ACTUAL PROBLEMS OF MODERN SCIENCE, EDUCATION AND TRAINING

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CONTENTS

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STRUCTURE AND CHEMICAL PROPERTIES OF PETROLEUM POLYMER RESINS DERIVED FROM SECONDARY PRODUCTS OF THE PYROLYSIS PROCESS

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Annotatsiya. Ushbu tadqiqotda piroliz jarayonining ikkilamchi mahsulotlaridan qisman oksidlovchi piroliz usuli yordamida neft polimer qatronlari (TAR) olindi. Qatronlarning kimyoviy tarkibi va strukturaviy xususiyatlari batafsil o‘rganildi. Piroliz 120–140 °C haroratda, 2, 4 va 6 soat davomida, bosqichma-bosqich havo yuborish sharoitida olib borildi. Natijada hosil bo‘lgan gazlar (metan, etan, propan, butan, CO va CO_2) tahlil qilindi. Suyuqlik fraksiyalari vakuum distillatsiyasi orqali yengil va og‘ir qismlarga ajratildi. Og‘ir fraksiya erituvchilarda eritilib, filtratsiya qilindi va erituvchi bug‘latish orqali toza qatron ajratib olindi. Mass-spektrometriya tahlili mahsulotning asosiy komponenti sifatida antrasen ($C_{14}H_{10}$) ni aniqladi. Qatronlarning fizik-kimyoviy xossalari ~1,2 g/sm³ zichlik, 120–140 °C oralig‘ida yumshash harorati va yuqori yopishqoqlikni o‘z ichiga oladi. Ushbu usul chiqindilardan yuqori qo‘shimcha qiymatga ega aromatik qatronlar olish imkonini beradi.

Kalit so‘zlar: *qisman oksidlovchi piroliz, neft-polimer chiqindilari, qatron, mass-spektrometriya, vakuum distillatsiya, aromatik birikmalar.*

Аннотация. В данном исследовании нефтеполимерные смолы (TAR) были получены из вторичных продуктов процесса пиролиза с использованием метода частично окислительного пиролиза. Химический состав и структурные свойства смол были тщательно изучены. Пиролиз проводился при температуре от 120 до 140 °C в течение 2, 4 и 6 часов в условиях поэтапной подачи воздуха. Образующиеся газы, включая метан, этан, пропан, бутан, CO и CO_2, были проанализированы. Жидкие фракции были разделены методом вакуумной дистилляции на легкие и тяжелые. Тяжелая фракция растворялась с использованием растворителей, фильтровалась, а затем чистая смола выделялась путём выпаривания растворителя. По данным масс-спектрометрии, основным компонентом продукта является

антрацен ($C_{14}H_{10}$). Физико-химические свойства смолы включают плотность около 1,2 г/см³, температуру размягчения в пределах 120–140 °C и высокую вязкость. Этот метод позволяет эффективно получать ароматические смолы с высокой добавленной стоимостью из отходов.

Ключевые слова: *частично окислительный пиролиз, нефтеполимерные отходы, смола, масс-спектрометрия, вакуумная дистилляция, ароматические соединения.*

Abstract. In this study, petroleum polymer resins (TAR) were obtained from the secondary products of the pyrolysis process using a partially oxidative pyrolysis method. The chemical composition and structural properties of the resins were thoroughly investigated. The pyrolysis was conducted at temperatures ranging from 120 to 140 °C for durations of 2, 4, and 6 hours under staged air injection conditions. The resulting gases, including methane, ethane, propane, butane, CO, and CO_2, were analyzed. The liquid fractions were separated by vacuum distillation into light and heavy fractions. The heavy fraction was dissolved using solvents, filtered, and the pure resin was recovered through solvent evaporation. Mass spectrometry analysis identified anthracene ($C_{14}H_{10}$) as the primary component of the product. The physicochemical properties of the resin included a density of approximately 1.2 g/cm³, a softening point between 120–140 °C, and high viscosity. This method offers a viable approach for obtaining high value-added aromatic resins from waste materials.

Keywords: *partially oxidative pyrolysis, petroleum-polymer waste, resin, mass spectrometry, vacuum distillation, aromatic compounds.*

Introduction

There is a wealth of research in the scientific literature regarding the composition and structure of petroleum-polymer waste resins obtained from pyrolysis processes. For example, Alvarez et al. conducted an in-depth study of resin composition and pyrolytic behavior of anthracene-based resins using Fourier transform infrared spectroscopy (FTIR), ultra-violet (UV), and size-exclusion chromatography (SEC) techniques. Their work also analyzed mesophase formation and preparation conditions, enabling the correlation of these factors with the physicochemical properties of the resins [1].

Furthermore, the effect of heating conditions on the physical and chemical properties of pyrolyzed petroleum resins has been extensively examined. Various studies have thoroughly investigated how resin preparation and thermal treatment influence parameters such as density, softening temperature, coke yield, and chemical composition [2, 3].

Literature Review

Analytical methods such as thermogravimetric analysis (TGA), differential scanning calorimetry (DSC), FTIR, and chromatography are widely applied in studying the structural changes and coking behavior of pyrolyzed materials. For instance, Zhang et al. (2022) identified differences in pyrolytic behavior and product composition across resins obtained from different sources [4].

Fuel additives, heating rates, and the use of intercalators significantly impact product quality and yield during pyrolysis. Moreover, the addition of mineral catalysts or sulfur agents-such as during the sulfur polymerization of anthracene petroleum resins-has been shown in numerous studies to enhance pyrolysis efficiency [5].

The thermal decomposition of resin-polymer composites has also been widely explored, with various researchers determining the kinetics and mechanisms involved [6]. In addition, there is extensive data on activated carbons derived from petroleum polymer resins and their BET surface area, DSC profiles, and other thermal properties, which are applicable across various fields of materials science [7]. Petroleum polymer resins are primarily obtained as secondary products from the pyrolysis of plastic waste, and their recycling enables the production of high value-added materials. In contrast to conventional methods, the secondary pyrolysis of these petroleum polymer resins was carried out in this study using staged air injection. This process, referred to as partially oxidative pyrolysis, allows for relatively mild pyrolysis at lower temperatures and leads to improved process efficiency.

Research Methodology

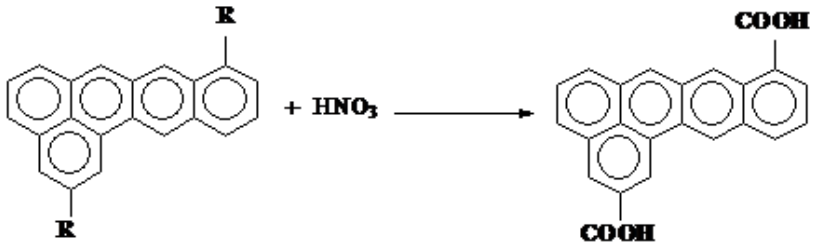
The pyrolysis process was carried out in a steel reactor with a volume of 1200 ml, designed to withstand high temperatures. The reactor was heated to 120–140 °C using an electric heater, and the temperature was continuously monitored using a thermocouple. The process was conducted for 2, 4, and 6 hours. To prevent excess oxygen, a controlled amount of air was introduced using a peristaltic pump and monitored via a rotameter, ensuring stability in product composition.

The extracted resin appeared as a black, dense substance with high viscosity, a softening point of 120–140 °C, and a density of approximately 1.2 g/cm³. The technology proved to be stable and efficient under laboratory conditions, providing a practical method for enhancing the usability of pyrolysis products.

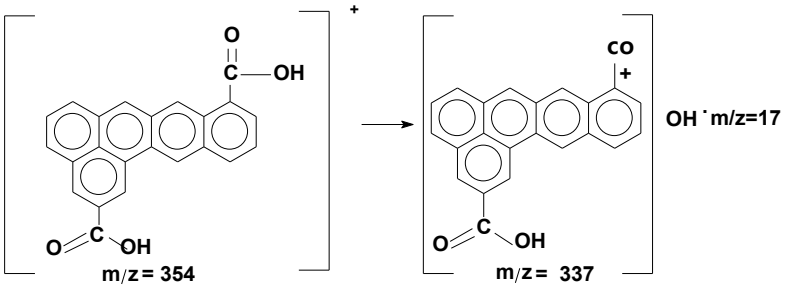
Analysis and Results

The chemical modification of aromatic compounds plays a significant role in modern organic synthesis, allowing for the tuning of their physicochemical properties and reactivity. Specifically, the introduction of a nitro group ($–NO_2$) into an aromatic ring is typically achieved via electrophilic aromatic substitution (EAS) reactions. This approach is central to the synthesis of nitroaromatic compounds.

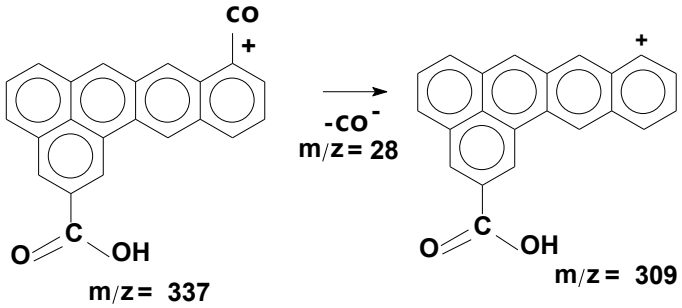
Nitro-substituted products possess not only high chemical reactivity but also find wide applications in pharmaceuticals, agrochemicals, and materials science. In this work, the nitration reaction of aromatic acids and its mechanism were studied, and methods for obtaining highly efficient nitroaromatic compounds were proposed.



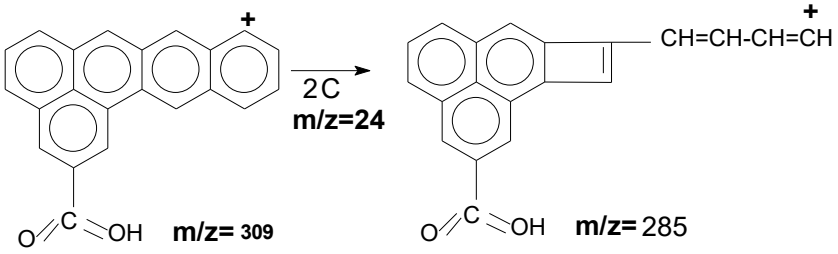
In electrophilic aromatic substitution (EAS), a nitro group is introduced into the aromatic ring using a nitrating mixture of concentrated nitric acid (HNO_3) and sulfuric acid (H_2SO_4), which generates the nitronium ion (NO_2^+) as the active electrophile. This ion preferentially attacks the ortho and para positions of the aromatic ring, leading to the formation of nitroaromatic compounds. These products are highly reactive and often serve as key intermediates in further organic transformations.



The observation of a molecular ion at m/z = 356 confirms the intact molecular mass. Despite the expected loss of a hydroxyl radical (17 Da) suggesting a fragment at m/z = 339, the presence of a peak at m/z = 337 indicates additional fragmentation processes, possibly involving rearrangement or the loss of a water molecule (H_2O, 18 Da). Such deviations offer valuable structural information and aid in elucidating the molecule's stability and substitution patterns.

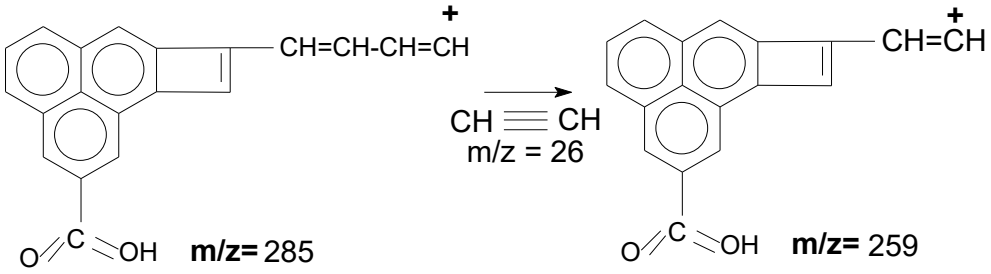


The fragmentation of the m/z = 337 ion involves the elimination of a carbonyl group (CO, 28 Da), producing a fragment ion at m/z = 309. This loss is indicative of the presence and location of specific functional groups within the molecular structure. The resulting spectral signals are well-defined and characteristic, providing valuable information about bond stability and potential fragmentation pathways.

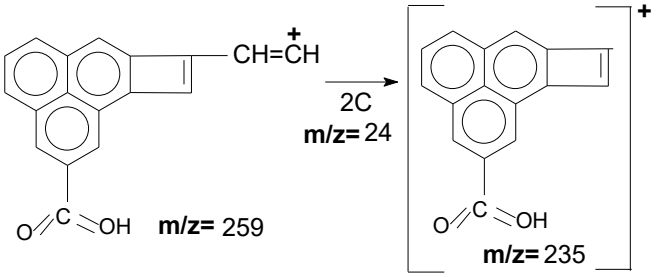


In the course of ionized fragmentation, the m/z = 309 ion undergoes the loss of a vinyl radical (C_2H_3, 23 Da), yielding a fragment ion at m/z = 286. This suggests the potential cleavage of a radical from the alkyl side chain, which is consistent with the widespread occurrence of vinyl groups in organic molecular structures. Such

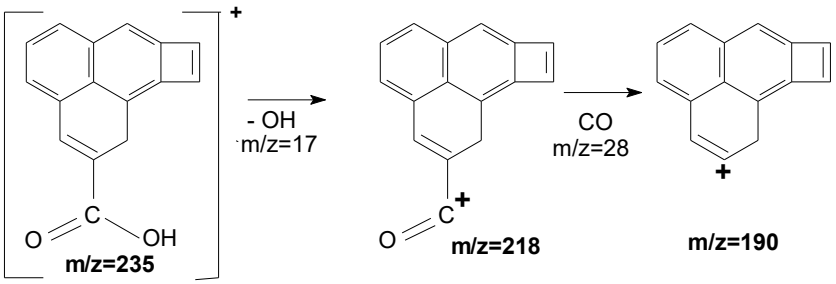
fragmentation patterns are useful for elucidating the side-chain architecture and stability of the compound.



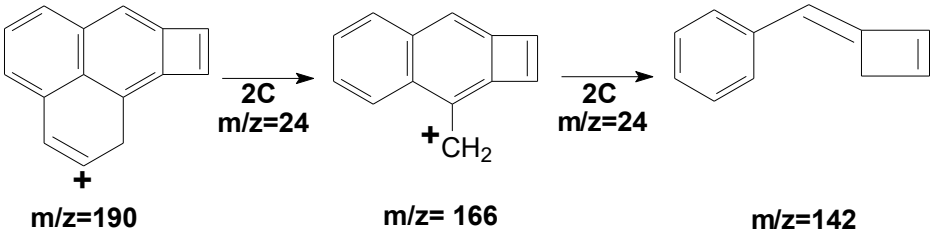
In the ionized fragmentation sequence, the ion at m/z = 286 undergoes the loss of a CH=CH–CH_3 group (approx. 27 Da), resulting in a fragment ion at m/z = 259. This fragmentation is indicative of alkyl group cleavage from the aromatic ring, providing insight into the structural modifications occurring within the molecule during the ionization process.



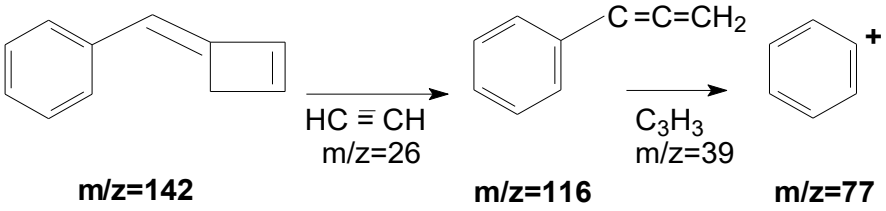
In this fragmentation step, ethylene (CH_2=CH_2, m/z = 24) is eliminated from the molecule, resulting in a fragment ion at m/z = 235 (259 – 24 = 235). Ethylene is thermodynamically less stable and readily dissociates under mass spectrometry conditions.



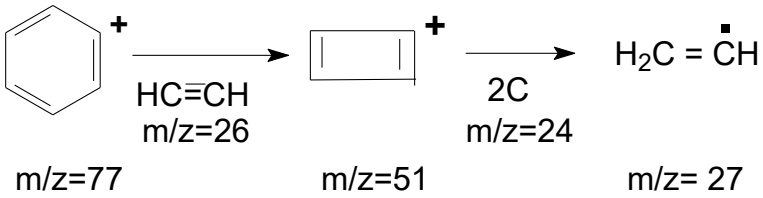
In the mass spectrometric ionized fragmentation, sequential losses of hydroxyl (–OH, m/z = 17) and carbonyl (CO, m/z = 28) groups occur from the molecule. In the first step, the ion at m/z = 235 loses a hydroxyl group, forming an ion at m/z = 218 (235 – 17 = 218). In the subsequent step, the loss of a carbonyl group results in the transition from m/z = 218 to m/z = 190 (218 – 28 = 190).



At this stage of mass spectrometric ionized fragmentation, two consecutive losses of ethylene (CH_2=CH_2, m/z = 24) occur from the ion at m/z = 190, resulting in fragment ions at m/z = 166 (190 – 24) and subsequently at m/z = 142 (166 – 24).



At these stages of the mass spectrometric ionized fragmentation process, sequential detachment of C_2H_2 (acetylene, m/z = 26) and C_6H_5 (benzyl cation, m/z = 77) ions occurs. From the initial molecular ion at m/z = 142, the C_2H_2 group is first lost, resulting in a fragment ion with m/z = 116. In the subsequent step, the C_6H_5 group (benzyl cation) detaches from the molecule, leading to the formation of an ion at m/z = 77 (116 – 39 ≈ 77, where smaller ions or neutral molecules with a combined mass of 39 may also be lost).



In the mass spectrometry analysis, sequential losses of C_2H_2 (m/z = 26) and C_2H_4 (m/z = 24) molecules from the ion at m/z = 77 (benzene cation) result in the formation of ions at m/z = 51 and m/z = 27. Intense ions observed in the spectrum at m/z = 337, 309, 259, 190, 142, and 77 correspond to structural fragments of the molecule. According to the mass spectrum analysis, the main component is anthracene ($C_{14}H_{10}$), with its molecular ion detected as the most intense peak at m/z = 178. This peak reflects a stable structure consisting of three fused aromatic rings. Fragmentation produces peaks at m/z = 152, 126, 110, 89, and 76, which are associated with the stepwise cleavage of C–C and C–H bonds (see Figure 1).

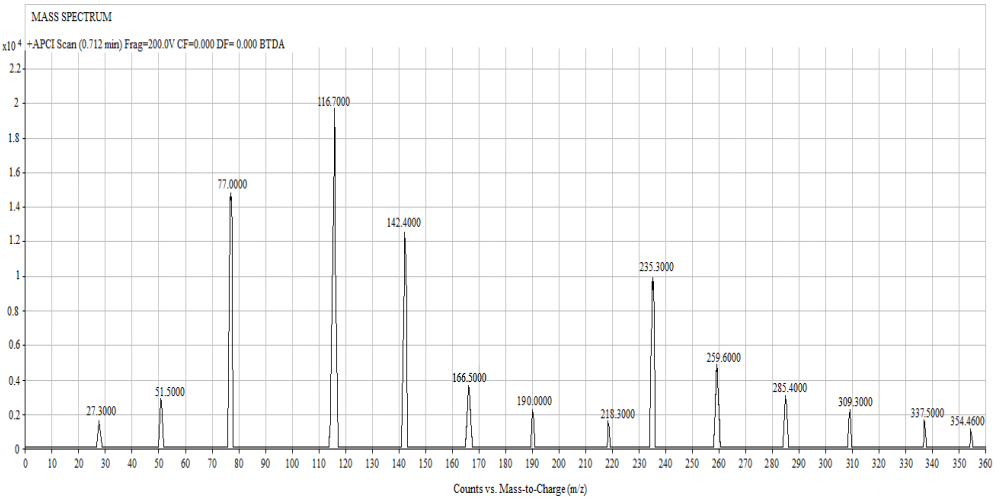
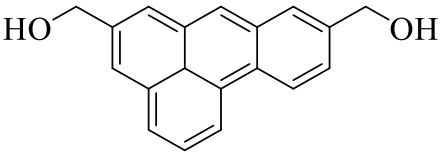
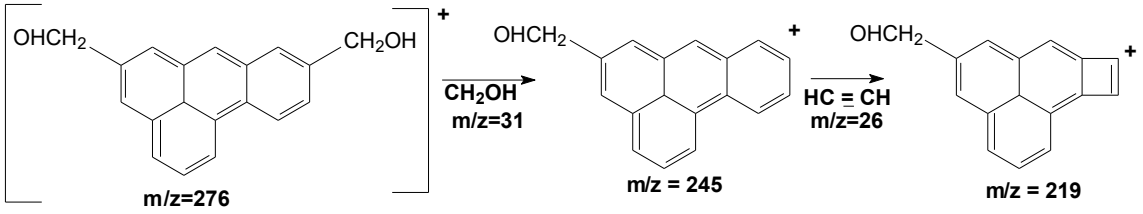


Figure 1. Mass spectrum of ionized fragmentation showing key molecular ions and fragment peaks.

