimchalari sifatida; va refrakter birikmalar, fosforlar va lazer faol materiallar sintezida qo‘llaniladi. Y(III) ionlarini aniqlashning kimyoviy va fizik-kimyoviy metodologiyalari tizimli ravishda ko‘rib chiqildi. Eksperimental ma’lumotlarni qayta ishlashda aniqlik va analitik samaradorlikni ta’minlash uchun optik analitik texnikalar uchun barcha texnik xususiyatlarga mos keladigan zamonaviy EMC-30PC-UV spektrofotometri qo‘shimcha instrumental apparatlar bilan birgalikda qo‘llanildi.

Kalit so‘zlar: *2,4-dinitrozo-1-gidroksi-5-aminonaftalin-6,8-disulfon kislotasi, ion radiusi, ittriy, spektrofotometr, induktiv bog'langan plazma massa spektrometriyasi (ICP-MS), siyrak yer elementlari (SYM), rentgen flurosentsiyasi (XRF).*

Аннотация. Элементы группы иттрия находят применение в производстве люминесцентных материалов; в качестве легирующих добавок для стали и чугуна для повышения термической стабильности; а также в синтезе тугоплавких соединений, люминофоров и лазерно-активных материалов. В данной работе систематически рассмотрены химические и физико-химические методы определения ионов Y(III). Для обеспечения точности и аналитической эффективности обработки экспериментальных данных использовался современный спектрофотометр EMC-30PC-UV, соответствующий всем техническим требованиям к оптическим аналитическим методам, в сочетании с дополнительным инструментальным оборудованием.

Ключевые слова: *2,4-динитрозо-1-гидрокси-5-аминонафталин-6,8-дисульфоновая кислота, ионный радиус, иттрий, спектрофотометр, масс-спектрометрия с индуктивно связанной плазмой (ICP-MS), редкоземельные элементы (РЗЭ), рентгенофлуоресцентный анализ (XRF).*

Abstract. Elements of the yttrium group find application in the production of luminescent materials; as alloying additives for steel and cast iron to enhance thermal stability; and in the synthesis of refractory compounds, phosphors, and

laser-active materials. Chemical and physicochemical methodologies for the determination of Y(III) ions were systematically reviewed. To ensure precision and analytical efficacy in processing experimental data, a contemporary EMC-30PC-UV spectrophotometer-compliant with all technical specifications for optical analytical techniques-was utilized in conjunction with complementary instrumental apparatus.

Keywords: *2,4-dinitroso-1-hydroxy-5-aminonaphthalene-6,8-disulfonic acid, ionic radius, yttrium, spectrophotometer, inductively coupled plasma mass spectrometry (ICP-MS), rare earth elements (REEs), X-ray fluorescence (XRF).*

Introduction

Particular emphasis is currently placed on the development of simple and cost-effective methodologies for the determination of yttrium ions within technological process streams, in alignment with strategic initiatives aimed at advancing the chemical industry sector in the Republic of Uzbekistan. Substantial progress has been achieved in this domain through targeted programmatic measures; notably, extensive research efforts are underway to enable both qualitative and quantitative determination of yttrium ions in technological waters, ore samples, and industrial by-products.

In the spectrophotometric determination of rare earth elements (REEs), instrumental configuration warrants special consideration, as the deployment of analytical instrumentation constitutes the final and conclusive stage of the investigative workflow.

Literature Review

The escalating global demand for yttrium within the series of rare earth elements (REEs: Y, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, and Lu) has catalyzed scientific efforts toward developing efficient recovery protocols for these metals from electronic waste streams. In the extraction of yttrium from luminescent lamp phosphor powders, the raw mixture was dissolved in sulfuric acid, followed by solvent extraction employing decanoic acid, trioctylphosphine oxide (TOPO), diethylphosphinic acid (DEPA), and Alamine 336 as extractants [1].

Diethylphosphoric acid has been utilized for the separation and preconcentration of REEs from electronic waste matrices. Optimization of extraction efficiency was achieved by modulating nitric acid concentration across the organic–aqueous phase boundary; Y^{3+} and Eu^{3+} ions were selectively partitioned using n-nonane and n-dodecane as organic diluents, with subsequent quantification performed via mass spectrometric analysis [2].

Yttrium significantly improves the ductility and corrosion resistance of yttrium–aluminum alloys; accordingly, an inductively coupled plasma atomic emission spectrometry (ICP-AES) methodology was developed for the precise determination of yttrium content in such alloy systems [3].

A protocol for the routine monitoring of yttrium and REEs in seawater matrices was established using inductively coupled plasma mass spectrometry (ICP-MS). The chelating resin Toyopearl AF-Chelate 650M facilitated the selective separation and preconcentration of trace REEs, thereby enhancing detection sensitivity [4]. For the adsorption-luminescent determination of yttrium ions in natural water samples, silica

gel-based adsorbents sequentially functionalized with polyhexamethylene guanidine (PHMG) and either 8-hydroxyquinoline-5-sulfonic acid (yielding SiO_2-PHMG-oxine) or 7-iodo-8-hydroxyquinoline-5-sulfonic acid (yielding SiO_2-PHMG-ferron) were employed as selective sorbent materials [5].

Research Methodology

The stoichiometric molar ratio of the complex formed between Y(III) and the reagent 2,4-dinitroso-1-hydroxy-5-aminonaphthalene-6,8-disulfonic acid was determined to be 1:1 using the Ostromislensky–Job continuous variation method and the Bent–French slope-ratio method. Employing the Tolmachyov approach for the calculation of true molar absorptivity, the genuine molar extinction coefficient for the yttrium complex was established as $\varepsilon_{true} = 11{,}550\ L \cdot mol^{-1} \cdot cm^{-1}$, with the corresponding stability constant determined as $K_{m\gamma} = 2.28 \times 10^5$ [6].

A spectrophotometric protocol was developed to establish the limit of detection (LOD) for Y(III) ions, yielding a value of 0.25 $\mu g \cdot mL^{-1}$. The analytical reliability of the obtained data is substantiated by a correlation coefficient approaching unity ($R^2 \approx 1.0$) [7].