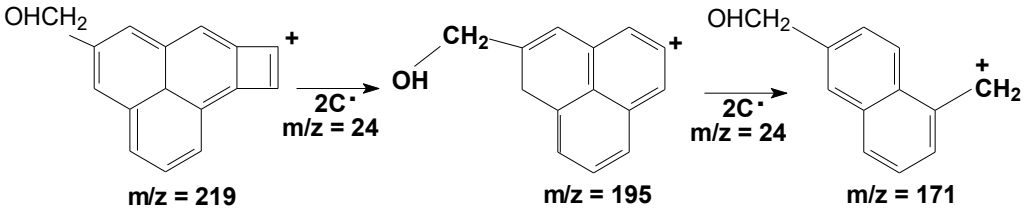
According to mass spectrometry data, the molecular ion of the compound is detected at m/z = 354.5, representing its full molecular mass. During the ionization process, sequential losses of water (m/z = 337.5), ethyl (m/z = 309.3), methyl (m/z = 285.4), and propyl (m/z = 259.6) groups occur. Subsequently, phenyl (m/z = 235.3), alcohol or ester-related ions (m/z = 218.3 and 190.0), as well as central aromatic-alkyl based ions (m/z = 166.5 and 142.4) are formed. Smaller ions at m/z = 116.7, 77.0, 51.5, and 27.3 correspond to aromatic and high-energy fragmentation products.



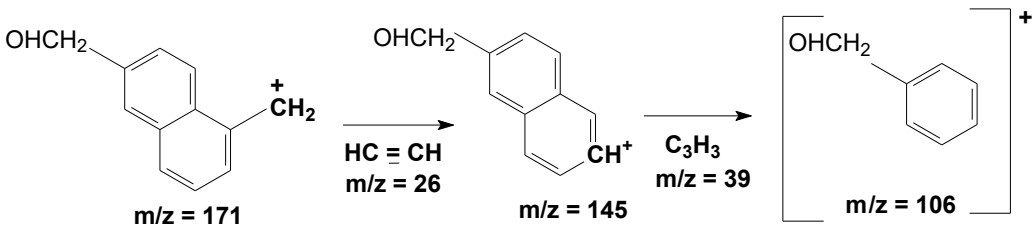
(3a^1*H*-benzo[*de*]anthracene-5,9-diyl)dimethanol



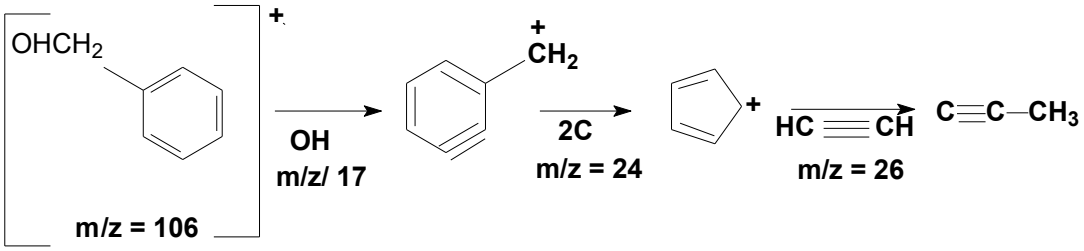
The compound under analysis shows a protonated molecular ion at m/z = 276 in the mass spectrometry results, indicating an approximate molecular mass of 275 g/mol. The spectrum reveals sequential ions corresponding to methyl (m/z = 245), ethyl (m/z = 219), propyl (m/z = 195), and larger alkyl groups (m/z = 145). The most intense signal at m/z = 106 represents the most stable cation retaining the aromatic core of the compound and is considered the base peak of the spectrum. Smaller signals at m/z = 89, 65, and 39 indicate deep molecular fragmentation and the presence of various functional groups.



The presented mass spectrometry data clearly demonstrate the molecular ion at m/z = 276 and its protonated fragmentation pattern, confirming that the compound has an approximate molecular mass of 275 g/mol. The main fragment ions in the spectrum reflect the sequential loss of methyl (–CH_3, m/z = 245), ethyl (–C_2H_5, m/z = 219), and propyl (–C_3H_7, m/z = 195) groups from the molecule. Additionally, the signal at m/z = 171 indicates specific cleavages between the molecular ion and its functional groups.



The mass spectrometry results of the presented compound show a protonated molecular ion detected at m/z = 276. During ionization, sequential losses of methyl (m/z = 245), ethyl (m/z = 219), propyl (m/z = 195), and other alkyl radicals are observed. The ion at m/z = 171 represents a stable cation formed as a result of a retro-cleavage process. Furthermore, ions at m/z = 145, 139, and 105 confirm the presence of aromatic and alkyl components within the molecular skeleton.



The mass spectrometry results of the presented compound show a protonated molecular ion detected at m/z = 276. During ionization, sequential losses of methyl (m/z = 245), ethyl (m/z = 219), and propyl (m/z = 195) radicals are observed. The ion at m/z = 171 is a stable cation, while the signals at m/z = 106 and 89 indicate the presence of aromatic and alkyl components. This spectrum reflects the compound's complex ion fragmentation and serves as a reliable diagnostic tool for structural elucidation (Figure 2).

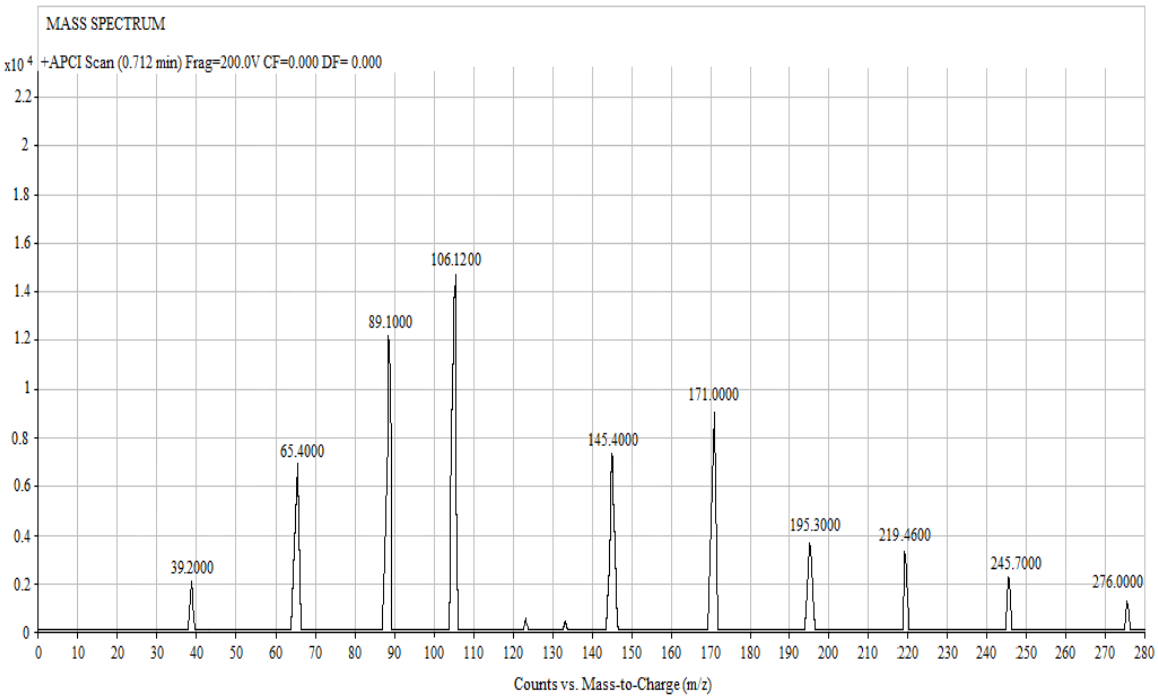


Figure 2. The molecular mass spectrum of the compound.

Figure 2 mass spectrometry spectrum, the main protonated molecular ion is detected at m/z = 276, indicating the molecular mass of the compound. During ionization, methyl (m/z = 245), ethyl (m/z = 219), and propyl (m/z = 195) alkyl groups are sequentially eliminated, representing the fragmentation of the molecule. The ions at m/z = 171 and 145 are stable fragments derived from phenolic or alkyl groups, while m/z = 106 and 89 correspond to ionized methanol and ethanol functional groups. The

smaller ions at m/z = 65 and 39 are stable fragments formed as a result of high-energy fragmentation.

Conclusion

In this study, the composition and structure of oil polymer resins (TAR) obtained as secondary products from the pyrolysis process under partially oxidative conditions were thoroughly analyzed using mass spectrometry. The obtained resins exhibited high density (~1.2 g/cm³), viscosity, and a softening point in the range of 120–140 °C, indicating a complex aromatic structure. In the mass spectrum, anthracene ($C_{14}H_{10}$) was identified as the main component, confirming the presence of a highly delocalized aromatic system. The sequential loss of methyl, ethyl, propyl, phenyl, hydroxyl, and carbonyl groups revealed the compound's fragmentation mechanism.

The findings demonstrate that these types of resins contain highly aromatic components, making them excellent raw materials for the paint and coating industry. In particular, anthracene and similar condensed aromatic structures possess properties such as high UV stability, durability, and adhesion, making them suitable for industrial lacquers, anti-corrosive coatings, and colorant production. The high molecular stability and complex aromatic nature of these resins provide a scientific basis for their use as functional additives or binding components.

Thus, aromatic resins derived from the pyrolysis process represent high-value-added products that can be effectively used in paint and coating industries through waste recycling.

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MATERIALS ON THE FAUNA OF SHIELD BUGS (PENTATOMIDAE) OF CENTRAL–EASTERN RESERVES OF THE REPUBLIC OF UZBEKISTAN

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Annotatsiya. Ushbu maqola 2025 yil iyun oyining birinchi dekadasida Markaziy-Sharqiy O‘zbekiston qo‘riqxonalarida uchragan Pentatomidae turlari haqida ma’lumotlar keltirilgan.

Kalit so‘zlar: *Hasharotlar, haqiqiy qalqonli qandala, O‘zbekiston, qo‘riqxona, kenja oila.*

Аннотация. В статье приведены сведения о видах семейства пентатомид, обнаруженных в заповедниках Центрально-Восточного Узбекистана в первой декаде июня 2025 года.

Ключевые слова: *Насекомые, щитники, Узбекистан, заповедник, подсемейства*

Abstract. This article presents information on Pentatomidae species found in the reserves of Central-Eastern Uzbekistan in the first decade of June 2025.

Keywords: *Insects, shield bugs, Uzbekistan, reserve, subfamiles*

Introduction

Central–Eastern Uzbekistan occupies the western spurs of the Tian Shan and the Zarafshan mountain system within Tashkent, Jizzakh, and Samarkand provinces. Its relief is a mosaic of foothill plains, intermontane valleys, and medium- to high-elevation massifs (Ugam–Chatkal, Pskem, Turkestan, and Zarafshan ranges) (Figures 1–4) [1, 4]. The regional drainage belongs chiefly to the Syr Darya basin via the Chirchiq, Pskem, Ugam, and Akhangaran rivers, and to the Zarafshan River system; major impoundments such as the Charvak Reservoir shape local hydro-regimes [2, 5]. The climate is sharply continental, with hot, dry summers and cold winters; precipitation and thermal amplitudes vary strongly with altitude and aspect. Within this physiographic framework, a network of protected areas-Ugam-Chatkal National Park, Zaamin State Nature Reserve, Zarafshan National Nature Park, Kitab State Geological

Reserve, and the Omonqoton (Amankutan) protected area-conserves juniper woodlands, rocky slopes, subalpine/alpine meadows, and riparian tugai fragments.

Figure 1. Oqtosh Mt. Range (photo by A.I. Iskandarov).

Figure 2. Kampirsoy waterfall, Bo‘stanlik district (photo by A.I. Iskandarov).

Figure 3. Midlands of the Zamin reserve (photo by A.I. Iskandarov).

The insect fauna is correspondingly diverse: steppe and semidesert assemblages dominate the piedmonts, while montane forest–meadow and scree specialists occur higher up, and riparian elements persist along valley bottoms. This environmental heterogeneity and strong elevational gradients generate high beta-diversity and fine-scale turnover among communities, making the region a natural laboratory for biogeographic, ecological, and conservation studies.

Figure 4. Kitob State Nature Reserve (photo by A.I. Iskandarov).

In this paper we provide data on 15 species of 2 subfamilies based on the collection made in the Central–Eastern Uzbekistan.

Research Methodology

Collecting was made using common methods (Fasulati 1971; Golub et al. 2012), net-sweeping herbaceous and arboreal vegetation and shrubs [3, 6]. The material collected amounts 244 specimens of shield bugs.

The coordinates were omitted for the following localities: Oqtosh Mts., 5.33 km NNE of Saylyk Village (41°20'42.5"N, 69°59'10.9"E); Omonqoton State Nature Reserve, 1.4 km E of Taxtaqoracha Pass (39°18'27.6"N 66°56'04.5"E); Zomin State Nature Reserve, 12 km WNW of Zaamin National Park (39°36'13.4"N 68°21'53.9"E); Zarafshon State Nature Reserve, 15 km ENE of Samarkand city (39°40'08.0"N 67°05'36.5"E); Kitob State Nature Reserve, 13.8 km ENE of Varganza Village (39°16'29.0"N 67°08'22.4"E).

Analysis and Results

Annotated list of the Pentatomidae of East Uzbekistan's reserve (Zarafshon, Kitob, Omonqo'ton, Zamin, Ugom–Chotqol):

1. Subfamily Pentatominae Leach, 1815

Aelia acuminata (Linnaeus, 1758) - Material. Omonqoton State Nature Reserve, 1.4 km E of Taxtaqoracha Pass, H= 1700 m. 5.06.2025, 2 males, 1 female.

Aelia rostrata Boheman, 1852 - Material. Zomin State Nature Reserve, 12 km WNW of Zaamin National Park, H= 2100 m. 8.06.2025, 1 male. Zarafshon State Nature Reserve, 15 km ENE of Samarkand city, H= 717 m. 7.06.2025, 1 male, 1

female. Kitob State Nature Reserve, 13.8 km ENE of Varganza Village, H= 1000 m. 4.06.2025. 2 males, 2 females

Ancyrosoma leucogrammes (Gmelin, 1790) - Material. Kitob State Nature Reserve, 13.8 km ENE of Varganza Village, H= 1000 m. 4.06.2025. Oqtosh Mts., 5.33 km NNE of Saylyk Village, H= 1246 m. 9.06.2025.

Brachynema germarii (Kolenati, 1846) - Material. Zarafshon State Nature Reserve, 15 km ENE of Samarkand city, H= 717 m. 7.06.2025, 1 male, 1 female.

Carpocoris coreanus Distant, 1899 - Material. Omonqoton State Nature Reserve, 1.4 km E of Taxtaqoracha Pass, H= 1700 m. 5.06.2025. 3 males, 2 females. Kumushkan Mts., 11.8 km ENE of Kumushkon Village, H= 1553 m. 9.06.2025. 2 males, 3 females.

Codophila varia Fabricius, 1787 - Material. Omonqoton State Nature Reserve, 1.4 km E of Taxtaqoracha Pass, H= 1700 m. 5.06.2025, 5 males, 4 females. Kitob State Nature Reserve, 13.8 km ENE of Varganza Village, H= 1000 m. 4.06.2025, 3 males, 5 females.

Dolycoris penicillatus Horváth, 1904 - Material. Kitob State Nature Reserve, 13.8 km ENE of Varganza Village, H= 1000 m. 4.06.2025, 6 males, 7 females. Omonqoton State Nature Reserve, 1.4 km E of Taxtaqoracha Pass, H= 1700 m. 5.06.2025, 5 males, 3 females. Zarafshon State Nature Reserve, 15 km ENE of Samarkand city, H= 717 m. 7.06.2025, 2 males, 4 females. Zomin State Nature Reserve, 12 km WNW of Zaamin National Park, H= 2100 m. 8.06.2025, 2 males, 2 females.

Eurydema maracandica Oshanin, 1871 - Material. Omonqoton State Nature Reserve, 1.4 km E of Taxtaqoracha Pass, H= 1700 m. 5.06.2025. 2 males, 3 females. Kumushkan Mts., 11.8 km ENE of Kumushkon Village, H= 1553 m. 9.06.2025, 3 males, 3 females. Zomin State Nature Reserve, 12 km WNW of Zaamin National Park, H= 2100 m. 8.06.2025, 3 males, 5 females.

Eurydema ornata (Linnaeus, 1758) - Material. Oqtosh Mts., 5.33 km NNE of Saylyk Village, H= 1246 m. 9.06.2025. 4 males, 3 females.

Neottiglossa leporina (Herrich-Schäffer, 1830) - Material. Zomin State Nature Reserve, 12 km WNW of Zaamin National Park, H= 2100 m. 8.06.2025, 2 males, 2 females.

Palomena prasine (Linnaeus, 1761) - Material. Kumushkan Mts., 11.8 km ENE of Kumushkon Village, H= 1553 m. 9.06.2025. 1 male

Stagonimus amoenus (Brullé, 1832) - Material. Oqtosh Mts., 5.33 km NNE of Saylyk Village, H= 1246 m. 9.06.2025. 2 males, 1 female. Kumushkan Mts., 11.8 km ENE of Kumushkon Village, H= 1553 m. 9.06.2025. 1 male, 1 female.

2. Subfamily Podopinae Amyot & Serville, 1843

Graphosoma italicum italicum (O. F. Müller, 1766) - Material. Kitob State Nature Reserve, 13.8 km ENE of Varganza Village, H= 1000 m. 4.06.2025, 7 males, 9 females. Kumushkan Mts., 11.8 km ENE of Kumushkon Village, H= 1553 m. 9.06.2025, 5 males, 4 females.

Graphosoma (Graphosoma) consimile Horvath, 1903 - Material. Kumushkan Mts., 11.8 km ENE of Kumushkon Village, H= 1553 m. 9.06.2025. 1 male, 1 female.

Tholagmus breviceps Jakovlev, 1883 - Material. Omonqoton State Nature Reserve, 1.4 km E of Taxtaqoracha Pass, H= 1700 m. 5.06.2025 1 male, 2 females.

Conclusion

In this study, 15 species of true shield bugs (Pentatomidae) belonging to two subfamilies were recorded. Samples were collected across mountain, foothill, and riparian habitats at approximately 717–2,100 + m a.s.l. Species composition and encounter rates were highest in the Zaamin, Ugam–Chatkal, and Kitab protected areas, indicating that the fine-scale microhabitat mosaic—structured by elevation, moisture, and vegetation cover—strongly shapes shield bugs diversity.

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UDC: 551, 574, 91

CLIMATE DYNAMICS OF THE MIRZACHUL REGION: A KÖPPEN–GEIGER CLASSIFICATION ANALYSIS (1901–1930 VS. 2070–2090)

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Annotatsiya. Markaziy O‘zbekistonning eng yirik sug‘oriladigan hududlaridan biri hisoblangan Mirzacho‘l (tarixan “Och dasht” nomi bilan mashhur) iqlim o‘zgarishiga juda sezgir mintaqalardan biridir. Ushbu tadqiqotda Köppen–Geiger tasnifi asosida tarixiy davr (1901–1930) va kelajak proyeksiyalari (2070–2090, SSP2-4.5 senariysi) solishtirildi. Bunda Beck va hammualliflari (2018) tomonidan ishlab chiqilgan yuqori aniqlikdagi (1 km) raster ma’lumotlar ArcGIS Pro dasturida qayta ishlangan. Natijalar shuni ko‘rsatdiki, XX asr boshida hududning 95 foizidan ortig‘ini egallagan cho‘l iqlimlari (BWk, BWh) XXI asr oxiriga kelib hududiy ulushi sezilarli darajada kamayadi. Natijada, hududda issiq yarim qurg‘oqchil (BSh – 91,1%) va O‘rta yer dengizi tipidagi (Csa – 8,8%) iqlim zonalari kengayadi. Bu esa bug‘lanishning kuchayishi, sug‘orish suvlariga talabning ortishi va sho‘rlanish xavfining kuchayishiga olib kelishi mumkin. Shu bilan birga, Csa zonalarining paydo bo‘lishi qishloq xo‘jaligini diversifikatsiya qilish imkoniyatlarini ochadi, biroq umumiy o‘zgarish geoekologik muvozanat va qishloq xo‘jaligi barqarorligini saqlash uchun jiddiy choralarni talab qiladi.