The developed spectrophotometric method for Y(III) determination, utilizing 2,4-dinitroso-1-hydroxy-5-aminonaphthalene-6,8-disulfonic acid as the chromogenic reagent, was successfully applied to the analysis of model, binary, ternary, and multicomponent mixtures. To mitigate interference from concomitant cations, solvent extraction employing a tributyl phosphate (TBP)–hexane (1:1, v/v) system in 2 M HNO_3 medium was recommended. The competitive performance of the proposed method was evaluated against the Uzbekistan State Standard (DavST), and its analytical accuracy was corroborated through parallel determination by X-ray fluorescence (XRF) and inductively coupled plasma mass spectrometry (ICP-MS) [8].

Analysis and Results

Analytical procedure: Aliquots of 1.0 mL of Y(III) standard solution (variable concentration), 2.0 mL of 0.1% (w/v) 2,4-dinitroso-1-hydroxy-5-aminonaphthalene-6,8-disulfonic acid (DNDGNDS) reagent solution, and 5.0 mL of buffer solution (pH 4.4) were sequentially transferred into a 25.0 mL volumetric flask.

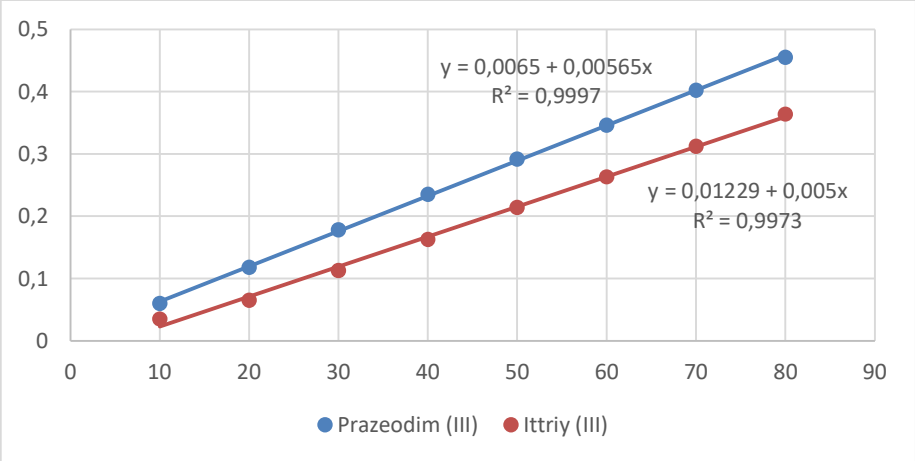

Figure 1. Correlation analysis for the coordination complexes formed between Praseodymium(III) and Yttrium(III) with the reagent 2,4-dinitroso-1-hydroxy-5-aminonaphthalene-6,8-disulfonic acid (DNDGNDS): determination of correlation coefficients.

The volume was adjusted to the mark with distilled water, and the solution was homogenized. Absorbance measurements were performed at the wavelength of maximum absorption for the Y(III) complex (λ_{max} = 620 nm) using a 1.0 cm path length quartz cuvette, against appropriate reagent blanks as reference solutions. The experimental data, together with results of statistical processing via least-squares regression analysis, are summarized in Table 1 and illustrated in Figure 1.

Table 1. Results of least-squares regression analysis of the calibration curve data for the coordination complex formed between Yttrium(III) and the reagent 2,4-dinitroso-1-hydroxy-5-aminonaphthalene-6,8-disulfonic acid (DNDGNDS).

№	Measu-red Y^{3+} x_i mkg/ml	Observed absorbance y_i f (R)	x_i^2	$x_i \cdot y_i$	Calculated absorbance y_{ip}	$y_i - y_{ip}$	$(y_i - y_{ip..})^2 \cdot 10^{-6}$
1	5,0	0,035	25	0,175	0,037	-0,002	4,00
2	10,0	0,065	100	0,65	0,062	0,003	9,00
3	20,0	0,113	400	2,26	0,112	0,001	1,00
4	30,0	0,163	900	4,89	0,162	0,001	1,00
5	40	0,214	1600	8,56	0,212	0,002	4,00
6	50	0,263	2500	13,15	0,262	0,001	1,00
7	60	0,312	3600	18,72	0,312	0,00	0
8	70	0,364	4900	25,48	0,362	0,002	4,00
9	80	0,415	6400	33,2	0,412	0,003	9,00
∑	**365,0**	**1,944**	**20425**	**107,08**	**1,933**	**0,011**	**33**

Using the data presented in Table 1, the regression parameters a (intercept) and b (slope), together with their respective variances S^2_a and S^2_β, were computed according to the following equations:

1) Calculation of the intercept parameter a and its variance S^2_a:

$$a = \frac{\sum xi^2 \cdot \sum yi - \sum xi \cdot \sum xi \cdot yi}{n \cdot \sum xi^2 - (\sum xi)^2} = 0{,}01229$$

$$Sy = \sqrt{\frac{\sum (Yi - Yi_p)^2}{n-2}} = \sqrt{\frac{(33 \cdot 10^{-6})^2}{9-2}} = 12{,}47 \cdot 10^{-3}$$

$$Sa = Sy \cdot \sqrt{\frac{\sum xi^2}{n \cdot \sum xi^2 - (\sum xi)^2}} = 1{,}247 \cdot \sqrt{\frac{20425}{9 \cdot 20425 - (365)^2}} = 7{,}92 \cdot 10^{-3}$$

$$\tan \alpha = \frac{a}{S_a} = \frac{0{,}01229}{0{,}0792} = 1{,}628$$

2) Calculation of the slope parameter b and its variance S^2_β:

$$b = \frac{n \cdot \sum xi \cdot yi - \sum xi \cdot \sum yi}{n \cdot \sum xi^2 - (\sum xi)^2} = \frac{9 \cdot 107{,}08 - 365 \cdot 1{,}944}{9 \cdot 20425 - (365)^2} = 0{,}005$$

$$Syi^2 = \frac{\sum (Yi - Yi_p)^2}{n-1} = \frac{(33 \cdot 10^{-6})^2}{9-1} = 1{,}361 \cdot 10^{-10}$$

$$Sb\sqrt{\frac{Sy^2}{\sum xi^2}} = \sqrt{\frac{1{,}361\cdot10^{-1}}{20425}} = 2{,}58\cdot10^{-5}$$

$\Delta Xb = tg\alpha \cdot Sb = 1{,}628 \cdot 2{,}58 = 4{,}20 \cdot 10^{-5}$

Based on these results, the calibration curve equation, expressed in the linear form $y_i = a + bx_i$, was established as:

$$y_i = a + bx_i \text{ ya'ni } y_i = a + bx_i = 0{,}01229 + 0{,}005\ x_i$$

where y_i denotes the predicted absorbance at λ_{max} = 620 nm, and x_i represents the Y(III) concentration (μg·mL⁻¹).