Kalit so‘zlar: *Mirzacho‘l, Köppen–Geiger tasnifi, iqlim o‘zgarishi, CMIP6 prognozlari, cho‘l qisqarishi, yarim qurg‘oqchil iqlim, sug‘orish barqarorligi.*

Аннотация. Мирзачульский регион в Центральном Узбекистане, исторически известный как “Голодная степь,” является одним из крупнейших орошаемых сельскохозяйственных районов Центральной Азии и отличается высокой климатической уязвимостью. В данном исследовании используется классификация Кёппена–Гейгера для сравнения климатического базиса начала XX века (1901–1930 гг.) и будущих проекций (2070–2090 гг.) по сценарию SSP2-4.5. Для анализа применялись высокоточные (1 км) растровые данные (Beck et al., 2018), обработанные в ArcGIS Pro. Результаты показывают, что пустынные климатические зоны (BWk, BWh), занимавшие более 95% территории в начале XX века, к концу XXI века практически исчезнут. Их заменят полузасушливые степные (BSh – 91,1%) и средиземноморские (Csa – 8,8%) климаты. Эти изменения указывают на рост испаряемости, усиление водного дефицита, рост риска засоления почв и возрастающую зависимость от ирригации. Появление климатов типа Csa может создать новые возможности для сельскохозяйственной диверсификации, однако в целом изменения отражают геоэкологическую трансформацию с серьёзными последствиями для землепользования, управления водными ресурсами и продовольственной безопасности региона.

Ключевые слова: *Мирзачуль, классификация Кёппена–Гейгера, изменение климата, прогнозы CMIP6, сокращение пустынь, полузасушливая степь, устойчивость ирригации.*

Abstract. The Mirzachul region in central Uzbekistan, historically known as the “Hungry Steppe,” represents one of the largest irrigated agricultural landscapes in Central Asia and is highly sensitive to climate change. This study applies the Köppen–Geiger classification to compare the historical climate baseline (1901–1930) with future projections (2070–2090) under the SSP2-4.5 scenario, using high-resolution (1 km) raster datasets processed in ArcGIS Pro. The results reveal that desert climates (BWk, BWh), which covered more than 95% of the area in the early 20th century, are projected to nearly disappear by the end of the 21st century. In their place, hot semi-arid steppe (BSh) becomes dominant (91.1%), while Mediterranean-type climates (Csa) expand to 8.8%. These shifts imply intensified evapotranspiration, increased irrigation demand, and potential risks of salinization. Although the emergence of Csa zones may create opportunities for agricultural diversification, the overall transition indicates a geoecological transformation with significant implications for land use, water governance, and regional food security.

Keywords: *Mirzachul region, Köppen–Geiger classification, climate change, CMIP6 projections, desert retreat, semi-arid steppe, irrigation sustainability.*

Introduction

One of the greatest irrigated agricultural regions in Central Asia is the Mirzachul region in central Uzbekistan, who has historically been known as the “Hungry Steppe.” It particularly at with from climate change owing to its geoecological sensitivity. This

study compares the historical baseline (1901–1930) with future projections (2070–2090) under the SSP2-4.5 scenario so as evaluate the spatiotemporal dynamics of climate zones in the Mirzachul region through the Köppen–Geiger climate classification. To calculate the extent of desert (BWh, BWk), semi-arid (BSh), and Mediterranean (Csa) climate types, high-resolution raster datasets (1 km) obtained from Beck et al. (2018) were processed in ArcGIS Pro.

The results suggest the climate system in the region is experiencing substantial changes. Desert climates dominated in the early 20th century, with BWk and BWh jointly accounting for up over 95 percent of the total area. These desert types are expected to nearly vanish by the end of the 21st century, as hot semi-arid steppe (BSh, 91.1%) and Mediterranean-type climates (Csa, 8.8%) take their place. Despite possible opportunities for agricultural diversification under Csa conditions, these shifts point to increased risks of soil salinization, increased reliance on irrigation, and intensified water stress.

The findings, that highlight the northward retreat of deserts and the expansion of semi-arid climates, are in line with global projections of climate zone shifts reported by the IPCC and studies based on Köppen-Geiger. For Mirzachul, these changes represent a geoecological shift with swift socioeconomic consequences together with to a climatological phenomenon. For it to sustain the harvest and ecological stability of this vital region, the study emphasizes the need of adaptive strategies in irrigation, crop selection, and water governance.

Literature Review

Climate classification research originates from Köppen's early 20th century system, later refined by Geiger, which linked vegetation to temperature and precipitation patterns [1]. Despite its simplicity, the Köppen–Geiger framework has remained widely used because of its ecological relevance [2].

Subsequent updates, such as those by Kottek et al. (2006) and Peel et al. (2007), improved global maps using gridded station data, though their coarse resolution limited detail in complex terrains [2, 3]. Beck et al. (2018) overcame this by producing 1 km resolution maps that integrated high-resolution climatologies with CMIP projections, offering greater accuracy and confidence measures [4].

For Central Asia, and Mirzachul in particular, these datasets are crucial. Historically dominated by desert and semi-arid climates (BWk, BWh, BSh), the region has been transformed by large-scale irrigation [9, 11]. Recent studies emphasize updating classifications to better capture salinization and water stress dynamics [10].

Global assessments (IPCC, 2021) project a 2.5–4.5 °C warming in Central Asia by 2100, with desert zones retreating and semi-arid climates expanding [6, 7, 8]. Such findings underline the value of applying high-resolution Köppen–Geiger data to assess Mirzachul's climate past and future.

The Mirzachul region in central Uzbekistan, historically known as the "Hungry Steppe," is one of the largest irrigated agricultural zones in Central Asia. Since the late 19th century, large-scale reclamation and irrigation projects have transformed its natural desert–steppe environment into productive farmland, today supplying wheat, cotton, and other crops vital for regional food security [9, 10, 11, 13].

Climate change, however, threatens this fragile balance. The IPCC (2021) projects that Central Asia will face considerable warming, altered precipitation regimes, and higher evapotranspiration during the 21st century [6]. Such trends are expected to intensify water scarcity, soil salinization, and agricultural stress, particularly in irrigated landscapes like Mirzachul [9, 12].

To analyze such transformations, the Köppen–Geiger classification remains a widely applied framework. It divides climates by long-term temperature and precipitation [1, 2], and has been refined with updated datasets and climate model outputs [3, 5]. High-resolution maps at 1 km scale now allow detailed regional assessments [4], while advances in CMIP5 and CMIP6 scenarios further improve projections [7, 8].

Future scenarios suggest that desert climates (BWh, BWk) in Central Asia may retreat northward, while semi-arid steppe (BSh) and Mediterranean-type (Csa) zones expand [4, 6, 7, 9, 11]. For Mirzachul, such changes imply not only climatic shifts but also far-reaching consequences for irrigation systems, agricultural productivity, and long-term land-use planning.

This study compares the historical baseline (1901–1930) with future projections (2070–2090, SSP2-4.5), using high-resolution Köppen–Geiger datasets processed in ArcGIS Pro. The results aim to trace both past and projected climate distributions in Mirzachul, offering insights into the region's future trajectory and its implications for agriculture, water management, and environmental sustainability.

Research Methodology

The Mirzachul region in central Uzbekistan extends across nearly 17,000 km², bounded by the Syr Darya River in the east and the Turkestan, Nurata, and Molguzar mountain ranges in the south. Historically known as the "Hungry Steppe," it forms a transitional landscape between deserts and semi-arid steppes [9, 11]. Since the 20th century, large-scale irrigation and reclamation projects have converted natural ecosystems into one of Central Asia's most intensively cultivated agricultural zones [10]. Its geographic location and ecological sensitivity make it a suitable case study for climate change impacts on irrigated lands.

Climate conditions were assessed using the Köppen–Geiger classification system [1–3]. Historical data represent the 1901–1930 baseline, while future projections (2070–2090) were obtained from CMIP6 multi-model ensembles under the SSP2-4.5 scenario [6–8]. High-resolution datasets (0.0083°, ~1 km) developed by Beck et al. (2018) [4], which combine observational climatologies (WorldClim, CHELSA, CHPclim) with CMIP6 outputs, were used to ensure spatial accuracy.

All analyses were carried out in ArcGIS Pro 3.x. Raster layers were clipped to the Mirzachul administrative boundaries using official shapefiles. Pixels were reclassified according to standardized Köppen–Geiger codes: BWh (hot desert), BWk (cold desert), BSh (hot semi-arid), and Csa (Mediterranean, dry summer). Zonal statistics were used to calculate pixel counts and convert them to area (km²) and percentages of the total region.

The historical baseline (1901–1930) was compared with future projections (2070–2090). Spatial differences in extent (Δ km² and Δ %) were calculated for each class.

Results were summarized in maps (Figures 1–2) and a comparative table (Table 1), which illustrate the transition from desert dominance in the early 20th century to semi-arid and Mediterranean climates by the end of the 21st century.

This approach follows earlier studies that applied the Köppen–Geiger framework to climate impact analysis [2, 4, 5]. Although uncertainties are inevitable in model ensembles, multi-model CMIP6 outputs provide robust projections [6–8]. The fine resolution of Beck et al.'s dataset offers advantages over earlier global maps [2, 3]. Still, local irrigation practices, microclimatic variability, and human-induced land-use changes-highlighted in regional studies [9, 12]-remain sources of uncertainty.

Analysis and Results

In the early 20th century, the Mirzachul region was dominated by desert climates. The cold desert (BWk) covered 11,642 km² (67.6%), while the hot desert (BWh) accounted for 4,773 km² (27.7%). Semi-arid steppe (BSh) and Mediterranean-type dry-summer climates (Csa) were negligible, occupying only 4.0% and 0.7% of the area, respectively. This climatic structure corresponds to historical accounts of the Golodnaya Steppe as an arid, unproductive zone that demanded significant reclamation before agriculture could be introduced [9, 10, 11]. The dominance of desert climates highlights the extreme aridity and continental conditions typical of Central Asia at that time [1, 3].

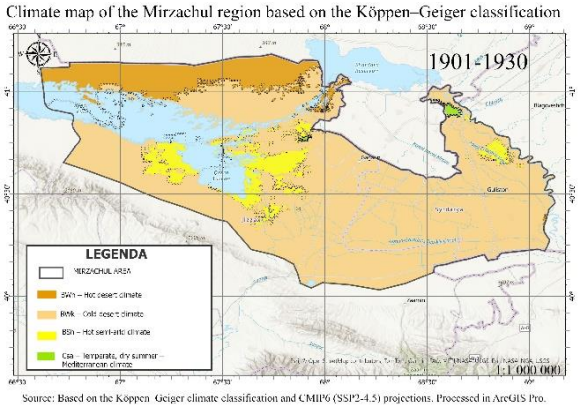

Figure 1. Climate map of the Mirzachul region according to the Köppen–Geiger classification (1901–1930).

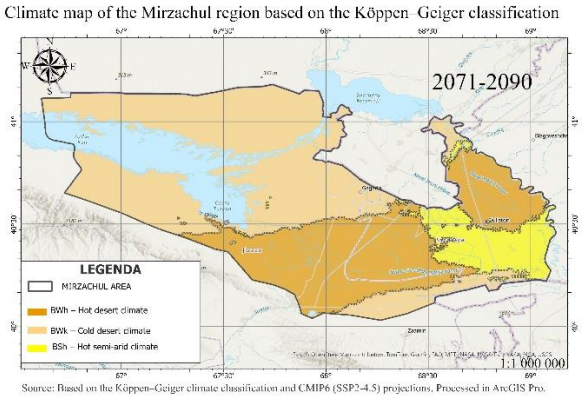

Figure 2. Climate map of the Mirzachul region according to the Köppen–Geiger classification (2070–2090, SSP2-4.5 scenario).

By the late 21st century, models indicate a sharp restructuring of the region's climate. Hot and cold desert zones (BWh, BWk), which once covered more than 95% of the area, are projected to vanish almost completely. Instead, hot semi-arid steppe (BSh) will expand dramatically, occupying 14,104 km² (91.1%), while Mediterranean climates (Csa) will grow to 1,362 km² (8.8%). A minor fraction of cold semi-arid pixels (BSk, <0.1%) may occur, though these likely represent localized model noise [4, 6].

The shift from desert to semi-arid and Mediterranean climates indicates a northward retreat of arid zones, in line with global projections of climate zone migration [2, 5, 7]. This transition carries critical implications: while the decline of hyper-arid deserts may seem beneficial, the dominance of BSh suggests intensified seasonal water stress and higher evapotranspiration, increasing dependence on irrigation. As Arabov & Yangiboyeva (2023) noted, irrigated lands in Mirzachul are already vulnerable to

seasonal water shortages [10]. The emergence of Csa conditions could offer opportunities for crop diversification, but only with careful management of salinity and groundwater [9, 12].

Table 1. Comparative Köppen–Geiger Climate Classification of the Mirzachul Region (1901–1930 vs. 2070–2090).

Code	Class	Description	Area 1901–1930 (km²)	Share 1901–1930 (%)	Area 2070–2090 (km²)	Share 2070–2090 (%)
BWh	Hot desert climate	Extremely arid, hot desert	4,773.22	27.68	—	—
BWk	Cold desert climate	Arid, cold desert	11,642.35	67.58	—	—
BSh	Hot semi-arid (steppe)	Semi-arid, hot steppe	691.48	4.01	14,104.35	91.13
Csa	Temperate, dry summer, hot summer	Mediterranean-type with hot dry summer	119.87	0.70	1,362.13	8.80
Total	—	—	**17,226.0**	**100.0**	**15,476.91**	**100.0**

These results are consistent with international assessments, including the IPCC Sixth Report, which identifies Central Asia as highly exposed to warming and aridity [6]. CMIP5 studies likewise project the expansion of semi-arid zones under moderate-to-high emission scenarios [8]. At the regional scale, Alimqulov (2023) stresses that future geoecological planning for Mirzachul must integrate climate-driven transformations alongside anthropogenic impacts [9]. Overall, the disappearance of deserts and expansion of semi-arid and Mediterranean climates marks not just a climatic transition, but a geoecological reconfiguration of the region's landscape and agriculture.

The findings demonstrate a profound transformation in the climatic structure of the Mirzachul region, where desert climates (BWk, BWh), which dominated over 95% of the area in the early 20th century, are projected to almost completely vanish by the late 21st century. In their place, semi-arid steppe (BSh) and Mediterranean (Csa) climates will expand significantly [2, 4, 6]. These results are consistent with global projections of a northward retreat of desert boundaries and the poleward migration of climate zones under intensified greenhouse gas emissions [5, 7].

From a regional perspective, this transition has critical implications for irrigated agriculture. Although the reduction of hyper-arid deserts might suggest improved conditions, the rapid expansion of semi-arid zones indicates intensified evapotranspiration, greater reliance on irrigation, and heightened risks of soil salinization. Earlier studies, including Rafikov (1976) and Eshniyozov (1986), already documented the challenges of reclamation under desert conditions [11, 12]. In future scenarios, these difficulties may persist in new forms, particularly through seasonal water shortages and increased irrigation demand [9, 10].

The emergence of Mediterranean-type climates (Csa) in southern parts of Mirzachul presents both risks and opportunities. While they may allow for diversified crop

production, hot and dry summers will further stress water resources [4]. Thus, adaptive strategies such as modern irrigation systems, drought-resistant crops, and integrated land–water management are essential. Overall, the study highlights that Mirzachul is not only experiencing a climatic transition but also a broader geoecological shift, with direct consequences for agriculture, water governance, and rural livelihoods across Central Asia.

Conclusion

This study applied the Köppen–Geiger climate classification to analyze the spatio-temporal transformation of climate zones in the Mirzachul region, comparing the historical baseline (1901–1930) with future projections (2070–2090) under the SSP2-4.5 scenario. The results reveal a profound restructuring of the region's climate: desert climates (BWh, BWk), which accounted for more than 95% of the area in the early 20th century, are projected to disappear almost entirely by the end of the 21st century. In their place, hot semi-arid steppe (BSh) becomes the dominant climate, while Mediterranean-type dry-summer (Csa) climates emerge and expand.

These shifts carry significant implications for the geoecological stability of Mirzachul. Although the decline of hyper-arid deserts might appear favorable, the expansion of semi-arid climates indicates increased evapotranspiration, heightened water stress, and greater reliance on irrigation. For a region historically dependent on large-scale reclamation and irrigation systems, such changes pose critical risks to sustainable agriculture, water resource management, and rural livelihoods. The projected emergence of Mediterranean-type climates offers opportunities for crop diversification but also demands adaptive strategies to address hot, dry summers and potential soil salinization.

At a methodological level, the study underscores the importance of using high-resolution Köppen–Geiger datasets and multi-model CMIP6 projections to capture climate variability in fragile transitional landscapes. These tools provide reliable evidence for understanding regional impacts of global climate change, yet limitations remain regarding irrigation feedbacks and localized microclimatic variations.

The climatic trajectory of Mirzachul reflects both regional vulnerability and global climate dynamics. The transition from desert to semi-arid and Mediterranean regimes represents not only a climatological shift but a geoecological transformation with profound socio-economic consequences. Policymakers, water managers, and agricultural planners must incorporate these projections into long-term strategies, prioritizing efficient irrigation technologies, drought-resistant crops, and integrated land–water management to safeguard the future sustainability of this critical agricultural region in Central Asia.

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THE INTERNATIONAL PRACTICES OF LAND RESTORATION AND THEIR ADAPTATION TO THE CONDITIONS OF TASHKENT REGION

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Annotatsiya. Maqolada Germaniya, Polsha, Kanada, AQSH, Xitoy, Qozog‘iston va Mo‘g‘uliston tajribalarida buzilgan yerlarni qayta tiklash amaliyotlari tahlil qilinadi. Turli mamlakatlarda qo‘llanilgan usullar - huquqiy asosga tayangan majburiy rekultivatsiya, bioenergetik o‘simliklarni ekish, o‘rmon rekultivatsiyasi yondashuvi (FRA), torf-mineral substratlar asosida tuproqni tiklash, yirik ekologik dasturlar va biomeliorativ choralarning samaradorligi taqqoslab o‘rganiladi. Shuningdek, FAO va UNEP kabi xalqaro tashkilotlar tomonidan ishlab chiqilgan barqaror yer resurslarini boshqarish konsepsiyalari ham ko‘rib chiqiladi. Tadqiqot natijalari shuni ko‘rsatadiki, Toshkent viloyati sharoitida xorijiy tajribalarni bevosita ko‘chirib qo‘llash emas, balki ularni mahalliy tabiiy va geografik xususiyatlarga moslashtirish zarur. Bunday moslashtirish amalga oshirilgan taqdirdagina ekologik barqarorlikni ta’minlashga xizmat qiladi. Mahalliy bilim va amaliyotlarni integratsiya qilish orqali hududning o‘ziga xos ekologik sharoitlariga mos barqaror rivojlanishni ta’minlash mumkin. Shu asosda muvofiqlashtirilgan model taklif etiladi: huquqiy asosga tayangan boshqaruv, landshaftga mos ekologik tiklash, mahalliy flora va faunadan foydalanish, jamoatchilikning faol ishtiroki hamda monitoring tizimi.

Kalit so‘zlar: *buzilgan yerlar, rekultivatsiya, landshaft yondashuvi, ekologik tiklash, huquqiy asos, bioenergetik o‘simliklar, monitoring, Toshkent viloyati.*

Аннотация. В статье анализируется опыт Германии, Польши, Канады, США, Китая, Казахстана и Монголии по восстановлению деградированных земель. Сравниваются методы, применяемые в различных странах: обязательная рекультивация на основе правовых норм, посадка биоэнергетических растений, лесная рекультивация (FRA), восстановление почвы на основе торфяно-минеральных субстратов, крупные экологические программы и биомелиоративные меры — с точки зрения их эффективности. Также изучаются концепции устойчивого управления земельными ресурсами, разработанные международными организациями, включая ФАО и ЮНЕП. Результаты исследования показывают, что в условиях Ташкентской области не следует напрямую копировать зарубежный опыт, а необходимо адаптировать его к местным природным и географическим особенностям. Такая адаптация имеет решающее значение для того, чтобы реализуемые стратегии были как выполнимыми, так и

эффективными в обеспечении экологической устойчивости. Интеграция местных знаний и практик позволит участникам процесса содействовать устойчивому развитию, соответствующему уникальным экологическим условиям региона. На этой основе предлагается координированная модель, основанная на правовой базе, экологической реставрации, учитывающей ландшафт, использовании местной флоры и фауны, активном участии населения и системе мониторинга.

Ключевые слова: *деградированные земли, рекультивация, ландшафтный подход, экологическая реставрация, правовая база, биоэнергетические растения, мониторинг, Ташкентская область.*

Abstract. The article analyzes the experiences of Germany, Poland, Canada, the USA, China, Kazakhstan, and Mongolia in restoring degraded lands. The methods employed in various countries—mandatory reclamation based on legal foundations, planting bioenergetic plants, the Forest Reclamation Approach (FRA), soil restoration based on peat-mineral substrates, large ecological programs, and biomeliorative measures—are compared from the perspective of effectiveness. The concepts of sustainable land management developed by international organizations, including FAO and UNEP, are also studied. The research findings indicate that it is necessary not to directly replicate foreign experiences in the conditions of the Tashkent region but to adapt them to local natural and geographical characteristics. This adaptation is critical to making sure that the strategies implemented are both feasible and effective in promoting ecological resilience. By integrating local knowledge and practices, stakeholders can foster sustainable development that aligns with the unique environmental conditions of the area. Based on this, a coordinated model is recommended, which is based on a legal framework, ecological restoration tailored to the landscape, the use of local flora and fauna, active community participation, and a monitoring system.

Keywords: *degraded lands, reclamation, landscape approach, ecological restoration, legal framework, bioenergetic plants, monitoring, Tashkent region.*

Introduction

One of the most essential natural resources is land, which is essential for both ecological sustainability and economic development. Due to the development of mining, construction, industrial activities, and other types of economic operations, large areas have lost their natural appearance and have become degraded lands. These regions seriously impair their ability to deliver ecosystem services in addition to upsetting ecological balance. Ecological stability, food security, and economic advancement-all essential to human society-are directly impacted by such degradation. The landscape approach is one of the most successful land reclamation techniques, according to international scientific and real-world experience. By combining ecological, social, and economic elements, this strategy helps to restore areas [1-3]. Thus, contemporary reclamation ideas seek to enhance local communities' quality of life, boost regional economies, and promote sustainable development in addition to restoring natural landscapes. International agencies like the FAO, UNEP, and IUCN,

along with developed nations like the USA, Canada, China, Germany, and Poland, have carried out extensive land reclamation projects in recent decades. As a result of these initiatives, national strategies that give priority to sustainable landscape management principles have been developed [2, 3]. It should be noted that the topic of restoring degraded lands has received a lot of attention on a global scale, and different nations have developed and enhanced reclamation plans [4]. Practice, however, demonstrates that current methods vary widely and frequently fall short of meeting the demands of lower-level productivity standards or natural-geographical system hierarchies [5, 6]. Furthermore, methodological flaws persist even in nations with national laws, and there are currently no unified international regulatory documents [7]. Because of this, restoring degraded lands is now considered both an ecological necessity and a critical global task for maintaining social and economic stability. This article's objective is to examine cutting-edge international reclamation methods, pinpoint their positive features, and formulate scientific suggestions for adapting them to the Tashkent region's circumstances. By looking at these methods, we hope to draw attention to effective tactics that can be modified for regional settings and eventually support sustainable land management. The socioeconomic advantages of land restoration will also be examined in this study, with a focus on how it promotes environmental stewardship and community resilience. The study will also evaluate possible obstacles and difficulties in putting these practices into practice in the Tashkent region, providing stakeholders a thorough framework. We intend to establish a collaborative approach that guarantees the long-term sustainability and success of reclamation initiatives by including local communities and legislators.

Research Methodology

Germany is a prominent leader in Europe in the restoration of degraded land. The nation has established a thorough and methodical strategy for the restoration of disturbed lands, primarily due to mining and industrial operations. This procedure is governed by the Federal Soil Protection Act (Bundes-Bodenschutzgesetz). Unger asserts that each degraded site must possess a compulsory customized restoration strategy [8]. In contemporary methodologies, the notion of harmonizing ecological, social, and economic objectives in landscape restoration is critically significant. This holistic strategy guarantees sustainable recovery and establishes equilibrium among natural ecosystems, local populations, and commercial interests. Nonetheless, in certain instances, the degree of social engagement and productive cooperation with stakeholders in attaining final results is not adequately emphasized [9, 10]. The methodology employed in the German experience comprises several primary stages:

1. Definition and classification of landscape-recognizing the inherent geographical and ecological attributes of a region.

2. Evaluation of landscape degradation-assessing the magnitude of soil degradation, deterioration of plant cover, and impairment of hydrological systems.

3. Measures for the conservation and restoration of local biodiversity encompass the rehabilitation of indigenous flora and wildlife.

4. Modification-reconfiguring land for agricultural, recreational, or other sustainable applications.

This experience is also applicable to the conditions of the Tashkent region.

Analysis and Results

The efficacy of reclamation is improved by taking into account the climatic characteristics of the region, employing techniques to stabilize vegetation in mining zones, and integrating forestry with agriculture. The approach aids in restoring ecological equilibrium while also generating new economic prospects for the local populace.

Approaches to the reclamation of post-mining lands in the Polish experience are considered advanced on a European scale. The main strategy for preparing open-pit areas, coal dumps, and sand quarries for reuse in the country is afforestation, taking into account indicators such as energy balance, carbon sequestration, and landscape energy efficiency. Studies indicate that reclaimed forests have a higher carbon sequestration capacity and energy efficiency compared to forests formed through natural succession [11]. During the reclamation process, the choice of tree species is made according to the characteristics of mining waste: pioneer species, particularly Pinus sylvestris with a wide ecological amplitude and the ability to adapt to poor soil, are planted on brown coal, hard coal, sand, and sulfur dumps depending on the soil's physicochemical conditions, and then enrichment with mixed deciduous species is recommended [11]. Reclamation plans for open-pit coal mines cover all stages, from land acquisition to the handover of the area after mine closure for reuse, and are documented with specific management methods [12]. Studies summarizing the experience of Central and Eastern Europe propose an optimized model for the "substrate × plant species × management" triad [13]. Additionally, research conducted on bioenergy crops, particularly Salix viminalis (plants of this species produce biomass that is subsequently used as raw material for biofuel production (biogas, bioethanol, pellets, etc.)), shows that assessing soil moisture, its physicochemical properties, and biofuel quality indicators allows for the effective use of this species on degraded or low-productivity lands [14]. Research conducted over the past decade has examined the efficiency and stoichiometry of nutrient uptake by various plant functional groups on mine spoils and found that herbaceous plants exhibit higher nutrient uptake rates compared to cereal crops under all conditions, thereby accelerating nutrient cycling in restored landscapes [15]. These experiments can also be applied in the conditions of the Tashkent region, but it is necessary to take into account the continental climate, hot and dry summers, soil salinity, and limited water supply. Therefore, restoration work should begin with classifying the substrate according to its geological and lithological origin and a clear definition of the goal. Restoring the soil layer according to agrotechnical requirements, selecting native plant species, limiting invasive species (these are plant species that have entered a specific territory from outside (non-native species), reproduce rapidly, displace native ecosystems, harm biodiversity, and disrupt the natural balance), and implementing monitoring systems can yield effective results.

In Canada's experience, open-pit oil sands areas in the province of Alberta are characterized by the disturbance of coniferous (boreal) forests and wetland (peatland) ecosystems and are recognized by the country as having accumulated leading expertise in restoration in North America. Studies indicate that restored soil profiles in post-

mining landscapes, especially with the addition of peat-mineral layers, can recover their basic functions within 15 years [16]. This recovery was determined based on indicators such as the restoration of vegetation biomass, the formation of an organic layer, nutrient cycling, and the decomposition rate of plant residues (litter) accumulated on the soil surface. However, other studies show that in peatland areas, open-pit oil extraction leads to the destruction of a significant portion of them, resulting in a sharp reduction in carbon stocks, and millions of tons of carbon are released into the atmosphere annually [17]. Three main components identify the rehabilitation process in Canada. Firstly, the primary focus is soil restoration, where the use of peat-mineral mixtures contributes to the restoration of the soil's main ecological and economic functions [16]. Secondly, although the approach aims to restore carbon stocks, it has been found that it is impossible to fully restore the carbon balance of the original peatland complex [17]. The third component consists of monitoring criteria by which the success of restoration is assessed through regular observation of nutrient cycling, vegetation structure, and soil processes.

When applying these experiments in the Tashkent region, it is recommended not to completely copy the Canadian model but rather to adapt its main principles. It is advisable to use a combination of organic components (e.g., compost, biochar) and mineral materials (clay-sand mixtures) when creating restorative soil layers. In this process, soil evaporation-transpiration (ET) rates and moisture reserves should be assessed separately under regional conditions. When selecting plant species, it is recommended to introduce combinations of native pioneer species that are drought and salt-tolerant (plants that are the first to appear in disturbed areas) instead of coniferous forest plants. Additionally, it is advisable to develop a separate restoration strategy for each type of degraded land by typifying them.

The results obtained based on advanced approaches to the reclamation of disturbed lands, particularly areas where mining was conducted, in the US experience are as follows:The Forest Restoration Approach (FRA) is a practical method that involves forming soil from high-quality base layers, using low-density mineral admixtures and organic layers, and employing a tree planting strategy that is appropriate for the landscape features. This approach is effective not only from an environmental perspective but also from economic and social standpoints and plays an important role in restoring the services of natural geographical complexes [18]. Long-term observations further confirm the effectiveness of this method:After more than 10 years of recovery in the Appalachian region, plant communities have returned to a level similar to the original forest ecosystems [19]. The chronosequence method was used as a technique for precise measurement of soil quality and properties, which revealed a significant improvement in soil components (silt, clay, organic carbon) over time in restored forest areas [20].

These results demonstrate the effectiveness of the landscape approach. Engaging the local population in the recovery process, their participation in environmental services and green economy projects will be effective for the Tashkent region. Degraded land in China is one of the most pressing environmental problems caused by the impact of industry and urbanization. To address this issue, the government is implementing strategic programs such as the "Land Reclamation Action Plan." These

programs aim to convert former mining areas into agroforestry, create anti-erosion shelterbelts, and build artificial reservoirs [20, 21].

According to research findings, large-scale ecological projects implemented on the Loess Plateau in recent decades, including the "Grain for Green" program, have significantly reduced soil erosion, increased biodiversity, and helped restore the hydrological balance [22]. This approach could also be effective in the Tashkent region. Specifically, it is recommended to create anti-erosion shelterbelts in foothill and plain areas, plant drought-resistant native tree and shrub species, and organize small artificial reservoirs to conserve water resources. Research conducted in Kazakhstan and Mongolia shows that effective scientific and practical solutions for the reclamation of land disturbed by mining have been developed, yielding positive results in the restoration of the region's landscapes. Studies conducted on the example of the Kokzhonsk phosphorite deposit in the semi-desert zone of Kazakhstan have scientifically substantiated the effectiveness of a bio-reclamation approach. The study involved restoration efforts across an area of 6,400 hectares through the planting of urea-enriched soil and native plant species, particularly the narrow-leaved oleaster (Elaeagnus angustifolia) and black saxaul (Haloxylon aphyllum). Consequently, yields climbed from 2200 kg/ha to 3300 kg/ha, the humus content of the soil increased from 0.18% to 1.14%, and the grass cover increased from 60% to 80%. However, long-term monitoring revealed that grass output dropped by 28.4% and humus content dropped by 47.6%, highlighting the necessity of ongoing land reclamation and agricultural practices during the restoration phase [23].

Table 1.

Country / Researcher	Main approach	Advantages	Relevant aspects for Tashkent region
Germany (Hüttl and Gerwin, 2005)	Mandatory reclamation based on federal law, landscape approach	Strong legal framework, long-term monitoring system	Integration into legislation, creation of monitoring and control system
Poland (Krzaklewski and Pietrzykowski, 2002)	Technical and biological restoration	Plantations of bioenergetic plants, soil fertility restoration	Planting bioenergetic plants, development of bioenergy opportunities
USA (Adams, 2017; Holl, 2002; Sena et al., 2021)	Forestry Reclamation Approach (FRA), long-term monitoring	Soil restoration with high-quality substrates, revegetation with local flora	Rehabilitation of mined or degraded lands through agroforestry combinations, establishment of a monitoring system
Canada (Rooney et al., 2012)	Ecoregion approach	Adaptation based on landscape classification	Development of individual strategies for each land type
China (Zhao et al., 2013; Sun et al., 2013)	Agroforestry integration	Anti-erosion forests, plant species adapted to desert conditions	Planting resilient vegetation against wind erosion
Kazakhstan (Konysbayeva et al., 2025)	Restoration of steppe vegetation, soil, and biogeographic landscapes	Restoration of pasture types, increase of local grass resources	Reduction of pasture degradation, reintroduction of local forage plants

Mongolia (Yuan et al., 2022)	Ecological restoration of mining areas	Plant species adapted to local conditions, climate-appropriate agrotechnics	Adaptation of restoration strategies to arid climate regions
FAO (FAO, 2015)	Sustainable land management	Mapping of landscape units, involvement of local communities, long-term monitoring	Implementation of landscape-adapted mapping and monitoring system for Tashkent region
UNEP *(UNEP, 2018)*	LDN concept	Integrated approach	Harmonization with international standards

However, in Mongolia, landscape monitoring and the problem of land restoration are strongly related.According to the findings of a methodical study of land cover changes in Kazakhstan and Mongolia using remote sensing technologies, pastures cover up to 91.5% of Mongolia, especially Dornod aimag, and the primary changes seen are associated with the conversion of pastures into agricultural land.The relationship between land use changes and restoration policies is evident in this case [24].

Numerous beneficial outcomes could arise from the implementation of these studies in the Tashkent area. In disturbed areas, it is advised to choose plant species that are suited to the local climate and soil conditions, enrich the soil with urea, and routinely check yields and humus content based on Kazakhstan's experience. Mongolia's experience is important for the Tashkent region in identifying land use changes based on remote sensing and developing strategies for sustainable management of pastures and agricultural lands. Specifically, it becomes possible to optimize agricultural policy and effectively plan the processes of protecting and restoring erosion-prone areas based on the results of digital monitoring.

Experience of International Organizations. The concept of "Sustainable Land Management," developed by the Food and Agriculture Organization of the United Nations (FAO), defines the methodological basis for applying a landscape approach in the process of degraded land restoration [2]. The following main recommendations were put forward in this concept: The first step involves mapping landscape units and evaluating the extent of their degradation. Secondly, engaging the local population in the restoration process and using native plant and animal species. Thirdly, we also conduct long-term monitoring of the restored lands. This approach includes a set of measures aimed at improving the ecological condition of disturbed lands, as well as raising the standard of living of the local population. Under the UN Environment Programmer's Land Degradation Neutrality program, countries have committed to ending and restoring land degradation by 2030 [3].

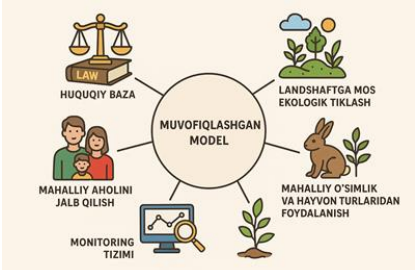

Figure 1. Sustainable land management.

The investigation revealed that each country had distinct lessons and methodologies: Germany enforces stringent regulations (Bundes-Bodenschutzgesetz) mandating site-specific reclamation and long-term environmental monitoring to ensure stability. Poland: The cultivation of trees and bioenergetic plantings contributes to the restoration of soil fertility and the sequestration of carbon. The Forestry Reclamation Approach (FRA) in the United States integrates soil rebuilding with continuous monitoring to restore vegetation and ecosystem services. In Canada, peat-mineral substrates facilitate soil recovery; yet, complete restoration of the carbon balance in peatlands remains unattainable. The Grain for Green program in China has mitigated erosion, enhanced biodiversity, and restored water flow equilibrium on the Loess Plateau. Kazakhstan: Biomeliorative interventions, including fertilization and the use of indigenous species, significantly enhanced rangeland productivity. In Mongolia, remote sensing technologies facilitated the monitoring of land use changes and supported the planning of restoration initiatives. The FAO and UNEP established worldwide frameworks that promote land use mapping, environmentally beneficial land restoration, and public engagement.

Conclusion

The study indicates that the success of land reclamation depends on systematic approaches that combine ecological, legal, and social dimensions. Germany and Poland highlight institutional strength and ecological restoration, Canada and the USA emphasize soil quality and monitoring, China focuses on erosion control and biodiversity, while Kazakhstan and Mongolia offer insights into biomeliorative and remote-sensing approaches. For the Tashkent region, the most effective strategy is an integrated model that includes:

- The strategy includes a robust legal and institutional framework.
- The strategy also involves landscape-based ecological restoration.
- We employ native species that are resistant to drought and salinity.
- The restoration process involves the active participation of the community.
- Continuous monitoring supported by remote sensing.

Such a model would enhance ecological resilience, improve soil productivity, and ensure sustainable socio-economic development in Uzbekistan.

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THEORETICAL AND METHODOLOGICAL FOUNDATIONS FOR THE FORMATION OF MESO-LEVEL HOUSING INFRASTRUCTURE

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Annotatsiya. Maqolada hududlarni kompleks rivojlantirish tizimining asosiy bo‘g‘ini sifatida mezodarajali uy-joy infratuzilmasini shakllantirishning nazariy va metodologik asoslari ko‘rib chiqiladi. Uy-joy infratuzilmasining demografik, fazoviy va iqtisodiy omillarni integratsiyalash orqali mintaqalarning barqaror o‘sishidagi o‘rni asoslab beriladi. Ko‘rsatilishicha, uy-joy sektori aholi joylashuvi fazoviy tuzilmasini belgilaydi, migratsion jarayonlarga ta’sir ko‘rsatadi hamda aholining hayot sifati shakllanishiga xizmat qiladi. 2024–2025-yillar statistikasi asosida O‘zbekistonning mezodarajadagi uy-joy fondining hududiy tafovutlari tahlil qilingan. Kompleks rejalashtirishning metodologik asoslari yoritilib, mintaqalarda uy-joy infratuzilmasini optimallashtirish bo‘yicha tavsiyalar berilgan.

Kalit so‘zlar: *uy-joy infratuzilmasi, mezodaraja, hududni kompleks rivojlantirish, urbanizatsiya, demografiya, mintaqaviy rejalashtirish, barqaror rivojlanish.*

Аннотация. В статье рассматриваются теоретические и методологические предпосылки формирования жилищной инфраструктуры мезоуровня как ключевого звена системы комплексного развития территорий. Обосновывается роль жилищной инфраструктуры в интеграции демографических, пространственных и экономических факторов устойчивого роста регионов. Показано, что жилищный сектор определяет пространственную структуру расселения, влияет на миграционные процессы и формирует качество жизни населения. На основе статистики 2024–2025 гг. проведён сравнительный анализ территориальных различий жилищного фонда Узбекистана по мезоуровню. Раскрыты методологические основы комплексного планирования и даны рекомендации по оптимизации жилищной инфраструктуры в регионах.

Ключевые слова: *жилищная инфраструктура, мезоуровень, комплексное развитие территории, урбанизация, демография, региональное планирование, устойчивое развитие.*

Abstract. The article examines the theoretical and methodological foundations for the formation of meso-level housing infrastructure as a key component of the system of integrated territorial development. The role of housing infrastructure in integrating demographic, spatial, and economic factors of regional sustainable growth is substantiated. It is shown that the housing sector determines the spatial

structure of settlement, influences migration processes, and shapes the quality of life of the population. Based on 2024–2025 statistical data, a comparative analysis of territorial differences in Uzbekistan's housing stock at the meso level is conducted. The methodological principles of integrated planning are outlined, and recommendations are proposed for optimizing housing infrastructure in the regions.

Keywords: *housing infrastructure, meso level, integrated territorial development, urbanization, demography, regional planning, sustainable development.*

Introduction

Modern processes of urbanization, spatial growth, and city transformation in Uzbekistan make the issue of integrated territorial development a central element of national regional policy. The formation of modern housing infrastructure has become not only an economic but also a socio-demographic challenge [1, 2]. Housing determines where labor resources are concentrated, how the migration balance is formed, and what infrastructural needs arise for the population. It also defines directions for spatial development, the level of comfort and quality of life, and lays the foundation for creating sustainable meso-level urban structures.

The meso-level, represented by regions and their agglomerations, acts as a connecting link between the macro-level-national spatial development strategy-and the micro-level, where specific urban projects are implemented and local settlement models are formed. The development of housing infrastructure at the meso-level ensures the coordination of demographic, economic, and engineering processes, contributing to the creation of a sustainable, balanced, and functionally integrated territorial system [3-6].

The residential neighborhood, as the basic element of the planning structure of settlements, serves as an important structural link within the urban planning system. It is at the neighborhood level that project decisions are concretized, ensuring the implementation of strategic meso-level guidelines in both space and time.

Therefore, housing infrastructure development should be considered not only within the framework of regional strategy but also at the neighborhood level-as spatial-functional units where real living conditions are formed, social connections develop, and human interaction with the urban environment occurs. This approach allows for more precise prioritization, adaptation of planning solutions to territorial characteristics, and the achievement of concrete results in providing the population with comfortable, energy-efficient, and safe housing [7, 8].

Research Methodology

The research methodology is based on systemic, structural-functional, and spatial-analytical approaches. Housing infrastructure is considered as an element of the spatial-economic system of a region, where three key components interact: demographic potential, infrastructure provision, and institutional planning mechanisms. Methods of comparative statistics, territorial analysis, and mathematical modeling of forecasted housing indicators were employed for the analysis.

This approach integrates tools from economic analysis, urban studies, regional planning, and demographic forecasting. Within this framework, housing infrastructure is interpreted as an element that integrates spatial and demographic processes. It shapes settlement patterns, influences employment structure, social mobility, and the quality of the urban environment.

The final stage of the methodology involves modeling and forecasting. The application of demographic and economic-mathematical models allows for the determination of optimal housing construction rates, the identification of infrastructural gaps, and the assessment of the long-term sustainability of territorial growth. These models provide a foundation for decision-making in meso-level planning. Special attention is given to defining criteria for the effectiveness of meso-level housing infrastructure and its impact on the structure of the regional economy.