Conclusion

Optimization of analytical conditions for the spectrophotometric determination of Yttrium(III) utilizing the organic reagent 2,4-dinitroso-1-hydroxy-5-aminonaphthalene-6,8-disulfonic acid (DNDGNDS)

The analytical potential of the organic reagent 2,4-dinitroso-1-hydroxy-5-aminonaphthalene-6,8-disulfonic acid (DNDGNDS) for the determination of Y(III) ions was systematically investigated, and optimal experimental conditions were established. It was determined that complete complexation between Y(III) and the DNDGNDS reagent proceeds quantitatively under acidic medium conditions.

The following parameters influencing complex formation were optimized: the wavelength of maximum absorption for both the free reagent and the resulting coordination complex; the composition and buffering capacity of the supporting electrolyte; the order of reagent addition; the equilibration time; the optimal pH range; and the effect of analyte concentration on analytical signal intensity.

Quantitative formation of the Y(III)–DNDGNDS complex was observed within the pH range of 4.0–5.0. Adherence to the Beer–Lambert–Bouguer law was confirmed for Y(III) concentrations spanning 2.5–80 μg (per 25.0 mL final volume).

The spectral characteristics of the complex were evaluated, and the molar absorptivity (ε) was determined. The stoichiometric composition of the complex was established as 1:1 (metal:ligand) using the Bent–French slope-ratio and Ostromislensky–Job continuous variation methods. The thermodynamic stability constant was calculated via the Tolmachyov approach ($K_{m\gamma} = 2.28\times10^5$), and infrared (IR) spectroscopic analysis was performed to elucidate the coordination mode of the ligand.

The limit of detection (LOD) for Y(III) using the developed spectrophotometric protocol was established as 0.25 μg·mL⁻¹. The method demonstrated high precision, with the relative standard deviation (RSD) not exceeding $S_r \leq 0.33\%$ (n = 5, P = 0.95).

The influence of potentially interfering foreign ions on the determination of Y(III) was evaluated, and the method was successfully applied to the analysis of synthetic mixtures simulating complex technological matrices.

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CREATION OF AN INTERACTIVE DIGITAL MAP OF OIKONYMS OF THE KHOREZM REGION

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Annotassiya. Ushbu maqolada Xorazm viloyatining geografik joylashuvi asosida toponimlar, xususan, oykonimlarning tabiiy geografik xususiyatlari tahlil qilingan hamda ularning interaktiv raqamli kartasini ishlab chiqish jihatlariga alohida e'tibor qaratilgan.

Kalit so'zlar: *toponim, oykonim, raqamli karta, interaktiv veb-karta, ArcGIS, GAT, kml/kmz, Google Maps bulutli geoinformatsion platformasi, orografik.*

Аннотация. В данной статье анализируются природно-географические особенности топонимов, в частности ойконимов, исходя из географического положения Хорезмской области, и особое внимание уделяется аспектам разработки их интерактивной цифровой карты.

Ключевые слова: *топоним, ойконим, цифровая карта, интерактивная веб-карта, ArcGIS, GAT, kml/kmz, облачная геоинформационная платформа Google Maps, орографик.*

Abstract. This article analyzes the natural and geographical features of toponyms, in particular oikonyms, based on the geographical location of the Khorezm region, and pays special attention to the aspects of developing their interactive digital map.

Keywords: *toponym, oikonym, digital map, interactive web map, ArcGIS, GAT, kml/kmz, Google Maps cloud geoinformation platform, orographic.*

Introduction

As we know, oikonyms are considered the most valuable monuments among toponyms from geographical, historical, and linguistic perspectives. Although many opinions have been expressed regarding the meaning of these names and the language they belong to, their origin cannot be considered definitively resolved. Settlements are a socio-economic category, and studying the formation, location, and naming patterns of cities and villages in close connection with natural, historical, and political conditions is of great scientific and practical importance.

Literature Review

Geographical place names have always been of interest to people since ancient times. Beginning from the Antiquity, great philosophers such as Herodotus, Strabo, Pomponius Mela, and Pliny wrote about the meaning, origin, and changes of geographical names in their works. Regarding the study of geographical place names in Uzbekistan, particularly in the Khorezm region, and their etymological meanings, numerous works serve as key and important sources in terminological and scientific fields. These include the sacred Zoroastrian book “Avesto,” the anonymous work “Hudud al-Alam,” as well as the writings of Muhammad al-Khwarizmi, Abu Rayhan Beruni, Istakhri, Zakariya ibn Muhammad al-Qazwini, Yaqut al-Hamawi, Ibn Battuta, Herman (Armenian) Vambery, Abdullah Khwarizmi, S.P. Tolstov, Abulghazi Bahadur Khan, Yusuf Bayoni, Munis and Ogahi, Ya.G. Ghulomov, A.Yu. Yakubovsky, F.A. Abdullaev, A.V. Ishayev, Z.D. Dosimov, and A. Otajanova.

Among the geographical regions mentioned in the Avesto, one of the most ancient sources concerning the place names of the Khorezm region, are ancient Khorezm, Gava (Soghd), Margiyona (Merv), Baqtria (Balkh), the Aral Sea (Vorukasha or Vurukasha), and the Amudarya (Daiti). In the Avesto, the word “Khorezm” means “Sunny land” (from “khvar” – sun, and “zam” – land), indicating that it was a sun-worshipping country.