Analysis and Results

Theoretical Foundations for the Formation of Housing Infrastructure. The theoretical basis for the formation of meso-level housing infrastructure relies on the concept of territorial hierarchy: macro-, meso-, and micro-levels. The meso-level serves as the coordination space between national strategies and municipal plans. It is at this level that key mechanisms of spatial development are formed, ensuring the interconnection of housing, transport, engineering, and social infrastructure. Housing infrastructure, in turn, directs urbanization processes, forms the settlement framework, and influences the demographic structure of the population [5, 7].

As a system-forming element, housing infrastructure comprises a combination of material, engineering, and social components that ensure the sustainable functioning of a territory. It is not merely a construction sector but forms the foundation for the organization of the urban environment, reflecting the balance between economic potential, engineering capacity, and the social structure of the population.

Housing infrastructure has a significant impact on the regional economy. It exhibits a pronounced multiplier effect-each unit of investment in housing construction and modernization stimulates employment in related sectors such as transportation, energy, building materials production, and services. In 2024, the combined contribution of the housing and construction sector to Uzbekistan's GDP amounted to 6.8%, while a 2.4% increase in the housing stock generated growth in domestic demand.

Urbanization plays a key role in spatial transformation. By 2025, the urbanization rate reached 52.7%, indicating continued growth in the urban population. The main centers of concentration are the Tashkent, Samarkand, and Fergana agglomerations [3]. In these regions, pressure on engineering and social infrastructure is increasing. Housing infrastructure, in turn, becomes an instrument for population redistribution and the creation of new urban centers of attraction.

Comprehensive Territorial Development (CTD) implies the synchronization of housing construction, transport networks, and social and engineering infrastructure. This approach creates an integrated system of spatial development, where housing becomes the core for the integration of all functional components. The implementation of CTD principles ensures the rational use of resources and the creation of sustainable urban agglomerations.

The analysis of meso-level housing infrastructure is based on statistical data from the State Committee of the Republic of Uzbekistan for 2024–2025. Key indicators considered include population size, urbanization rate, housing stock volume, and the share of the private sector.

As of April 1, 2025, the permanent population of the country was 37.5 million, with 19.1 million residing in urban areas. The average household size is five people. The total housing stock amounted to 703.8 million m², providing 18.9 m² per person, exceeding the normative standard of 16.0 m² per person [3].

The table below demonstrates that regions exhibit varying intensities of housing development. For example, in Tashkent, the per capita housing area is almost twice that of the southern regions. Cities with high urbanization show an increase in vertical development, whereas peripheral areas are dominated by private housing. This reflects the heterogeneity of meso-level structures and underscores the need for balanced housing policies [3].

Table 1. Analytical Indicators of Regional Housing Infrastructure in Uzbekistan (2025).

№	Region	Population (thousands)	Urbanization (%)	Housing Stock (million m²)	Estimated Number of Housing Units	Private Sector Share (%)
1	Republic of Karakalpakstan	2,100	44	47,2	466,7	73
2	Andijan Region	3,550	60	74,0	788,9	62
3	Bukhara Region	2,050	49	43,1	455,6	71
4	Jizzakh Region	1,530	48	36,5	340,0	71
5	Kashkadarya Region	3,150	45	55,7	700,0	74
6	Navoiy Region	1,100	51	28,3	244,4	69
7	Namangan Region	3,200	57	66,2	711,1	65
8	Samarkand Region	3,870	54	77,8	860,0	67
9	Syrdarya Region	910	46	22,4	202,2	70
10	Surkhandarya Region	2,650	42	49,3	588,9	77
11	Tashkent Region	3,100	63	58,2	688,9	54
12	Fergana Region	4,200	58	82,4	933,3	63
13	City of Tashkent	2,850	100	69,5	633,3	42
14	Khorezm Region	2,000	47	41,0	444,4	75

The average level of urbanization in Uzbekistan is 53%, while the share of the private housing sector across the country averages 68%. This indicates a transition toward a mixed housing model, in which private sector development and multi-story construction proceed in parallel [2].

In cities with populations exceeding one million (Tashkent, Samarkand, Fergana), high housing density stimulates the development of vertical infrastructure, including underground parking, utility networks, and public spaces.

Problems in the meso-level formation of housing infrastructure. Research and analytical observations have revealed a number of systemic problems that hinder the effective formation and development of housing infrastructure at the meso-level. These issues are interrelated and collectively determine the sustainability of territorial growth [4, 6, 9]:

Imbalance between urbanization and infrastructure growth. The pace of urban population growth significantly outstrips the development of engineering, transport, and utility systems. This leads to the overloading of existing networks, deficits in energy and water capacities, and a decline in the quality of housing and communal services. As a result, there is a disproportion between population density and infrastructure provision, especially in major cities and urban agglomerations;

Uneven spatial development. A growing gap in infrastructure provision exists between major agglomerations and peripheral areas, which provokes migration outflows from small and medium-sized cities. This process increases population concentration in the capital and regional centers, placing additional pressure on social and engineering systems and raising the level of spatial differentiation;

Increased building density and land scarcity. Due to limited land, particularly in the Tashkent and Samarkand agglomerations, intensified use of urban land becomes necessary. This requires the development of vertical construction and comprehensive reconstruction of settlements. However, excessive densification can lead to a deterioration of the ecological quality of the urban environment and reduce residential comfort;

Aging housing stock. About one-third of existing residential buildings require major repairs or reconstruction. The wear and tear of utility networks and the low level of energy efficiency significantly limit the potential for territorial development. Modernization of the housing stock should be a priority in meso-level development policies, as it directly affects social stability and quality of life;

Lack of integration between planning and demographic forecasts. Insufficient coordination between demographic forecasting and urban planning processes results in an unbalanced population distribution, overload of social infrastructure, and inefficient use of land resources. The absence of a unified analytical framework reduces forecast accuracy and the quality of managerial decisions.

These problems underscore the need for further scientific research in spatial modeling, forecasting housing needs, and developing optimization tools to ensure comprehensive development of meso-level territories. Only a systemic approach can shift from reactive mitigation to strategic management of housing infrastructure development.

Conclusion

Meso-level housing infrastructure represents not only the physical basis of settlement but also a key element of strategic management of spatial development. Its condition and dynamics have a direct impact on regional economic activity, the quality of life of the population, and the sustainability of urbanization processes. Modernization and balanced development of housing infrastructure should be

considered a necessary condition for sustainable territorial growth and the formation of an effective regional settlement structure.

The main conclusions of the study are as follows:

– housing infrastructure is a system-forming element of comprehensive meso-level territorial development, linking demographic, economic, and planning processes into a unified spatial management model;

– pronounced spatial inequality is observed, which requires adjustment of state regulatory instruments and strengthening of planning coordination between urbanized centers and peripheral areas;

– integration of predictive models (demographic, economic-mathematical, and spatial) forms the basis for scientifically grounded design of housing programs and planning solutions;

– the development of digital platforms and geographic information systems (GIS) opens new opportunities for operational monitoring of housing infrastructure and enhances the efficiency of managerial decision-making;

– a comprehensive approach to territorial development allows for minimizing interregional disparities, ensuring synchronization of infrastructure investments, and improving the quality of the urban environment.

Recommendations and directions for Improving Meso-Level Housing Infrastructure Policy:

- implement a housing needs forecasting system using demographic and socio-economic models that take into account migration flows, age structure, and natural population growth. This will allow for long-term planning of housing construction volumes and help avoid territorial imbalances;
- implement comprehensive housing stock modernization programs, giving priority to energy-efficient technologies, renovation of outdated districts, and improving the comfort of the urban environment;
- synchronize housing construction with the development of transport, engineering, and social infrastructure, ensuring that each new project aligns with the principles of comprehensive territorial development (CTD);
- introduce territorial investment balancing mechanisms aimed at redistributing resources between developed and peripheral regions, ensuring even development and enhancing regional connectivity;
- create a unified information-analytical system for meso-level spatial monitoring, including indicators of housing availability, building density, energy efficiency, and demographic dynamics;
- intensify scientific research and design initiatives focused on the application of economic-mathematical models, digital modeling, and systems analysis in the management of housing infrastructure;
- develop and implement regulatory and methodological documents that govern the interrelation between housing policy, urban planning, and regional development.

Meso-level housing infrastructure is a key element of the spatial development system. It determines the direction of urbanization processes, shapes sustainable socio-economic connections, and supports the implementation of comprehensive territorial development strategies. For Uzbekistan, a priority is the synchronization of housing

construction with the development of transport, engineering, and social infrastructure, as well as the implementation of mathematical models for forecasting housing needs. Developing meso-level territorial management systems will allow for a more balanced population distribution and improve the quality of life at the regional level.

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INTERNATIONAL EXPERIENCE AND NATIONAL TASKS IN THE DEVELOPMENT OF SCIENTIFIC PLANNING OF HOUSING INFRASTRUCTURE

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Annotatsiya. Maqolada urbanizatsiya sharoitida uy-joy infratuzilmasini ilmiy rejalashtirish bo‘yicha xalqaro tajriba tahlil qilinadi. Germaniya, Fransiya, AQSh va Yaponiya ilmiy modellari tahlil qilinib, ular demografik prognozlash, raqamli texnologiyalar va barqaror rivojlanish tamoyillarini integratsiya qilishga asoslangan. Xorijiy tajribalarining ijobiy tomonlari (innovatsiyalar, energiya tejamkorligi, fuqarolik ishtiroki) hamda cheklovlari (yuqori xarajatlar, ijtimoiy qarama-qarshiliklar, texnologiyalarga bog‘liqlik) ko‘rib chiqilgan. Shuningdek, O‘zbekistonda uy-joy infratuzilmasini ilmiy rejalashtirishni rivojlantirish bo‘yicha vazifalar belgilangan.

Kalit so‘zlar: *uy-joy infratuzilmasi, urbanizatsiya, raqamli modellashtirish, demografik prognozlash, barqaror rivojlanish, xorijiy tajriba, strukturaviy tavsif.*

Аннотация. В статье рассматривается зарубежный опыт научного планирования жилищной инфраструктуры в условиях урбанизации. Проанализированы научные модели Германии, Франции, США и Японии, которые основаны на интеграции демографического прогнозирования, цифровых технологий и принципов устойчивого развития. Рассмотрены как положительные аспекты зарубежных практик (инновации, энергоэффективность, гражданское участие), так и ограничения (высокие затраты, социальные противоречия, зависимость от технологий). Сформулированы задачи в развитии научного планирования жилищной инфраструктуры в Узбекистане

Ключевые слова: *жилищная инфраструктура, урбанизация, цифровое моделирование, демографическое прогнозирование, устойчивое развитие, зарубежный опыт, структурное описание.*

Abstract. The article examines international experience in scientific planning of housing infrastructure under urbanization conditions. Scientific models from Germany, France, the USA, and Japan are analyzed, which are based on the integration of demographic forecasting, digital technologies, and sustainable development principles. Both the positive aspects of foreign practices (innovation, energy efficiency, civic participation) and their limitations (high costs, social conflicts, technological dependency) are considered. The article also formulates tasks for the development of scientific planning of housing infrastructure in Uzbekistan.

Keywords: *housing infrastructure, urbanization, digital modeling, demographic forecasting, sustainable development, international experience, structural description.*

Introduction

Accelerating urbanization processes worldwide necessitate the development of innovative scientific approaches to the design of residential neighborhoods. In developed countries, a neighborhood is perceived not merely as a basic unit of residential construction, but as a complex socio-spatial system that integrates digital infrastructure, environmental sustainability, and civic engagement. For Uzbekistan, analyzing international experience is strategically significant, as it enables the identification and adaptation of optimal housing infrastructure models [1, 2].

Planning housing infrastructure in conditions of intensive urbanization requires a comprehensive integration of scientific approaches, combining demographic analysis, mathematical modeling, and population needs forecasting. International practice demonstrates a high level of evidence-based decision-making in residential planning, offering valuable insights for countries with rapidly developing urban agglomerations, including Uzbekistan.

Developed nations have accumulated considerable experience in scientific and digital planning of residential areas, granting neighborhoods (Stadtquartier, Quartier,

Neighborhood) the status of key units for sustainable and manageable urban growth. Among the most advanced frameworks are the German engineering-system model, the French socio-humanitarian approach, and the American digitally-oriented methodology. Each model presents a unique architecture for scientific and regulatory implementation, reflecting national priorities and urban development strategies.

In several European countries, the scientific approach to neighborhood design demonstrates a high level of integration across engineering, demographic, environmental, and digital domains. Notably, Germany and France exemplify neighborhoods (Stadt quartier / Quartier) as multifunctional, sustainable, and socially active structures, designed not only as residential units but as catalysts for future-oriented urban growth [3].

Leading universities and research centers globally actively investigate housing infrastructure development. Key institutions include the Massachusetts Institute of Technology (USA), Cambridge University (UK), Technical University of Munich (Germany), National University of Singapore, Peking University (China), as well as European Union research bodies dedicated to developing models of sustainable urban development.

The United Nations has made a substantial contribution through initiatives such as UN-Habitat's Global Housing Strategy and Housing2030, offering guidance for improving housing standards and formulating national strategies in the context of urbanization. The European Union's Affordable Housing Initiative and the New European Bauhaus program focus on renovation and new construction aligned with demographic dynamics. Germany enforces the federal Building Energy Act (Gebäudeenergiegesetz) as a regulatory standard for new housing, whereas the UK applies the National Planning Policy Framework to define infrastructure development requirements and sustainable residential placement principles.

Significant research efforts are also underway in CIS countries, including the Russian Academy of Architecture and Construction Sciences, National Research University "Higher School of Economics" (Russia), Al-Farabi National University (Kazakhstan), the National University of Uzbekistan named after Mirzo Ulugbek, and the Tashkent Architectural and Construction Institute. These centers develop contemporary methodological approaches for forecasting housing infrastructure, incorporating demographic and urbanization factors, and devising management tools for residential development.

Key contributions in this domain include theories of urban development, concepts of balanced population settlement and urban environment optimization, methods for analyzing and forecasting housing infrastructure, approaches to sustainable urban development and housing system modeling (MIT, USA; Technical University of Munich, Germany), spatial planning research (Cambridge University, UK), and demographic forecasting with emphasis on migration impacts on housing construction (Peking University, China). In Japan, Toyo University has substantiated practical strategies for improving housing infrastructure under intensive urbanization. Collectively, these studies provide a robust methodological foundation for integrated territorial development, accounting for urbanization trends, demographic dynamics, and socio-economic processes. Such a foundation is essential for informing evidence-

based planning and strategic interventions in Uzbekistan's housing infrastructure development.

Literature Review

Contemporary research in urban planning emphasizes the need to integrate demographic forecasting, digital technologies, and socio-economic factors. Alessandro Coppola (Italy) proposes three alternative approaches to urban development: the creation of a land bank aimed at collecting unused land for repurposing; the development of an environmental program through the mobilization of residents and local communities; and investments by local charitable organizations [4]. Nikitenko S.N. (Russia) analyzes the main principles of urban renovation in several foreign countries, reviewing historical experiences and approaches to updating urban development [5]. Karina M. Pallagst and René Fleschurz (Germany), along with Tetsuji Uemura (Japan), conducted a comparative study to examine changes in planning culture in shrinking cities in the USA, Germany, and Japan. Their results highlight the interdependence between changes in planning culture and social transformations, potentially informing the future reconfiguration of urban spaces [6].

The literature review indicates that without meaningful public participation, urban planning projects may fail to meet the specific needs of residents.

Research Methodology

The methodological foundation of the study includes a comparative analysis of foreign neighborhood planning models; demographic forecasting considering population structure; multi-criteria optimization integrating environmental, social, and engineering parameters; and a systems approach utilizing automated, analytical, and digital platforms.

Analysis and Results

One of the most illustrative examples of a successful scientific approach to residential neighborhood planning is Germany. The country employs comprehensive urban models based on multi-criteria optimization, which include building density, transport accessibility parameters, insolation and microclimate requirements, as well as social and demographic factors. Leading research institutions such as Fraunhofer-Gesellschaft, the Technical University of Berlin, the University of Stuttgart, and DLR develop and implement applied digital solutions for urban planning and analysis. The adoption of Building Information Modeling (BIM) and Digital Twin concepts allows for simulating neighborhood behavior under various development and operational scenarios. Particular attention in Germany is given to sustainable and energy-efficient design, exemplified by construction standards such as Passivhaus, Plusenergiehaus, and the implementation of zero- and positive-energy districts (Zero Emission Quartier). For instance, the Vauban neighborhood in Freiburg is an eco-friendly residential area with complete exclusion of private car traffic, solar panels, rainwater reuse systems, and architectural solutions developed with active participation from local residents and experts. Another example is HafenCity in Hamburg, featuring innovative climate adaptation strategies, digital infrastructure management, and comprehensive urban development.

Beyond technical and environmental considerations, the German approach includes civic engagement mechanisms and interdisciplinary design procedures. Programs such as "Soziale Stadt," "Stadtumbau," and "KfW Förderprogramme" involve communities, consultants, engineers, and researchers in project development and implementation. This ensures real social needs are met, prevents territorial degradation, and fosters resilient and inclusive communities [6].

Scientific and Technical Foundations of Planning.

Germany relies on an advanced research and technical infrastructure (Fraunhofer, TU München, DLR, etc.) and actively applies multi-criteria optimization models, GIS, BIM, digital twins, and scenario-based forecasting. Key considerations include sustainability (energy and climate), transport connectivity, insolation, and resident participation. Smart City, Null-Emissionsquartier, and Passivhaus concepts underpin dozens of neighborhoods, from Vauban (Freiburg) to HafenCity (Hamburg).

France, in turn, emphasizes social inclusion, short-distance accessibility, and urban landscape renovation. Approaches rely on the concept of ville du quart d'heure ("15-minute city"), which promotes local resilience and neighborhood autonomy. French research institutions (CSTB, ParisTech, ANRU) develop building life cycle assessments (LCA) and digital methods for forecasting social mobility, with widespread citizen participation in territorial governance [4].

The USA approaches neighborhood planning using advanced scenario modeling, smart city technologies, risk assessment tools, and economic-spatial models. Key research centers include the MIT Department of Urban Studies and Planning, Harvard Graduate School of Design, Berkeley College of Environmental Design, Brookings Institution, and Urban Land Institute (ULI).

American practice centers around "Neighborhood Planning" and "Community-Based Design," focusing on infrastructure resilience modeling and real-time digital simulation. Widely used platforms include UrbanSim, CityEngine, and Sidewalk Labs, alongside IoT technologies, BIM 360, ArcGIS Urban, and forecasting for housing demand, transport load, and energy consumption.

In Japan, scientific neighborhood planning (ちいきまちづくり — local city development) is implemented through university consortia, private developers, urban planning bureaus, and research institutes. Leading institutions include the University of Tokyo (UTokyo), Nagoya University, and the National Institute for Land, Infrastructure, and Transport (MLIT NLI). Characteristic features include planning based on demographic models of aging populations, the use of GIS and Urban Information Systems to account for seismic zones, density, and accessibility, a focus on adaptive reuse of urban space (compact city, densification), and the implementation of "Resilient Neighborhoods" with autonomous energy, water, and evacuation systems [6].

Sustainability and Digitalization. Japan actively uses the CASBEE system (Comprehensive Assessment System for Built Environment Efficiency), a national standard for assessing neighborhood sustainability. Digital twin platforms integrated with IoT sensors and early-warning systems for emergencies are being developed. The USA implements integrated digital platforms such as UrbanFootprint and Envision Tomorrow, enabling the modeling of social, economic, and environmental impacts of

new neighborhoods at the pre-design stage, including water, climate, crime, migration, and transport analysis. In Germany, digital technology is a mandatory element of federal construction programs, and energy standards such as Passivhaus and Plusenergiehaus are codified. In France, HQE, RT2020, and BBC standards are implemented, alongside digital reconstruction of aging neighborhoods, 3D scanning platforms, solar balance modeling, and transport vulnerability assessments. These countries strive for energy neutrality and minimal environmental impact, creating neighborhoods that combine low energy consumption, transport connectivity, digital infrastructure, and high social activity, demonstrating a high level of digitalization and sustainable development.

Japan has developed the unique “Machizukuri” institution - a form of social and spatial governance where residents collaborate with municipalities to develop local development plans, considering disasters, population aging, and social cohesion.

Examples of Neighborhoods. Below are examples of neighborhoods where scientifically-based methods for optimizing housing infrastructure have been actively applied in Table 1.

Table 1. Optimized housing infrastructure.

Country	City	Neighborhood Name	Features
Germany	Freiburg	Vauban	Eco-friendly district; car-free; sustainable housing
	Hamburg	HafenCity	Climate adaptation; digital twin
France	Paris	Clichy-Batignolles	Green space; "15-minute city" concept
	Lyon	La Duchère	Inclusive redevelopment with digital tools
USA	San Francisco	Mission Bay	Digital modeling
	New York	East Harlem	Redevelopment of old, dispersed neighborhoods and lifestyle adaptation
Japan	Kanagawa	Fujisawa SST	Sustainable "smart neighborhood"; solar energy; energy self-sufficiency
	Toyama	Toyama City Center	"Compact city" project; adaptation to aging population; downtown renovation

Below is a comparison of selected indicators of scientific neighborhood planning given as Table 2.