Place names and geographical terms related to the Khorezm region from the Middle Ages can also be frequently found in the works of Abdullah Khwarizmi in his dictionary “Miftah al-Ulum” (The Key to Sciences), as well as in the writings of al-Istakhri, Zakariya ibn Muhammad al-Qazwini, Yaqut al-Hamawi, Ibn Battuta, and Herman (Armenian) Vambery.

Khiva Khan Abulghazi Bahadur Khan, in his works “Shajarayi Tarakima” and “Shajarayi Turk,” mainly discusses the origin of Turkic tribes [2]. Yusuf Bayoni (1859-1923), in his works “Shajarayi Khwarazmshahi” and “History of Khorezm,” provides information on many place names and terms related to the history and geography of Khorezm and the peoples of Central Asia. Munis (1778-1829) and Ogahi (1809-1872),

in their chronicle “Firdaws al-Iqbal,” present information on the origin and meanings of local place names [14, 15].

In the 19th and 20th centuries, information on the history, geography, and economy of the Khiva Khanate, including place names, is detailed in V.V. Bartold’s work "Information on the Aral Sea and the Lower Reaches of the Amu Darya from Ancient Times to the 17th Century (1902), as well as in S.P. Tolstov’s works “In Search of the Ancient Khorezm Civilization” and “Ancient Khorezm” [14].

During the years of independence, some Khorezm toponyms have been analyzed in S. Qorayev’s work “Toponyms of the Regions of Uzbekistan” [15], in P.N. Ghulomov’s “Russian-Uzbek Dictionary of Geographical Terms and Concepts” [8], in the “Explanatory Dictionary of Geographical Terms and Concepts” [9], in textbooks such as “Toponymy and Geographical Terminology” (2000), and in M.T. Mirakmalov’s monograph “Natural Geographical Features and Geographical Linguistics of Uzbekistan’s Toponyms” [9].

Research Methodology

As we know, one of the most widespread types of toponyms is oikonyms. Oikonyms (from Greek “oikos” – house, dwelling) refer to the name of any inhabited settlement. In ancient times, any large settlement, especially cities, were surrounded by walls, sometimes even by two concentric walls. For example, the inner part of the city of Khiva was called by the Arabic word “madina,” the Persian-Tajik term “shahristan,” or the Persian word “darun” – meaning “inner city”; while the outer part of the city was referred to by the terms “rabod” (“city”) or “berun” (“outer city”). To this day, Khiva is traditionally divided into the Inner City (fortress, city) – Ichan-Qal’a (inner defensive wall) and the Outer City (rabod) – Dishan-Qal’a (outer defensive wall) [1, 3, 4].

Currently, oikonyms include administrative-territorial units (regions, districts, cities, towns, villages, auls); inhabited settlements and their components (neighborhoods, main streets, streets, squares, parks, avenues), as well as other similar objects. Today, depending on population size and economic-administrative significance, settlements are divided into such types as towns (posyolka), auls (small villages or herders’ villages), qo’rg’oncha (a village that has split off from a larger village), and mahalla (an independent village or a part of a larger village). In Uzbekistan, more than 11,000 inhabited settlements are registered on the portal (look at the https://geonames.kadastr.uz/).

Mahmud al-Kashgari noted that in the Turkic language, the word “kend” was used instead of “city,” but that members of the Oghuz tribe understood “kend” to mean a village. Even today, in the Azerbaijani language, which belongs to the Oghuz group, the word “kend” is used to mean village. A village is essentially a smaller inhabited settlement. The word “qishloq” means “place to spend the winter,” and is the opposite of “yayloq” (pasture) – “place to spend the summer” [7].

Just as the toponyms of a region with an ancient and long history are themselves ancient, the names of cities and villages such as Khorezm, Khiva, Urgench, Hazorasp, Qalajiqqal’a, Katqal’a, Tuproqqal’a, Gurlan, Xonqa, and Vazir are measured in millennia [12].

Oikonyms preserve a great deal of information about the history of a region in their very names. Sometimes, the natural geographical features of a region also serve as the basis for the formation of oikonyms. Examples include hydrooikonyms, orooikonyms, phytookonyms, or zoookonyms, among others. The scientific study and classification of the formation and origin of geographical names, including oikonyms, have been carried out by many local and foreign toponymist scholars.

Analysis and Results

It should be taken into account that the form of any classification and its effectiveness depend primarily on the purpose of the research being conducted. Due to the variety of approaches to the classification of toponyms, many scholars have grouped them in different ways. In the 19th century, the first scientific attempts were made to classify geographical names into various morphological groups and semantic types. For example, H.R. Mill (1898), V.P. Semyonov-Tyan-Shansky (1924), A.M. Selishchev (1939), V. Tashitsky (1958), J.R. Stewart (1970), E.M. Chernyakhovskaya (1970), E.M. Murzayev (1989), A.V. Superanskaya (1984), S.N. Basik (2006), and others addressed issues of toponymic classification in their works [5]. Throughout their careers, they developed classification systems for geographical place names that were complementary yet had distinct differences. However, despite the abundance of such research, a unified set of principles for the classification of toponyms has not yet been developed.

In Uzbekistan, the classification of toponyms taking into account their geographical characteristics has been carried out by scholars such as H. Hasanov (1985), S. Qorayev (1998), P. Gulomov (2013), K. Seyitniyazov (1998), M. Mirakmalov (1998, 2020), Q. Hakimov (2010), and M. Avezov (2020) [6]. Rather than studying village and city names separately, it is advisable to classify them into groups and analyze them accordingly.

The Khorezm region is located in the northwestern part of the Republic of Uzbekistan, occupying a portion of the ancient Khorezm lands on the left bank of the lower Amu Darya River. Its total land area is 6,050 km^2, of which 74% of the region's territory is situated on the left bank of the Amu Darya, where agriculture has been practiced since ancient times.

The region's geographical position lies between 40°37' and 41°59' north latitude and 60°02' and 62°26' east longitude. The region is bordered by the Republic of Turkmenistan to the south and southwest across the Unguzorti Karakum Desert, by the Republic of Karakalpakstan to the northwest and north (mainly along the Amudarya River), and by the Bukhara region to the northeast and southeast.