Table 2. Comparison of selected indicators of scientific neighborhood.

Criterion	Germany	France	USA	Japan	Uzbekistan
Scientific Integration	Models + Engineering	Spatial and Social Models	Digital Forecasting	Demographic Adaptation; Seismic Resilience	Partial, Applied Approach
Digital Technologies	BIM, Twin City	Digital Simulations	UrbanSim, ArcGIS	Smart Infrastructure	In Development
Energy Efficiency	Passivhaus	HQE, RT2020	LEED, WELL	ZEH, CASBEE	Requires Standardization
Civic Participation	Neighborhood Governance	Consultations	Community Councils	Machizukuri	Insufficient

Demographic Adaptation	Limited	Partial	Only in Special Districts	Deep Integration	Initial Stage

The above analysis of the scientific experience of developed countries allows us to highlight the following strategic models of housing infrastructure planning:

Germany - a leader in scientific and engineering modeling of sustainable neighborhoods, integrating digital modeling and energy efficiency.

France - a center of social inclusion and landscape-urban planning approaches; a socio-ecological "15-minute city" model emphasizing local infrastructure.

USA - a digital and institutional leader with advanced forecasting tools.

Japan - an example of cultural, demographic, and seismic-resilient neighborhood adaptation.

Challenges and limitations in adapting international experience. Despite the high level of scientific and technological development in residential environment design, the experience of developed countries is not without shortcomings and contradictions, particularly when adapting it to the conditions of other nations. The main structural, social, regulatory, and economic limitations identified in their practices are given below as Table 3, Table 4, Table 5, and Table 6.

Table 3. Limitations of the German model.

Category of Problem	Problem Description
High Implementation Cost	Neighborhood projects require significant investments at the construction and operational stages.
Excessive Technocratic Focus	Overemphasis on engineering aspects while underestimating the social infrastructure of the area.
Example**:** In the Hafen City project, issues were observed with inflated housing costs, the exit of small businesses, and reduced social diversity.	

Table 4. Limitations of the French model.

Category of Problem	Problem Description
Fragmentation of Models	Lack of a unified platform for integrating digital data between municipalities.
Financial Instability	Some projects are postponed due to complex subsidy procedures and insufficient funding.
Example: In the Saint-Denis and La Courneuve districts near Paris, after renovation, part of the population was forced to leave their housing due to rising rental rates.	

Table 5. Limitations of the American model.

Category of Problem	Problem Description
Excessive Standardization	Universal criteria (LEED, Smart Growth) do not always adapt to local climatic conditions.
Spatial Inequality	Neighborhoods in subsidized zones develop, while others remain in decline.
Example: In renovation projects in Detroit and Baltimore, cases of partial gentrification and housing inaccessibility were observed.	

Table 6. Limitations of the Japanese model.

Category of Problem	Problem Description
High Dependence on Technological Solutions	Reliance on expensive digital technologies and IoT infrastructure.
Aging Population Issue	In neighborhoods with a high proportion of elderly residents, economic activity declines.
Example: In Aomori City, the implementation of "smart neighborhoods" was accompanied by protests due to the closure of schools, transport routes, and employment centers in peripheral areas.	

Despite existing terminological differences, planning systems in various countries are inevitably embedded within their national contexts. This is because urban planning specialists use specific terms to denote the peculiarities of planning activities within a particular country. Consequently, scientific literature has established designations such as the "German," "French," or "Japanese" planning system. Each system is shaped by specific institutional and cultural conditions, reflecting regulatory, legal, and spatial features. For example, in Germany, the planning system largely relies on the federal structure of the state, ensuring a clear management hierarchy and a well-defined vertical of planning levels [4].

For Uzbekistan, it is relevant to conduct systematic scientific research aimed at developing housing infrastructure, focusing on the following priority areas:

- Based on scientific studies, it is necessary to develop theoretical and methodological foundations that allow housing infrastructure to be considered not merely as a collection of construction objects, but as a key element of comprehensive regional development. This approach ensures a transition from fragmented land development to a systematic spatial development model, where housing becomes a factor integrating demographic, economic, and environmental processes.

- Special importance is given to the study and development of effective models and methods for forecasting the housing environment. These models must take into account the dynamics of urbanization processes, the social needs of the population, and demographic trends, including age structure, migration flows, and natural population growth rates. Scientifically grounded forecasts will enable the formulation of housing policies based on a long-term balance of supply and demand.

- The development and practical application of economic-mathematical models and algorithms for optimizing housing infrastructure contribute to the comprehensive and balanced development of territories. Such models make it possible to consider spatial constraints, investment efficiency, and social sustainability, which is particularly important under conditions of accelerated urbanization and limited land resources.

- Equally significant is the development of methodological foundations for integrating demographic forecasting models with territorial planning tools. This creates the possibility of forming a comfortable and safe living environment, adapted to projected changes in population size and structure. Implementing such approaches will ensure balanced settlement, rational use of land and engineering resources, and the minimization of social risks associated with overpopulation in specific areas.

- Theoretical prerequisites for the harmonious combination of technical and social solutions should prevent the formation of neighborhoods with low comfort levels and insufficient engineering infrastructure. Within this framework, it is necessary to develop integrated planning tools that account for drainage systems, levels of insolation, and sanitary-hygienic conditions. Unbalanced drainage solutions and insufficient sunlight can contribute to the development of diseases related to humidity, poor ventilation, and lack of ultraviolet exposure, directly affecting residents' health.
- It is also necessary to develop methodological foundations and methods for creating a unified digital platform in the form of a problem-oriented tool system. Such a platform will enable the adaptation of digital tools for designing and managing housing infrastructure to the real conditions of the region. It should be based on the results of scientific research and incorporate elements of artificial intelligence, allowing for a structured description of planning, analysis, and monitoring processes in territorial development.

Implementing these directions will not only establish a comprehensive meso-level housing infrastructure management system but also critically evaluate the feasibility of transferring foreign scientific models to the national context. This will allow identifying elements applicable in the context of Uzbekistan and highlight areas requiring adaptation, taking into account the country's climatic, regulatory, demographic, and socio-cultural characteristics.

Conclusion

Analysis of international approaches shows that modern neighborhood planning and the development of housing infrastructure are based on principles of interdisciplinarity, digitalization, and social adaptation. For Uzbekistan, it is crucial to develop theoretical and methodological foundations for the creation and implementation of economic-mathematical models and methods to establish a national system for managing meso-level housing infrastructure.

1. The experience of developed countries confirms that multi-criteria assessment of housing infrastructure parameters allows for the identification of optimal solutions with minimal financial costs and maximum social benefits. For Uzbekistan, the implementation of such mechanisms is particularly relevant due to the need for rational resource use and modernization of outdated housing stock, while adhering to national traditions, climatic conditions, regional specifics, and legislative requirements.
2. Effective planning of housing infrastructure should aim to create compact, energy-efficient, and sustainable urban development that considers the actual characteristics of the territory and the needs of the population. This requires the introduction of instrumental mechanisms to support urban design, as well as systems for managing reconstruction and the integration of existing settlements. Special attention should be paid to improving engineering infrastructure and enhancing the quality of social and domestic services.
3. Practice demonstrates the feasibility of approaches based on the principles of integrated territorial development (ITD), functional mixing, and early-stage implementation of social infrastructure facilities. Such an approach ensures reduced project implementation timelines, optimization, and increased urban resilience. For

Uzbekistan, it is particularly important to develop integrated development models that provide balance and integration between residential facilities and engineering networks.

4. A key direction for improvement is the implementation of scientifically grounded methods for forecasting the housing environment, integrated with digital planning technologies. The creation of a unified digital platform in the form of a problem-oriented instrumental system will allow the combination of demographic, economic, and engineering data to generate optimal territorial development scenarios. The use of artificial intelligence elements and modeling algorithms will ensure high analytical accuracy and enhance the efficiency of management decisions.

5. When planning housing infrastructure, particular attention should be given to engineering and environmental aspects—organization of drainage systems, provision of adequate sunlight, prevention of flooding and excessive humidity. These factors directly affect the sanitary and hygienic conditions of the territories and residents' health, reducing the risk of respiratory and infectious diseases. The formation of such standards should become an integral part of comprehensive territorial development policies.

Meso-level housing infrastructure is a system-forming element of the spatial and socio-economic development of Uzbekistan. Its improvement requires a combination of theoretical research, digital tools, interdisciplinary approaches, and management solutions. The implementation of the proposed measures will create a sustainable, balanced, and comfortable residential environment that ensures a high quality of life for the population and harmonious regional development.

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ACTUAL PROBLEMS OF MATHEMATICS, PHYSICS AND MECHANICS

UDC: 535, 004.738

OPTOELECTRONIC DEVICE FOR INFORMATION PROTECTION IN FIBER-OPTIC COMMUNICATION LINES

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Annotatsiya. Ushbu maqola optik tolali aloqa tizimlariga ruxsatsiz kirishning barcha mumkin bo‘lgan usullarini tahlil qiladi va ma’lumotlarni yig‘ishning halokatli, buzilmaydigan va optik-radio to‘lqin usullarini ko‘rib chiqadi. Ruxsatsiz ma’lumotlarni yig‘ishga qarshi kurashishning optoelektron usuli va optik tolali aloqa tizimlarida ruxsatsiz ma’lumotlarni yig‘ishning zamonaviy texnik vositalari ishlab chiqildi. Ruxsatsiz ma’lumotlarni yig‘ishga qarshi kurashning ushbu optoelektron usulini amalga oshiradigan optoelektronik qurilma va optik tolali aloqa tizimlarida ruxsatsiz ma’lumotlarni yig‘ish uchun zamonaviy texnik vositalar ishlab chiqilgan.

Kalit so‘zlar: *optik tolali tizimlar, axborot xavfsizligi, ruxsatsiz kirish, optoelektronika, yorug‘lik diodi, fotodiod, optoelektronik qurilma.*

Аннотация. Проведен анализ всех возможных способов несанкционированного доступа к волоконно-оптическим системам связи и рассмотрены деструктивные, неразрушающие и оптико-радиоволновые методы сбора информации. Разработаны оптоэлектронный метод противодействия несанкционированному сбору информации и современные технические средства несанкционированного сбора информации в волоконно-оптических системах связи. Разработано оптоэлектронное устройство, реализующее оптоэлектронный метод противодействия несанкционированному сбору информации и современные технические средства несанкционированного сбора информации в волоконно-оптических системах связи.

Ключевые слова: *волоконно-оптические системы, информационная безопасность, несанкционированный доступ, оптоэлектроника, светодиод, фотодиод, оптоэлектронный прибор.*

Abstract. All possible unauthorized accesses to fiber-optic communication systems were analyzed, and destructive, non-destructive, and optical-radio wave methods of data collection were considered. An optoelectronic method for countering unauthorized data collection and modern technical means for

unauthorized data collection in fiber-optic communication systems was developed. An optoelectronic device implementing an optoelectronic method for countering unauthorized data collection and modern technical means for unauthorized data collection in fiber-optic communication systems was developed.

Keywords: *fiber-optic systems, information security, unauthorized access, optoelectronics, light-emitting diode, photodiode, optoelectronic device.*

Introduction

Recently, one of the most promising and developing areas of communication network construction in the world is fiber-optic communication lines (FOCL). The priority area of development of the transport network of Uzbekistan is the transition of the network to the widespread use of FOCL and the implementation of work to provide all populated areas of the republic with a fiber-optic network, access to high-speed Internet for all households, and coverage of all international and national highways with mobile Internet.

Throughout the world, considerable attention is paid to ensuring information security-the state of protection of society's information environment, ensuring its formation, use, and development in the interests of citizens, organizations, and the state. In recent years, the Republic of Uzbekistan has implemented a set of measures to improve its information security.

In light of the above, the development of effective methods and technical means for protecting information in fiber-optic communication lines (FOCLs) is a pressing issue.

Analysis of possible information leakage channels

An analysis of existing methods and means for covertly intercepting information in fiber-optic communication systems (FOCS) revealed that a new generation of technical means for information intelligence (TMIS) is being developed for covertly intercepting information from FOCS [1]. The operating principle of all known TMIS is based on recording the portion of optical radiation scattered by the surface of the fiber-optic line's cladding.

An analysis of potential information leakage channels in fiber-optic communication systems revealed the following methods of data extraction [2]:

1. Destructive data extraction methods – based on the use of fiber-optic splitters, which are activated by cutting the fiber-optic line.

2. Non-destructive data extraction methods – based on recording optical radiation scattered on the surface of the fiber-optic line.

3. Optical-radio wave methods – in which the optical radiation extracted from the surface of the fiber-optic line is converted into a high-frequency electrical signal.

Destructive methods and means for data extraction in fiber-optic communication lines are more reliable and simpler than other methods.

The use of fiber-optic splitters in a fiber-optic communication line ensures sufficient intensity of optical radiation emitted from the fiber. This, in turn, ensures reliable operation of the photodetector, as well as the covert data extraction device.

Non-destructive methods extract data without damaging the optical fiber. They use specialized equipment that records the small portion of the signal energy dissipated through the fiber [3].

Non-destructive methods are covert, as they have virtually no effect on the parameters of the radiation propagating through the fiber, but they have low sensitivity.

Optical-radio wave data collection methods are based on the principle of converting optical radiation into a high-frequency electrical signal, which is emitted by an antenna as electromagnetic radiation [4].

This method of data collection utilizes optical-radio wave bugs, which are pre-installed in the fiber-optic communication line (FOCL) by the manufacturer. These bugs can be installed in any segment of the FOCL (optical splitters, patch cords, optical couplings, optical regenerators, optical amplifiers, etc.).

Optoelectronic method of information protection

An optoelectronic method for counteracting unauthorized information retrieval and modern technical means in fiber-optic communication systems is proposed.

The fiber-optic communication line (FOCL) carrying the information signal is irradiated by a noise-like optical signal at the receiver, which propagates along the entire length of the fiber-optic communication line in the opposite direction of the information signal. Thus, a mixed signal is formed in the FOCL, consisting of the information signal and the noise-like signal. Therefore, if information is intercepted unauthorizedly from any section of the FOCL, the signal received by the intruders will be a mixed signal and cannot be separated from the information signal due to the unknown nature of the change in the noise-like signal.

At the receiving end of the fiber-optic communication line, the noise-like signal in the mixed signal is compensated by the same noise-like signal irradiated by the fiber-optic communication line. To achieve this, in the transmitting end of the fiber-optic communication line, the transmitted information signal $u_c(t)$ is converted into optical radiation $p_c(t)$ and focused onto the input of the fiber-optic communication line, which has two outputs at the receiving end of the fiber-optic communication line. The information signal, converted into optical radiation, travels the entire length of the fiber-optic line and is focused from the first output onto the sensitive area of the radiation receiver.

From the receiving part, an optical noise-like signal $p_n(t)$ is introduced from the second output of the fiber-optic line, which propagates in the opposite direction of the information signal along the entire length of the fiber-optic line.

In this case, the total optical signal acts on the sensitive area of the radiation receiver:

$$p_f(t) = p_c(t) + p_n(t) \quad (1)$$

According to expression (1), a photoelectric signal will be generated at the output of the radiation receiver:

$$u_f(t) = u_c(t) + u_n(t) \quad (2)$$

where $u_c(t)$ – information signal at the output of the radiation receiver $u_n(t)$ – noise-like signal at the output of the radiation receiver.

To compensate for the noise-like electrical signal, the phase-inverted noise-like electrical signal from the output of the noise-like signal source is added to the mixed electrical signals in expression (2).

Then we have

$$u_f(t) = u_c(t) + u_n(t) - u_{n0}(t) \quad (3)$$

where $u_{n0}(t)$ - phase-inverted noise-like electrical signal.

Given that $u_n(t) = u_{n0}(t)$ on the basis we have:

$$u_f(t) = u_c(t) \quad (4)$$

Using the proposed method for protecting an information signal from unauthorized access in a fiber-optic communication line, a noise signal is generated at the receiving end before the sum signal is formed and transmitted to the transmitting end of the fiber-optic communication line for mixing with the information signal. At the receiving end, during the process of shifting the delayed inverse noise signal toward the sum signal, a complete phase match occurs between the noise signal and its inverse signal. As a result, the noise signal is completely compensated, the information signal is isolated, and information in the fiber-optic communication line is protected from unauthorized access.

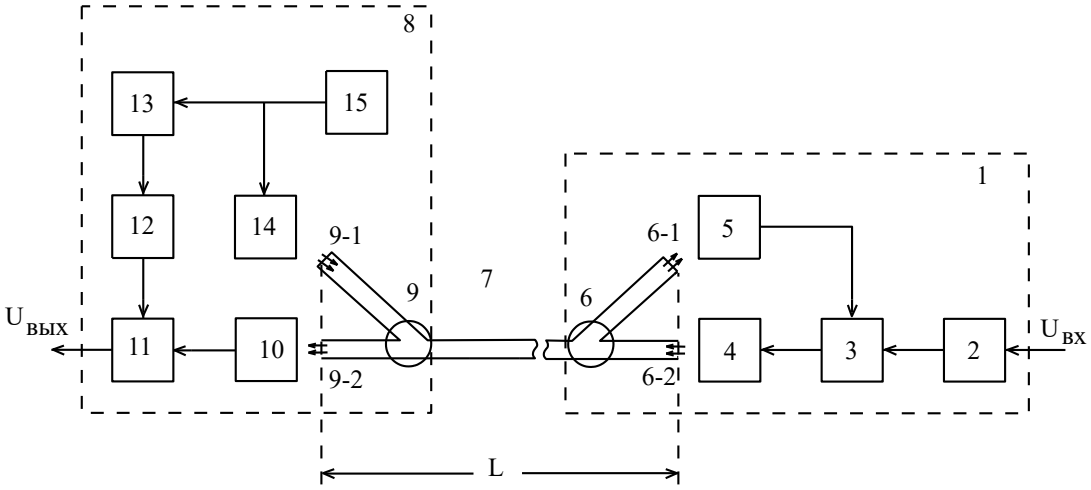

Figure 1. Block diagram of the optoelectronic information security device.

Optoelectronic device for information protection in fiber-optic communication lines.

Figure 1 shows a block diagram of an optoelectronic device implementing the proposed method of protecting an information signal from unauthorized access in a fiber-optic communication line. The optoelectronic device implementing the proposed method of protecting an information signal from unauthorized access in fiber-optic communication lines comprises, on the transmitting side 1, an information signal generator 2, a mixer 3, a source 4 of transmitted optical radiation, a noise signal photodetector 5, a directional coupler 6 with inputs 6-2 and an output 6-1, a fiber-optic communication line 7, on the receiving side 8, a directional coupler 9 with an input 9-1 and an output 9-2, a sum signal photodetector 10, a mixer 11, delay lines 12, an inverse noise signal generator 13, a source 14 of noise optical radiation and a noise signal generator 15.

When implementing the proposed method of protecting an information signal from unauthorized access in a fiber-optic communication line, the following operations are performed:

- on the receiving side 8 of the fiber-optic communication line 7:

1) using generator 15, a noise signal is generated;
2) using inverter 13, an inverse noise signal is generated;
3) using delay line 12, the inverse noise signal is delayed for a time $t_{зад} = 2L/v$,
4) the noise signal modulates the transmitted noise optical radiation in the optical radiation source 14,
5) through the input 9-1 of the directional coupler 9, the transmitted noise optical radiation is introduced into the fiber-optic communication line 7,
4) the noise signal modulates the transmitted noise optical radiation in the optical radiation source 14,
5) through the input 9-1 of the directional coupler 9, the transmitted noise optical radiation is introduced into the fiber-optic communication line 7,
1) using the generator 2, the transmitted information signal is generated,
2) through the output 6-1 of the directional coupler 6, the received noise optical radiation is output from the fiber-optic communication line 7,
3) using the photodetector 5, a noise signal is generated from the received noise optical radiation,
4) a sum signal is generated by mixing the information and noise signals using the mixer 3,
5) the transmitted optical radiation is modulated with the sum signal in the source 4 of the transmitted optical radiation,
6) through the input 6-2 of the directional coupler 6, the transmitted optical radiation is introduced into the fiber-optic communication line 7,

- on the receiving side 8 of the fiber-optic communication line 7:

1) the received optical radiation is output from the fiber-optic communication line 7 through the output 9-2 of the directional coupler 9,
2) a sum signal is formed from the received optical radiation using the photodetector 10,
3) an information signal is isolated by mixing the delayed inverse noise signal with the sum signal using the mixer 11.

Conclusion

All possible unauthorized accesses to fiber-optic systems were analyzed, and destructive and non-destructive data retrieval methods, as well as optical-radio wave methods, were considered. An optoelectronic method for countering unauthorized data retrieval was developed, using modern technical means in fiber-optic systems. An optoelectronic device implementing an optoelectronic method for countering unauthorized data retrieval and using modern technical means in fiber-optic systems was developed.