The northernmost point of the region is near the Nuronbobo tugai (riparian forest) near the village of Olchin in the Gurlan district (41°54' N, 60°24' E). The southernmost point falls within the Tuproqqal'a district (41°02' N, 60°00' E). The surface elevation of the region rises from the southwest (85 m) toward the northeast (208 m) (Figure 1).

Due to the fact that the region's territory is located within the Turan Lowland, its relief is not complex. For this reason, large orographic features are almost entirely absent here. As a result of long-term historical and economic human activity, the natural landscape has completely changed and has now transformed into an

anthropogenic landscape in its present form [16, 17]. The average elevation of the region's territory above sea level is 146 meters, which corresponds to the lowland area of present-day Uzbekistan. The surface structure of the region is flat, with a very slight overall slope; the main gradient direction uniformly decreases from the southeast toward the northwest.

Furthermore, it is important to conduct research on the collection and grouping of geographical place names, the creation of international and national databases of geographical names, the analysis of their overall system, the identification of their geographical characteristics, the consideration of natural geographical aspects in the naming and renaming of geographical objects, and the creation of thematic maps related to geographical names.

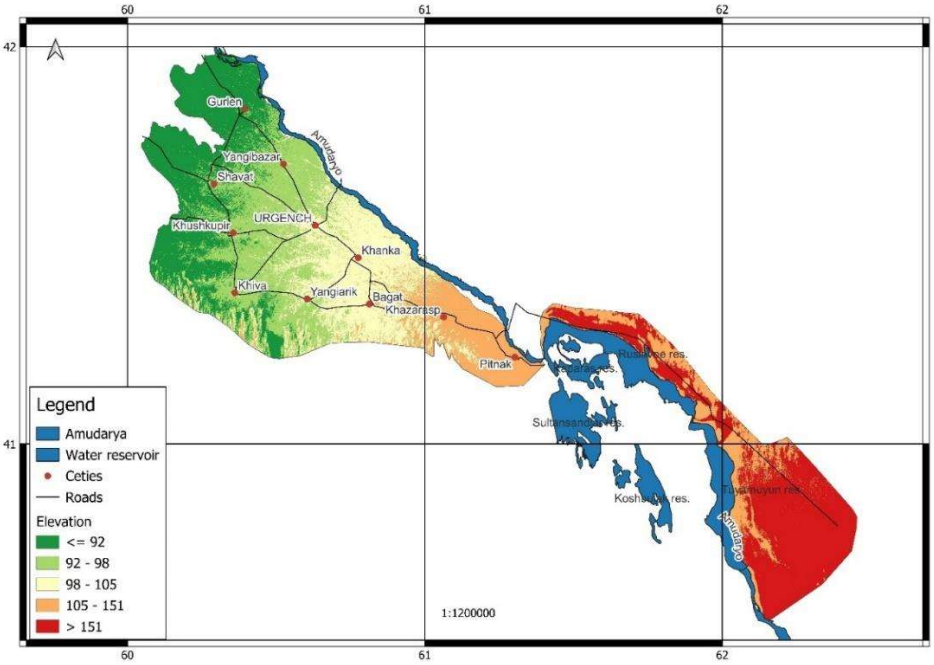

Figure 1. Elevation map of Khorezm region.

In the current era of globalization, the demand for electronic information resources is steadily increasing. In this regard, presenting the results of scientific research from various fields in the form of electronic resources serves to facilitate the rapid and convenient dissemination of social knowledge within society. Especially at a time when the flow of information has accelerated, the need for modern digital maps and mobile applications is greater than ever [10].

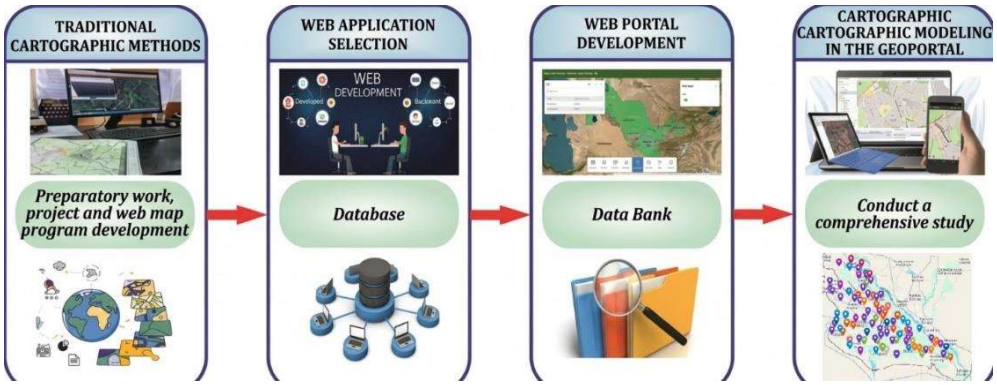

Figure 2. Web map creation system sequence.

Today, there are several major geoportals that provide general information about various regions of the world. As a result of the rapid development of information and communication technologies, and particularly the Internet, interactive maps are able to promptly present users with the information they need. Unlike conventional maps, each cartographic symbol on an interactive map has not only a typical information component but also a specific hidden layer of data that can be displayed when needed. This approach makes it possible to avoid overloading the map with conventional symbols while ensuring that it remains convenient, understandable, and easy to read.

The structure of the thematic GIS interactive web map of the Khorezm region will be implemented according to the scheme proposed below (Figure 2).

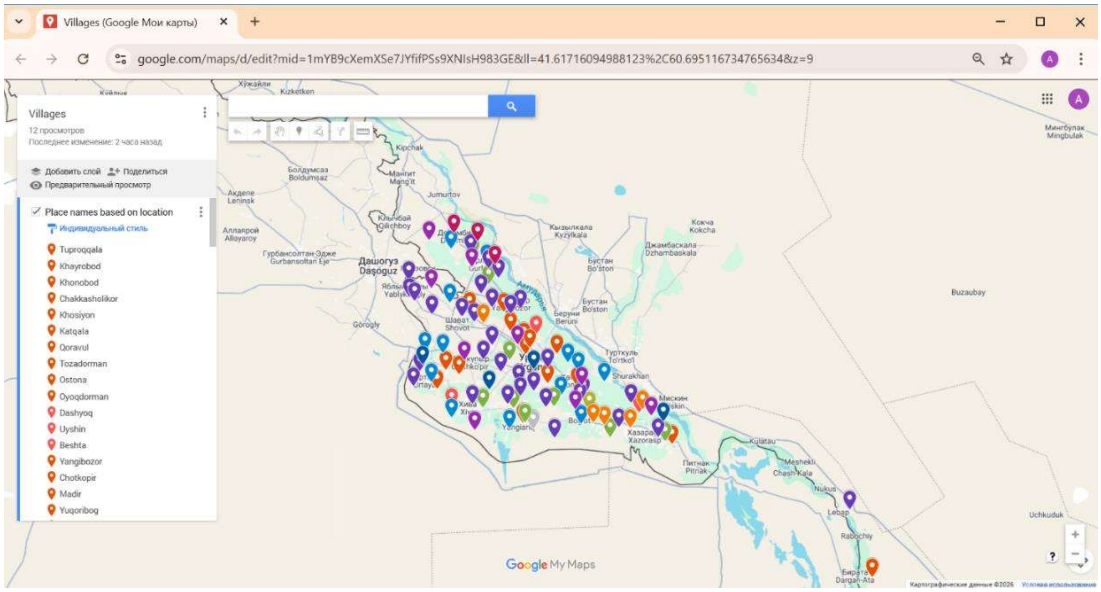

Figure 3. Regional villages and their classification.
www.google.com/maps/d/edit?mid=1mYB9cXemXSe7JYfifPSs9XNIsH983GE&usp=sharing

The statistical and attributive data collected on the research object (coordinates, object names, quantitative indicators) were imported into the platform in the form of tables in csv or xlsx format [11].

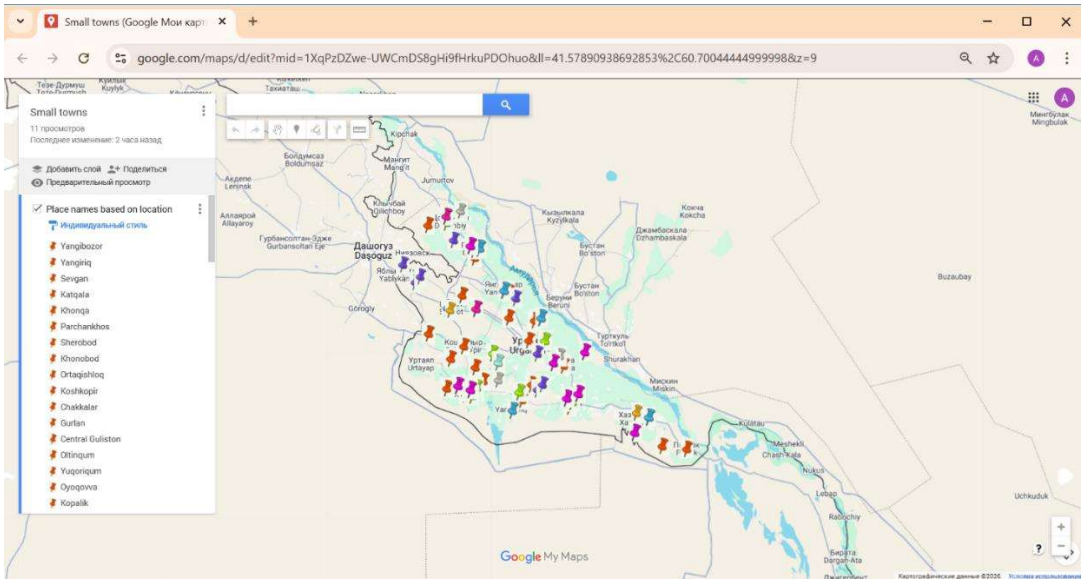

Figure 4. Towns and villages in the region and their classification.
www.google.com/maps/d/edit?mid=1XqPzDZwe-UWCmDS8gHi9fHrkuPDOhuo&usp=sharing

The system automatically geolocated point objects on the map based on (*Latitude*) and (*Longitude*) coordinates. The generated electronic map was exported in the final stage in *kml/kmz (Keyhole Markup Language*) format.

Data in this format was later integrated into professional software such as Google Earth Pro and ArcGIS, and in-depth geospatial analysis was conducted.

As a result, the creation of toponymic electronic digital maps of the Khorezm region and the determination of geospatial characteristics, as well as the analysis of the regularities of the location of objects, will be carried out, and a thematic electronic map will be formed. The use of the Google Maps cloud geoinformation platform will allow digitizing the results of the research and creating an interactive monitoring system.

Conclusion

Thus, the many toponyms in the region indicate that the region's nature, geographical location, relief, waters, flora and fauna, as well as the distinctiveness of its soil cover, are reflected in its place names. Taking into account the natural geographical characteristics of a region when naming or renaming geographical objects ensures that the name of the object remains preserved unchanged for a long time.

Currently, research is covering neighborhoods and streets of cities and villages at the micro level. Through this, the younger generation will have the opportunity to obtain and use toponymic information about the area in which they live and grow up in a scientifically based, fast, and convenient manner. At the same time, we propose the following suggestions for further in-depth study of the region's toponyms and for improving the digital map:

to expand the user base, program a function that displays information (text, photos, audio) when clicking on a point (pop-up feature);

to create opportunities for researchers and students to freely use and download the data on the map, and to publish it on a dedicated domain or within a university website;

to add a function that allows comparison of the ancient and medieval toponymic layers of the Khorezm oasis with a modern map;

to ensure that the map opens correctly on smartphones in order to increase the effectiveness of its use.