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UDC: 537.3, 537.5, 538.9

ANALYSIS OF CONDUCTION CURRENT AND DISPLACEMENT CURRENT IN THE CHARGING AND DISCHARGING PROCESS OF A CAPACITOR

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Annotatsiya. Ushbu maqola orqali fizpraktikum kursidan ma’lum bo‘lgan “Kondensatorni zaryadlash va razryadlash jarayonini o‘rganish” ishidagi ba’zi muammoli va murakkab bo’lgan savollarga yechim topishga harakat qildik. Undan tashqari, buni muhim jihati talabalar ushbu laboratoriya ishini nafaqat nazariy jihatdan balki grafiklarini ham yaxshi tushunishlari va ko‘plab talabalarga murakkablik tug’diradigan jihatlarini to‘liq yoritib berishdan iborat.

Kalit so‘zlar: *kondensator, siljish toki, o‘tkazuvchanlik toki, kvazistatsionar tok, elektr maydon.*

Аннотация. В данной статье предпринята попытка найти решения некоторых проблемных и сложных вопросов, возникающих в лабораторной работе “Изучение процесса зарядки и разрядки конденсатора”, известной из курса физического практикума. Кроме того, важным аспектом является то, чтобы студенты понимали эту лабораторную работу не только с теоретической стороны, но и хорошо усваивали её графическое представление, а также чтобы подробно были освещены моменты, которые вызывают затруднения у многих обучающихся.

Ключевые слова: *конденсатор, ток смещения, ток проводимости, квазистационарный ток, электрическое поле.*

Abstract. This article seeks to address complex and problematic questions encountered in the physics practicum exercise “Studying the Charging and Discharging Process of a Capacitor.” Another important aspect is ensuring that students understand this laboratory work not only theoretically but also through

its graphical analysis, with detailed explanations of points that often present difficulties for many students.

Keywords: *Capacitor, displacement current, conduction current, quasi-stationary current, electric field.*

Introduction

Nowadays, many problems are observed among students regarding a deep understanding of the concept of displacement current. University students specializing in physics are required to have a solid grasp of this important concept. To reinforce the knowledge gained on this topic, it is recommended to perform the educational laboratory work titled *"Study of the Charging and Discharging Processes of a Capacitor."* During this laboratory exercise, students are expected to strengthen their understanding of concepts such as displacement current, quasi-stationary current, and conduction current. At the same time, some interesting questions may arise throughout the laboratory work. This article provides answers to some of these questions. For example, it is well known that direct current does not pass through a capacitor. However, the purpose of studying the above-mentioned laboratory work is to analyze how the current flowing through the circuit changes over time during the charging and discharging processes of the capacitor. At first glance, these two statements seem contradictory, and a question arises: How does current pass through a capacitor? If it does not, then how can the measurement of current with an ammeter be explained? It is known that alternating current can exist even in open circuits. When current passes through a capacitor, a time-varying electric field, or displacement current, appears between its plates [1]. So, what is displacement current? If we answer this question based on Maxwell's analysis, we know that any varying magnetic field produces a circulating electric field. By analyzing various electromagnetic processes, Maxwell concluded that any change in the electric field gives rise to a circulating magnetic field [1]. In other words, he discovered that the reverse of the previously mentioned idea also exists. That very time-varying electric field is called displacement current. If there is alternating current in a conductor, then there is also a time-varying electric field inside the conductor. Therefore, both conduction current and displacement current exist within the conductor. The time-varying electric field generates a magnetic field, and the magnetic field of the conductor is determined by their sum-that is, by the total current [1, 2].

$$j_{total} = j + \frac{\partial D}{\partial t} \tag{1}$$

In formula (1), both terms may be equal in magnitude but opposite in sign. Therefore, the total current may be greater than, less than, or, in a particular case, even equal to zero compared to the conduction current. Displacement current mainly plays a significant role in poorly conducting media. In well-conducting materials, displacement current can usually be neglected in comparison with conduction current [2, 3, 4]. As we know, all technical alternating currents are quasi-stationary currents. An example of quasi-stationary currents is the process of charging and discharging a capacitor.

The process of accumulating electric charges on the plates of a capacitor is called charging. The reverse process is called discharging [2]. The charging process of a capacitor begins at the moment when a direct current source is connected in series with a resistor and the capacitor, and it continues until the potential difference between the capacitor plates becomes equal to the EMF of the source. Over time, the current decreases, and as a result, at the moment of complete charging, the current in the circuit becomes zero [4,5]. Thus, the current in the circuit gradually decreases from its maximum value and tends toward zero. During the discharging of the capacitor, the displacement current is directed from the inner plate to the outer plate [5], while the conduction current is directed in the opposite way. Therefore, the total current becomes equal to zero.

Research Methodology

The charging and discharging processes of a capacitor can be carried out in various ways. In this work, the *"ammeter method"* is considered. When performing the experiment using the ammeter method, the circuit shown in Figure 1 is used.

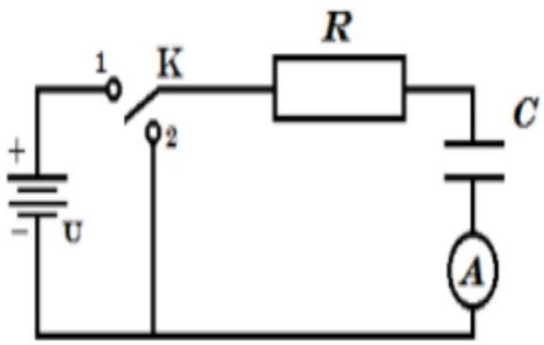

Figure 1. Schematic image of the ammeter method.

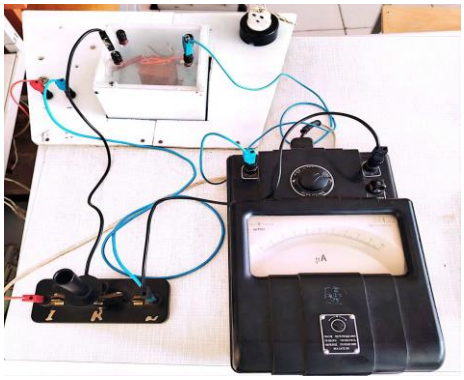

Figure 2. Digital camera image of the circuit.

If we assemble the same circuit using the necessary instruments—namely, a microammeter, a high-capacitance capacitor, a high-resistance resistor, a power source, and a switch—the following circuit is obtained (see Figure 2).

Looking at the circuit in Figure 2, if we switch K from the neutral position to position 1, then at the moment of switching, i.e., at $t = 0$, the charge $q = 0$. From that moment, the capacitor begins to charge. According to the above-mentioned conditions, the process is considered quasi-stationary, and Kirchhoff's second law is applied to the closed circuit [2, 6]; that is, the sum of the voltage drops along the closed loop is equal to zero.

$$U_R + U_C = U_0 \tag{1}$$

or

$$IR + \frac{1}{C}q = U_0 \tag{2}$$

Using the fact that the first derivative of charge with respect to time is equal to the current, expression (2) can be rewritten in a different form.

$$\frac{dq}{dt}R + \frac{1}{C}q = I_0 R \tag{3}$$

By solving the differential equation obtained in expression (3), it is possible to determine the time dependence of the amount of charge passing through the capacitor [6]. If we further simplify expression (3),

$$Rdq = \left(I_0 R - \frac{1}{C} q\right) dt \tag{4}$$

We integrate both sides of the resulting expression (4).

$$\int \frac{dq}{I_0 RC - q} = \int \frac{dt}{RC} \tag{5}$$

$$\ln(I_0 RC - q) = -\frac{t}{RC} + C' \tag{6}$$

Here, $C' = const$. By applying the initial conditions mentioned above (i.e., at $t = 0$, $q = 0$), we obtain the following expression.

$$\ln\left(1 - \frac{q}{I_0 RC}\right) = -\frac{t}{RC} \tag{7}$$

$$q(t) = I_0 RC\left(1 - \exp\left(-\frac{t}{RC}\right)\right) \tag{8}$$

Therefore, the expression for the charging current of the capacitor at any time ttt can be written as follows: $I(t) = \frac{dq(t)}{dt}$

$$I(t) = I_0 \exp\left(-\frac{t}{RC}\right) \tag{9}$$

Thus, when the capacitor is charging, the current decreases exponentially over time [6-8]. If the switch is moved from position 1 to position 2, then at $t = 0$ the charge is $q = q_0$, and the capacitor begins to discharge; that is, the current flows in the opposite direction along the closed circuit [8,9]. From this, it follows that the discharge current of the capacitor is opposite to the charging current. For the discharge current of the capacitor, the following expression is obtained

$$I(t) = -I_0 \exp\left(-\frac{t}{RC}\right) \tag{10}$$

Analysis and Results

Using the results obtained in laboratory conditions, graphs of the time dependence of the current for the charging and discharging processes were plotted. The obtained results can be seen in the following Table 1.

Table 1. For the charging and discharging process.

***I* (*μA*)**	***t* (*s*)**	***I* (*μA*)**	***t* (*s*)**
4,3	7,1	-3,1	12,09
4,1	26,49	-3,0	26,49
4,0	39,39	-2,9	38,24
3,9	48,99	-2,8	54,28

3,8	63,57	-2,7	69,24
3,7	68,79	-2,6	84,80
3,6	86,96	-2,5	99,96
3,5	94,74	-2,4	118,91
3,4	110,41	-2,3	136,55
3,3	117,73	-2,2	156,62
3,0	160,45	-2,1	172,33
2,8	197,21	-2,0	195,39
2,7	211,17	-1,9	213,60
2,6	229,86	-1,8	239,60
2,5	246,86	-1,7	257,88
2,4	267,83	-1,6	290,86
2,3	290,58	-1,5	314,80
2,0	317,98	-1,4	348,64
1,8	379,23	-1,3	377,52
1,7	406,14	-1,2	416,40
1,6	433,97	-1,1	444,69
1,5	452,84	-1,0	496,24
1,4	490,21	-0,9	534,37
1,3	520,19	-0,8	588,69
1,0	670,27	-0,7	642,83
0,8	779,46	-0,6	722,44
0,7	822,34	-0,5	793,85
0,6	971,10		

As can be seen from the Figure 3, the current decreases over time. The reason is that the capacitor plates are isolated and separated by a dielectric, so charge does not pass directly between them. Instead, due to the change in the electric field between the plates, a displacement current is generated over time [10, 11]. Thus, the current passing through the ammeter is the conduction current, while the current through the capacitor is the displacement current. In the experiment, a very high-resistance resistor ($R \approx 20\ M\Omega$) and a high-capacitance capacitor ($C \approx 20\ \mu F$) were used.

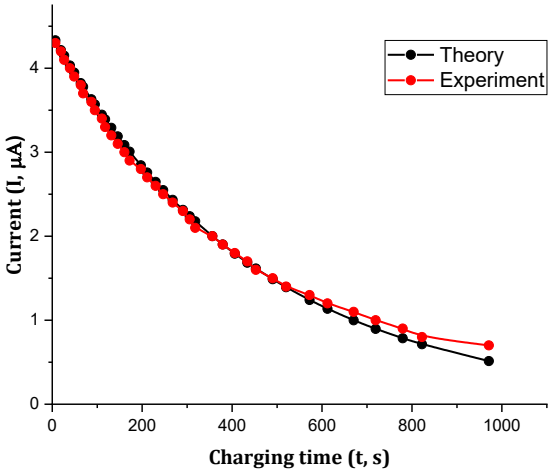

Figure 3. Capacitor charging process.

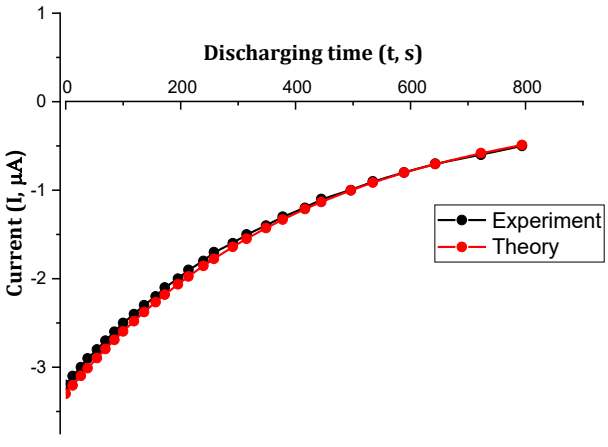

Figure 4. Capacitor discharging process.

The current was measured in microamperes. To charge a large-capacitance capacitor, naturally, a significant amount of charge is required. Over time, the capacitor gradually accumulates charge, and its voltage approaches the EMF of the source. As a result, the current through the capacitor decreases over time. Furthermore, as

mentioned earlier, during the discharge process at $t = 0$, the current has its maximum value, but its sign is opposite to that of the charging current. This is because, as observed from the circuit, in the discharge process the current begins with a negative value, i.e., it flows in the reverse direction. During the charging process, however, the opposite occurs. This theoretical conclusion is clearly confirmed by the graph in Figure 4.

Conclusion

In conclusion, when we speak of electric current, we should always understand it as the sum of two components: the conduction current and the displacement current. In certain parts of an electric circuit, the current may consist only of conduction current, in others only of displacement current, and in some parts of the sum of both. In this work, the aim was not only to analyze the charging and discharging processes of a capacitor, but also to provide students with a comprehensive explanation of electric current—especially the concepts of displacement current and conduction current, which are often difficult for students to grasp. By distinguishing and deeply understanding the notions of displacement current, conduction current, and quasi-stationary current, students can more effectively master not only other laboratory experiments but also topics related to electric currents in general.

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UDC: 37, 37.01/.09, 37.02

METHODS OF CREATING DIDACTIC MATERIALS USING INTERACTIVE EDUCATIONAL PLATFORMS IN THE EDUCATIONAL PROCESS

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Annotatsiya. Ushbu maqolada ta’lim jarayonida raqamli texnologiyalardan foydalanish imkoniyatlari, muammolari va yechimlari to‘g‘risida ma’lumotlar keltirilgan. Shuningdek, ta’lim platformasi yordamida o‘quv jarayonida raqamli didaktik materiallar tayyoralsh usullari hamda ulardan foydalanish bo‘yicha taklif va tavsiyalar taqdim etilib, uning samaradorligini aniqlash bo‘yicha tajriba-sinov ishlari olib borildi. Tajriba-sinov ishlari natijalarining samaradorlik darajasini aniqlashda Student-Fisher mezonidan foydalanildi.

Kalit so‘zlar: *interaktiv, ta’lim platformasi, ta’lim resursi, hot, multimedia, texnologiya, ta’lim resursi, interaktiv, viktorina, QR-kod, PIN-kod, innovatsiya, kompyuter, planshet, smartfon, Student-Fisher.*

Аннотация. В данной статье представлена информация о возможностях, проблемах и решениях использования цифровых технологий в образовательном процессе. Также с помощью образовательной платформы были представлены методы подготовки цифровых дидактических материалов в образовательном процессе и предложения и рекомендации по их использованию, а также проведена экспериментальная работа по определению ее эффективности. Для определения уровня эффективности результатов экспериментальной работы использовался критерий Стьюдента-Фишера.

Ключевые слова: *интерактив, образовательная платформа, образовательный ресурс, актуальный, мультимедиа, технология, образовательный ресурс, интерактивный, викторина, QR-код, PIN-код, инновация, компьютер, планшет, смартфон, Студент-Фишер.*

Abstract. This article provides information on the possibilities, problems, and solutions of using digital technologies in the educational process. Also, with the help of the educational platform, methods for preparing digital didactic materials in the educational process and proposals and recommendations for their use were presented, and experimental work was carried out to determine its effectiveness. The Student-Fisher criterion was used to determine the level of effectiveness of the results of the experimental work.

Keywords: *interactive, educational platform, educational resource, hot, multimedia, technology, educational resource, interactive, quiz, QR code, PIN code, innovation, computer, tablet, smartphone, Student-Fisher.*

Introduction

In today's globalization process, digital technologies, along with such priority areas as public administration, economy, medicine, agriculture, create the opportunity to achieve many innovative achievements in the field of education. First of all, digital technologies provide equal access to educational resources for all students, regardless of place and time, and secondly, they are being implemented by educational organizations for the purpose of remote access to educational services and effective management of the education system [1-2].

In this regard, the field of information technology occupies an important place in the development of our republic. The use of digital technologies in the modern educational process is an important requirement of today. Digital technologies help not only to improve the quality of education, but also to make the educational process more convenient, effective, and individualized. Therefore, the use of digital technologies in the educational process is one of the main directions for improving the quality and effectiveness of education. In this case, it is important to rationally use technologies and integrate them into the education system. Thus, through digital education, the foundation is laid for the future generation to have knowledgeable, modern, and innovative thinking.

Literature Review

Research on the scientific and theoretical foundations of the introduction of modern information technologies in education has been conducted by a number of scientists of our country. Including Abdiqodirov A.A., Begimkulov U.Sh., Ergasheva G.S. paid special attention to the methodology of using electronic educational resources and interactive methods in increasing the effectiveness of teaching subjects in higher educational institutions [1-3]. Lutfillaev M.Kh., Tursunov S.K., Muminov B.B., Fayzieva M.R., Shoymardonov T.T. conducted scientific research on the creation of electronic information resources for computer science and their implementation in the educational process. These studies have shown the relevance of using pedagogical software in the education system [4-6]. Taylakov N.I., Zakirova F.M., Turaev B.Z., Nuralieva P.E., Israilova L.S. conducted research on the use of digital technologies in the educational process and their role in the formation of students' independent thinking skills [7-9]. Akhmedova Z.K., Rasulova R.T., K.Sh. Mamatov's research demonstrates the importance of modern interactive educational platforms, their integration into the educational process, and their impact on effectiveness [10-12].

Research on the problems of implementing distance learning in the countries of the Commonwealth of Independent States, the theory and practice of using information educational environments, educational platforms was studied by such scientists as Yakushina E.V., Gareeva G.A., Karmanovsky A.V., Skvorsov A.A., Kuleshova G.M., Mirzabekova O.V., V.V. Polovinkina [13, 14].

Today, various interactive platforms are used in organizing the assessment of students' knowledge in subjects. In particular, when conducting theoretical classes in schools, vocational schools, and higher education, the use of interactive tasks in assessing students' knowledge yields a favorable effect. Because connecting to the covered and new topic forms the student's skills in the subject. When assessing using

special devices, the student has the opportunity to use distractions, i.e., other resources. This leads to the emergence of a gap in the student's attention and in the ineffectiveness of the intended result of the lesson.

Research Methodology

Currently, the Kahoot! platform is one of the modern pedagogical software tools that helps create various interactive educational resources and quizzes, share them, and make the learning process more interesting and meaningful. Tests can be created by registering via email on the kahoot.com platform. However, when using the free version of the platform, it is possible to create questions in only two forms (see Figure 1).

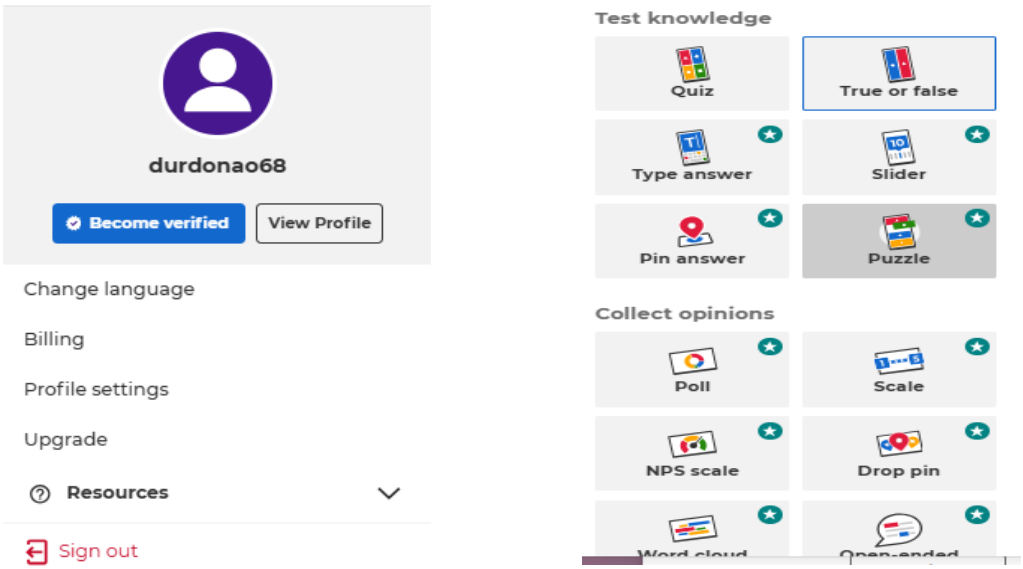

Figure 1. Khoot! platform usage

Kahoot! Resources created on the platform are usually presented to learners in the form of games. In this case, students from their own devices https://kahoot.it will be able to enter a special PIN code or join the educational game using a QR code and answer questions on the topic in real time, including according to the set timer.