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UDC: 528.9, 004.9, 91

ANALYSIS OF THE VEGETATION STATUS OF AGRICULTURAL CROPS USING THE NDVI INDEX (as an example of Khorezm region)

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Anotatsiya. Ushbu maqolada Sentinel-2 A/B sun'iy yo'ldoshining 10 metrlik o'lchamiga ega ko'p spektrli ma'lumotlari va NDVI (Normallashtirilgan farqli vegetatsiya indeksi) indikatori asosida Xorazm viloyatining 2025-yil vegetatsiya mavsumidagi o'simlik qoplamining fazoviy-vaqtli taqsimlanishi o'rganildi. Google Earth Engine va QGIS platformalaridan foydalanilgan holda bulutli va noxolis piksel ma'lumotlari filtrlandi, yakuniy natijalar ko'rsatkichlari esa beshta sinfga ajratildi. Tahlil natijalari bo'yicha siyrak vegetatsiyali hududlar (37.74%) eng katta ulushni tashkil qilib, buning asosiy sabablari cho'llanish, suv taqchilligi va sho'rlanish jarayonlari hisoblanadi. Yaxshi va zich vegetatsiyali hududlar asosan Amudaryo havzasi va irrigatsiya tarmoqlari bo'ylab joylashgani, NDVI va Sentinel-2A/B asosidagi monitoring qurg'oqchil hududlar uchun yuqori aniqlikdagi va samarali texnologiya ekani ilmiy asoslandi.

Kalit so'zlar: *GIS, masofadan zondlash, NDVI, qishloq xo'jaligi, Sentinel-2A/B, vegetatsiya, cho'llanish.*

Аннотация. В данной статье исследовано пространственно-временное распределение растительного покрова Хорезмской области в вегетационный сезон 2025 года на основе многоспектральных данных Sentinel-2A с пространственным разрешением 10 метров и индекса NDVI (нормализованный разностный вегетационный индекс). С использованием платформ Google Earth Engine и QGIS были отфильтрованы облачные и аномальные пиксели, итоговые результаты классифицированы по пяти категориям. Анализ показал, что наибольшая доля приходится на зоны с редкой растительностью (37,74%), что объясняется процессами опустынивания, дефицитом воды и засолением почв. Зоны с хорошей и плотной растительностью, как правило, приурочены к бассейну Амударьи и ирригационным сетям. NDVI и Sentinel-2A/B доказали высокую точность и эффективность для мониторинга растительности в засушливых регионах.

Ключевые слова: *Вегетация, ГИС, дистанционное зондирование, NDVI, опустынивание, сельское хозяйство, Sentinel-2A/B*

Abstract. This article analyzes the spatial-temporal distribution of vegetation cover in Khorezm region during the 2025 growing season using 10-meter spatial resolution Sentinel-2A/B multispectral data and the Normalized Difference Vegetation Index (NDVI). By leveraging Google Earth Engine and QGIS platforms, cloud-contaminated and anomalous pixels were filtered and the results were classified into five vegetation categories. The study reveals that sparse vegetation areas (37.74%) constitute the largest share, primarily due to desertification, water scarcity, and soil salinization. Productive vegetation zones are predominantly located along the Amudarya basin and irrigation networks. The findings substantiate that NDVI and Sentinel-2A/B based monitoring is a highly accurate and efficient technology for managing arid land vegetation.

Keywords: *Agriculture, desertification, GIS, NDVI, remote sensing, Sentinel-2A/B, vegetation*

Introduction

Periodic monitoring of vegetation cover in managing ecosystem conditions and agricultural resources in arid zones is of paramount scientific and practical importance. Particularly in the context of climate change and the global depletion of water resources, an accurate assessment of plant growth dynamics and the impact of drought is a fundamental prerequisite for ensuring regional food security. Establishing rational land use in regions with extreme climatic conditions directly requires methodologies for the systematic assessment of crop conditions [1-7].

In modern geomorphological and agrolandscape studies, remote sensing and geographic information systems (GIS) technologies play an indispensable role in observing these processes. Remote sensing of the Earth via satellite imagery enables the collection of high-resolution spectral data over vast areas within a short timeframe. Compared to traditional field geobotanical surveys, these digital technologies significantly save time, labor, and economic resources, while facilitating the modeling of processes on a spatial-temporal scale [3, 5].

One of the most validated and widely utilized methods for the quantitative and qualitative assessment of vegetation cover is the Normalized Difference Vegetation Index (NDVI). This theoretical index relies on the spectral reflectance characteristics of plant leaves, specifically the strong absorption of visible red light by chlorophyll pigments and the high reflectance of near-infrared light by the cellular mesophyll structure. The NDVI metric serves as an indicator that objectively reflects the intensity of the photosynthetic process, biomass quantity, physiological health of crops, and the overall ecological potential of a given region [6].

The Khorezm region, one of the crucial agro-industrial regions of Uzbekistan, possesses distinct and complex climatic and hydroecological characteristics. Situated in a strictly arid climate, the region continuously suffers from severe ecological stress factors such as secondary soil salinization, a high groundwater table, and a shortage of irrigation water during the growing season. Despite these challenges, this province remains one of the major agrarian centers holding critical strategic importance in the national agriculture, particularly in the cultivation of water-intensive crops such as cotton, winter wheat, and rice [1].

Research Methodology

To study the vegetation dynamics of the Khorezm region, which was selected as the research object, a multispectral dataset from the Sentinel-2A/B satellite operated by the European Space Agency was utilized. Specifically, images in the Surface Reflectance (SR) format were chosen because they are fully corrected for atmospheric effects and accurately represent the true spectral characteristics of the Earth's surface. One of the most significant advantages of the Sentinel-2A/B satellite system is the high spatial resolution of 10 meters in its optical bands, which allows for the precise, micro-level detection of changes across agricultural fields [4].

Complex preprocessing procedures, such as the retrieval, filtering, and cloud masking of the initial satellite imagery, were carried out using the Google Earth Engine (GEE) open cloud platform. Leveraging the centralized, high computational power of the GEE system, a massive archive of spatial data was analyzed in a short timeframe, resulting in the generation of high-quality, cloud- and shadow-free mosaic composite images of the study area. The synthesis of the final thematic maps and the extraction of spatial statistics, based on the digital raster data exported from GEE, were successfully completed within the QGIS software environment [6].

The period from April 1 to September 30, 2025, was purposefully selected for the analysis. Based on the agrometeorological conditions of the Khorezm region, this timeframe comprehensively covers the most active growth and development stages of the primary economic crops, namely cotton, winter wheat, and rice. The multispectral images acquired during this six-month vegetation period provide the most informative and representative data regarding crop canopy formation, biomass accumulation dynamics, and ultimate yield potential [8, 9].

Analysis and Results

The NDVI algorithm was applied to mathematically evaluate the density and condition of the vegetation cover. The calculation of this index is performed using the standard equation (equation 1) [10].

$$NDVI = (NIR - RED) / (NIR + RED) \quad (1)$$

In this equation, Band 8 (B8) of the Sentinel-2A/B multispectral sensor represents the near-infrared (NIR) wavelength, while Band 4 (B4) corresponds to the visible red (RED) radiation spectrum. Through the mathematical ratio between these two distinct spectral bands, the intensity of the chlorophyll-bearing vegetation cover in the region was determined, and the obtained results were categorized into five standardized bioclimatic classes. Atmospheric correction of the satellite imagery was performed using the Sen2Cor algorithm to remove atmospheric distortions. Subsequently, cloud and shadow pixels were identified and corrected based on the Scene Classification Layer (SCL).

Table 1. NDVI Condition classes.

№	Category (NDVI value range)	Condition	Area (ha)	Share (%)
1.	(-1– 0)	Water or barren land	11793.91	1.86
2.	(0–0.2)	Sparse vegetation	239349.95	37.74
3.	(0.2–0.4)	Moderate vegetation	107086.02	16.88
4.	(0.4–0.6)	Good vegetation	177471.02	27.98
5.	(0.6–1.0)	Very high vegetation	98510.69	15.53

Source: Compiled by the author based on Sentinel-2A/B satellite data and NDVI classification

The analysis of the acquired remote sensing data reveals that the vegetation cover in the Khorezm region is distributed with sharp spatial stratification. The category covering the largest area is sparse vegetation (NDVI value range of 0–0.2), which accounts for 37.74 percent of the region's total area, or 239,349.95 hectares in absolute terms. This condition is logically explained by the region's naturally arid climate, rapidly progressing desertification processes, and the widespread prevalence of open sandy and barren lands not actively utilized in agriculture. Furthermore, ecologically degraded areas formed as a result of moderate to severe soil salinization, particularly solonchaks, have also made a significant negative contribution to the high prevalence of this class [5].

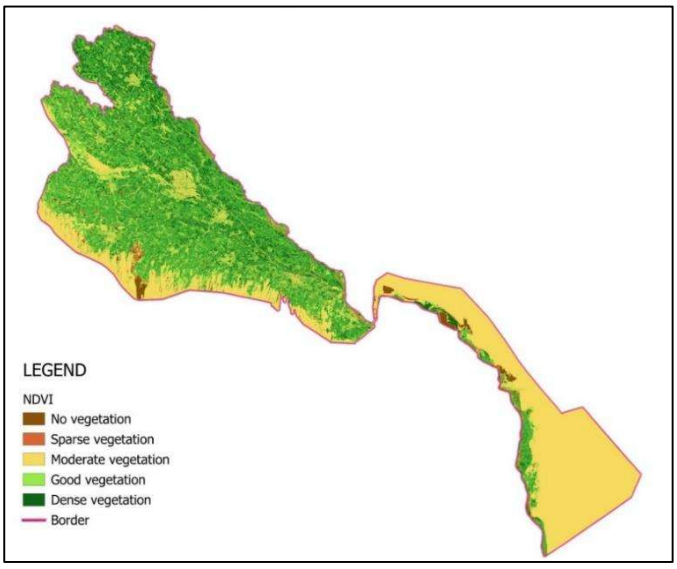

Figure 1. NDVI of Khorezm Region.

According to the research results, the fourth and fifth classes, representing good and very high (dense) vegetation levels, collectively occupied approximately 43.51 percent of the region's territory. Specifically, agrolandscape areas in good condition accounted for 177,471.02 hectares (27.98%), while regions with the highest photosynthetic density comprised 98,510.69 hectares (15.53%). The maps clearly demonstrated that these areas with high bioproductive indicators were spatially formed directly along the channels and floodplains of the Amudarya river basin, as well as in the main crop fields traversed by large engineering irrigation networks. In particular, the recording of maximum NDVI values in the massifs where water-intensive rice and cotton plantations the foundation of the regional economy are located, proves the deep interrelation between land and water resources.

Areas with zero or negative values accounted for only 1.86 percent (11,793.91 hectares) of the total area, primarily encompassing natural lakes, riverbeds, collector-drainage and large irrigation canals, as well as hard-surfaced sections (asphalt and buildings) of urban and rural settlements. Intermediate areas belonging to the moderate vegetation class (16.88 percent or 107,086.02 hectares) mainly corresponded to desert pastures, low-yield hayfields, or late-planted crop fields that were in the initial stages of their development phase at the time of image acquisition. When analyzed from an ecological and agronomic perspective, it is evident that the overall vegetation potential of the region is characterized by acute polarization; namely, high biomass potential exists solely within continuously artificially irrigated oases, whereas the surrounding foundational areas remain under the persistent threat of water scarcity and severe salinization [2, 8].

Conclusion

The conducted spatial-temporal analyses have profoundly revealed the specific distribution patterns of vegetation cover within the agricultural landscapes of the Khorezm region. The exceptionally high proportion of degraded areas with sparse vegetation, resulting from the systemic impact of moisture deficiency and secondary soil salinization in the region, necessitates the immediate expansion of adaptive measures such as agroforestry reclamation and drip irrigation. The positioning of areas with good and dense vegetation cover entirely along the axis of hydrological networks confirms the absolute dependence of the regional agro-industrial system on river waters. The methodology utilizing 10-meter spatial resolution Sentinel-2 A/B multispectral data and the cloud-computing-based NDVI index applied in this study has proven to be a highly accurate and economically viable approach for monitoring the ecological stability and agronomic condition of arid regions. In the future, these remote sensing tools will serve as a scientifically grounded foundational base for developing strategies for the digital management of water resources, the mapping of salinized lands, and the adaptation of agriculture to climate change in the Khorezm region and its adjacent territories.

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