To make interactive learning games and questions interesting and understandable, you can also add pictures, videos, and diagrams (see Figure 2).

Figure 2. Khoot! The process of adding videos and charts on the platform.

Kahoot! the platform provides detailed reports on participants, allowing teachers to take an individual approach and present content that students struggle to master in different forms (Figure 3).

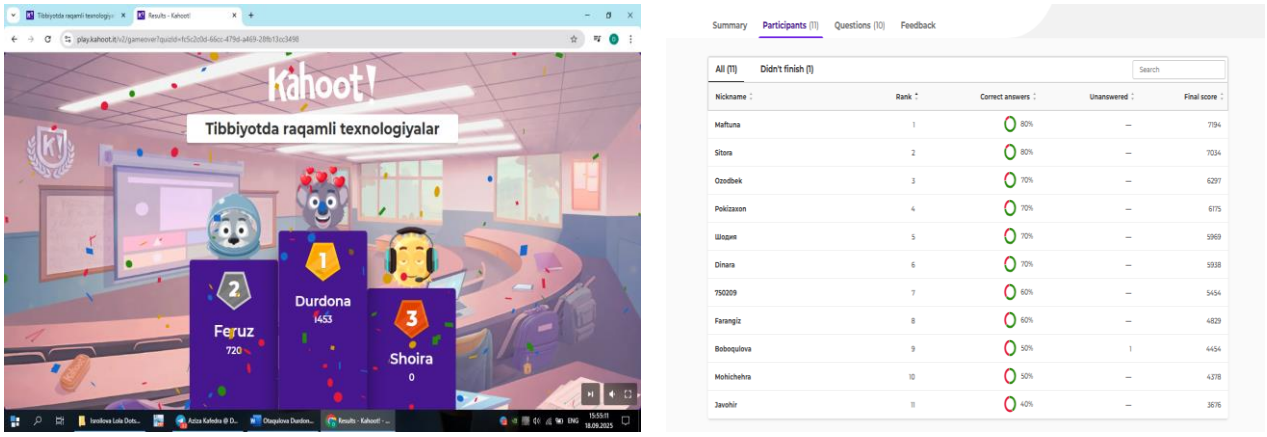

Figure 3. Khoot! Report window on the platform.

Kahoot! The platform is one of the pedagogical software tools that helps to organize interesting and meaningful lesson processes, present educational resources to students in the form of games, form the ability to memorize topics related to science, create additional opportunities for their independent learning, and digitalize the educational process in today's age of innovations. Learners can use interactive educational resources created through this platform using any device (computer, tablet, smartphone, etc.), in the classroom or virtual environment, online or at home to complete independent assignments.

Analysis and Results

In higher educational institutions Kahoot! experimental work was carried out to determine the level of effectiveness in assessing students' knowledge using the platform. Kahoot! 56 students in the areas of "General Medicine" and "Pediatrics" were involved in the experimental and control groups to assess the knowledge gained in theoretical and practical classes on the subject "Information Technologies in Medicine" using the platform. The control group was not given this opportunity. The results of the student involved in this experiment were analyzed, and a mathematical-statistical analysis was carried out based on the Student-Fisher criterion in order to verify their reliability. Matching means for the samples when using this criterion:

$$\overline{X} = \frac{1}{n}\sum_{i=1}^{4} n_i X_i \,,\ \overline{Y} = \frac{1}{n}\sum_{i=1}^{4} n_i X_i .$$

Above the formula was used according to the calculation results, it turned out that the average academic performance of the experimental group was higher than in the group, i.e., increased by 10.9%.

Conclusion

In the process of digital transformation, it is impossible to imagine the education sector without modern information and communication technologies. In particular, the use of interactive educational platforms in the preparation of didactic materials for strengthening theoretical and practical information in the educational process allows

not only to effectively convey knowledge, but also to connect interdisciplinary integration, to form students as active participants, and to develop their creative thinking potential.

In conclusion, the use of didactic tools using interactive educational platforms is not only a technological approach, but also a methodological update that takes the educational process to a qualitatively new level.

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UDC: 37, 37.01/.09, 796

PYRAMID OF TRAINING FOR INTEGRATION OF THE SPORT OF MINI VOLLEYBALL INTO VOLLEYBALL

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Annotatsiya. Ushbu maqolada kichik voleybol sport turini voleybolga integratsiyalashda mashg‘ulotlar piramidasi bo‘yicha ko‘rsatma va takliflar keltirilgan. Mazkur piramidada voleybol elementlarining mashg‘ulotlarda birlashishi bilan bog‘liq topshiriqlar berilgan bo‘lib, mashqlar asosida piramidaning pastki qismidan to uning uchigacha “zinama-zina” tutash mashqlar orqali “Progres” holatiga erishilgan. Tadqiqot natijalari bu mashg`ulotlar piramidasini voleybol mashg`ulotlarida keng qo‘llashni tavsiya etadi.

Kalit so‘zlar: *Piramida, kichik voleybol, voleybol. integratsiya, sifat, mashg‘ulot, natija.*

Аннотация. В данной статье содержатся рекомендации и предложения по тренировочной пирамиде при интеграции детского волейбола в обычный волейбол. В данной пирамиде заложены задания, связанные с интеграцией элементов волейбола в тренировку, а состояние “Прогресс” достигается за счет упражнений, которые выполняются “шаг за шагом” от основания пирамиды к ее вершине. Результаты исследования рекомендуют широкое использование данной тренировочной пирамиды в тренировках по волейболу.

Ключевые слова: *Пирамида, малый волейбол, волейбол. интеграция, качество, тренировка, результат.*

Abstract. This article provides guidelines and suggestions for a training pyramid when integrating the sport of mini volleyball into volleyball. This pyramid provides tasks related to the integration of volleyball elements in training, and the “Progress” state is achieved through exercises that are performed “step by step” from the bottom of the pyramid to its top. The results of the study recommend the widespread use of this training pyramid in volleyball training.

Keywords: *Pyramid, mini volleyball, volleyball. integration, quality, training, result.*

Introduction

In modern sports, particularly in volleyball, the intensification of competition necessitates the implementation of contemporary methods and the advancement of training practices with innovative approaches. In our study, we conducted research on integrating mini-volleyball into volleyball training within the framework of a training pyramid. Our article aligns to a certain extent with the Decree of the President of the Republic of Uzbekistan № PQ-421 dated December 4, 2024, titled “On Measures to

Develop Team Sports and Improve the System for Selecting Talented Youth," and the Decree № PQ-274 dated July 19, 2024, by President Sh.M. Mirziyoyev, titled "On Measures to Further Develop Volleyball Sports" [1-3].

Literature Review

Issues related to the development of volleyball and sports, the role and significance of a healthy lifestyle in enhancing athletes' physical abilities, have been explored by researchers such as Pulatov A.A., Ayraretyans L.R., Rakhimov V.Sh., Salamov R., Seytkhalilov E.A., Tulenova Kh.B., Shukurllayev J.M., and M.A. Qurbonova. Additionally, topics concerning the introduction of an acmeological approach into educational practice, the adoption of effective teaching methods, creative and critical approaches to educational practices, and the ability to analyze the outcomes of one's efforts from a research perspective have been investigated by scholars including Ashurov N.R., Bekmurodov M., Mavlonov O'.,G'oziyev E., Karimova V., Ma'murov B.B., Saliyev A.Sh., Tillayeva G.H., Ernazarova G.O., and M.Sh. Islamova [2-6].

Research Methodology

The training pyramid forms the core content of the study, tailored to the specific requirements of volleyball parameters and transferable skills (see Figure 2). Through the integration of mini-volleyball into volleyball, a system of adaptive complex exercises aimed at developing skills has been developed to enhance the effectiveness of volleyball training.

Acmeology of the Training Pyramid. Here, "acme" refers to the "pinnacle," signifying the achievement of the highest level. We represented the training stages in the form of a pyramid, termed the "Training Pyramid" (see Figure 1). This pyramid is designed based on the level of mastery of the exercises performed by trainees. It requires the implementation of exercises by generalizing aspects such as their content, structure, characteristics, classification, and execution.

For instance, in one of the pyramids, tasks are assigned related to general physical preparation exercises; in another, to the classification of specialized exercises; and in the third, to the integration of mini-volleyball and volleyball elements during training sessions. Based on the existing exercises, a progressive state is achieved through interconnected exercises, moving "step by step" from the base of the pyramid to its apex.

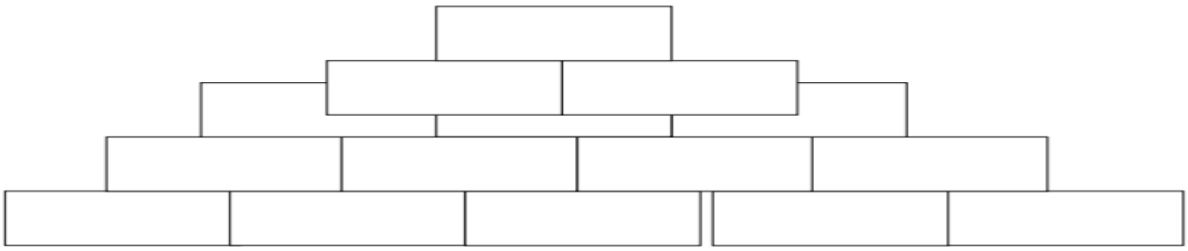


Figure 1. Skeleton of "step by step" exercises from the base of the pyramid.

For example, the "Pyramid Based on Mini-Volleyball Rules." Through the training sessions of the first level of this pyramid, progression is made to the second level (step). From there, through specialized exercises, advancement is made to the third level. In

the same manner, progression continues to the fourth and fifth levels, ultimately conquering the pyramid.

In this pyramid, tasks related to the classification of mini-volleyball and volleyball trainees are implemented. To progress from the base to the apex of the pyramid, it is necessary to utilize mini-volleyball exercises.

During the research process, to integrate mini-volleyball into volleyball and enhance the effectiveness of the training pyramid, a methodological and programmatic framework for training was developed and defined as shown in Figure 2.

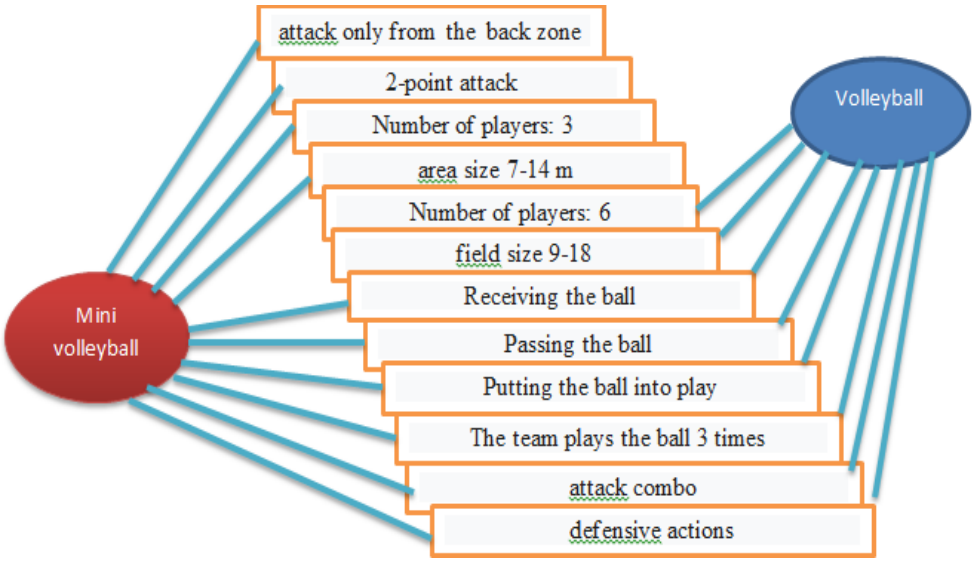
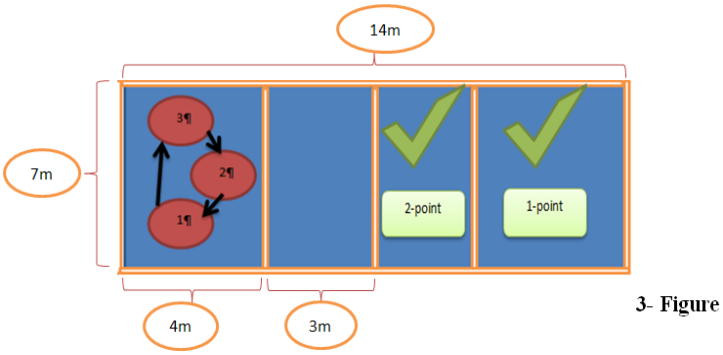


Figure 2. The methodological and programmatic framework for training enhancement.

During the research process, a methodological and programmatic framework for training was developed to enhance the effectiveness of offensive techniques in volleyball through the elements of mini-volleyball, and it was defined as follows:

The playing court was designated. The court is rectangular in shape, with a length of 14 meters and a width of 7 meters (see Figure 3). The smaller size of the court compared to standard volleyball, along with the reduced number of players, contributes to a certain extent to improving the individual physical, technical, and tactical preparation of trainees [7].

The positioning and movement patterns of players were developed (see Figure 3). During the game, three players participate. Offensive actions are performed exclusively from the back zone. This approach enhances the trainee's field of vision, improves attacking skills, agility, and ball reception and control abilities, thereby contributing to their overall development [7].



3- Figure

Figure 3. The playing court design.

Points and zones were distributed as follows: If the ball lands in the attack zone, 2 points are awarded; if it lands in the defensive zone, 1 point is awarded (see Figure 3). This approach increases the trainee's motivation to score points. Incorporating these exercises into the training process has facilitated the formation of a progressive pyramid for the technical and tactical preparation of volleyball players.

Analysis and Results

The analysis of the trainees' performance was conducted based on the following descriptions (see Table 1).

Table 1. The analysis of the trainees' performance.

	Research Criteria
1	Standing long jump
2	Accuracy and consistency in ball passing
3	Effectiveness of ball reception resulting from the application of the attack method from the back zone
4	Trainees' decision-making and ability to anticipate situations

1. The performance of the standing long jump, as applied in training sessions, demonstrated an improvement in leg strength and vertical jump performance, with the indicator rising from 71% to 87% over the course of an annual training cycle. The primary challenges for trainees were related to coordinating movements for jumping and striking the ball.

2. The accuracy and consistency of ball passing, as practiced in training, took an average of 6 weeks to master. The proportion of accurate and consistent targeted ball passing increased from 46% to 58%, and the number of errors in this method was reduced by 12%. The challenges in this regard were relatively complex, as the focus was on passing the ball to a precise point with consistent accuracy.

3. The effectiveness of ball reception resulting from the application of the attack method from the back zone, as practiced in training, required an average of 7 weeks to master. This method aims to complicate the opponent's ability to receive the ball. The effectiveness of ball reception increased from 41% to 69%, and the number of errors in this method was reduced by 28%.

4. Efforts to enhance trainees' decision-making and situational anticipation skills during a 7-week training period yielded positive results. Trainees achieved the ability to execute block-free attacks and improve the quality of deceptive movements based on the game situation. As a result, the effectiveness of decision-making and situational anticipation increased from 34% to 61%, with a 27% reduction in errors associated with this method. The main challenges in training were related to distracting and deceiving the opponent, maintaining consistency in scoring, and executing effective strikes.

The research process was conducted among student participants of volleyball clubs at Chirchiq State Pedagogical University and the Ajiniyoz Nukus State Pedagogical Institute.

Table 2. Indicators of Research Results.

	Criterion	Previous indicators	New indicators	Difference %
1	Standing Long Jump	71%	87%	16%
2	Accuracy and Consistency of Ball Passing	46%	58%	12%
3	Effectiveness of Ball Reception Resulting from the Application of the Attack Method from the Back Zone	41%	69%	28%
4	Trainees' Decision-Making and Situational Anticipation Ability	34%	61%	27%
	Average Indicator	**48%**	**68,75%**	**20,75%**

Mathematical Expression of Results. The provided data were expressed in percentages using the following mathematical formula:

$$Kq\,\frac{J}{Q}\cdot 100\% \qquad (1)$$

here,

J-the number of correct responses provided by students in the questionnaires during the experimental trials.

Q-the total number of students in the group whose results are being evaluated.

Mathematical-statistical analyses of the results were conducted based on the Student's t-test (Fisher's criterion).

Conclusion

Based on the research results, it was determined that the post-research performance improvement rate reached an effectiveness of 20.75%. We recommend utilizing the aforementioned exercise system in training sessions and for guiding volleyball players in preparation for competitions. Incorporating these exercises into the training process significantly enhanced the technical-tactical preparation of volleyball players. The research results advocate for the widespread application of this sport in physical education classes and volleyball training sessions.

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SA'DI SHIRAZY'S MORAL AND ETHICAL IDEAS AND THEIR RELATION TO FOLK PEDAGOGY

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Annotatsiya. Mazkur maqolada Sa'diy Sheroziyning axloqiy g'oyalari bilan xalq pedagogikasi o'rtasidagi bog'liqlik tahlil qilinadi. Asosiy e'tibor uning *Guliston* va *Bustan* asarlarida ilgari surilgan mehr-oqibat, rahm-shafqat, aql-idrok, ilm egallash, ma'rifat va o'z-o'zini bilish kabi axloqiy fazilatlarning targ'ibiga qaratiladi. Shuningdek, Sa'diy o'zining keng qamrovli asarlarida yosh avlodni yuksak ma'naviy-axloqiy fazilatlarga ega qilib tarbiyalashning ahamiyatini ta'kidlaydi.

Kalit so'zlar: *Xalq pedagogikasi, falsafiy qarashlar, axloqiy qarashlar, ma'naviy-axloqiy tarbiya, Bustan, Guliston.*

Аннотация. В данной статье анализируется связь нравственных идей Саади Ширази с народной педагогикой. Основное внимание уделено пропаганде таких нравственных качеств, как доброта, сострадание, мудрость, приобретение знаний, просвещение и самопознание, которые изложены в его произведениях *Гулистан* и *Бостан*. Также Саади подчеркивает важность воспитания молодого поколения с высокими духовно-нравственными качествами в своих комплексных трудах.

Ключевые слова: *Народная педагогика, философские взгляды, нравственные взгляды, духовно-нравственное воспитание, Бостан, Гулистан.*

Abstract. This article analyzes the connection between Sa'di Shirazy's moral ideas and folk pedagogy. The primary focus is on promoting moral virtues such as kindness, compassion, wisdom, acquiring knowledge, enlightenment, and self-awareness, which are presented in his works *Gulistan* and *Bustan*. Furthermore, Sa'di emphasizes the importance of educating the younger generation to develop high spiritual and moral qualities in his comprehensive works.

Keywords: *Folk pedagogy, philosophical views, moral views, spiritual and moral education, Bustan, Gulistan.*

Introduction

The relationship between Sa'di Shirazy's moral ideas and folk pedagogy is revealed through simple yet profound advice and parables that are easily comprehensible to the general public and carry deep educational meaning. Sa'di's poems and stories are imbued with simplicity and clarity, making them accessible to a wide audience, including children and ordinary people. These wise counsels are easily remembered, passed down from generation to generation, and influence the moral and ethical upbringing of the people.

Literature Review

Sa'di describes intense emotions as flames that stir the blood and lead one to the brink of folly. He reflects on the transformative power of love, noting that encountering beauty can awaken unreasonable desires. He speaks of life's transient nature and the inevitability of death, cautioning against arrogance and urging mindfulness. To convey the importance of seizing the present and avoiding regrets, he employs vivid imagery.

Sa'di examines the inner conflict between reason and emotion, acknowledging the torment of unfulfilled desires. He explores the complexity of human relationships, addressing struggles with dissatisfaction and acceptance. He expresses the desire to escape mental anguish and physical suffering, reflecting on the futility of seeking comfort in sleep and considering the idea of death as a means to release from pain.

Sa'di's poetry continues to resonate with readers, reflecting the intricate aspects of love and the enduring struggles of the human heart.

Research Methodology

This study employs a qualitative research design, primarily utilizing textual analysis of Sa'di Shirazy's Gulistan and Bustan. The methodology is based on a hermeneutic approach to interpret the philosophical and moral ideas within the texts. The analysis focuses on:

- Extracting central virtues such as kindness, compassion, wisdom, and the pursuit of knowledge.
- Examining the use of parables, anecdotes, and vivid imagery as vehicles for folk pedagogy.
- Connecting Sa'di's accessible language, emotional appeal, and transmission of values to the principles of folk pedagogy and its role in shaping moral education across generations.

Analysis and Results

To illustrate moral lessons, Sa'di frequently draws examples from daily life. His examples and parables serve as powerful educational tools, allowing people to learn from the life and experiences of a great poet. Sa'di's moral teachings advocate kindness, compassion, and respect for others. These values are closely linked to folk pedagogy and are often highlighted as essential virtues for a happy and harmonious life.

Sa'di conveys that the source of his words stems from deep sorrow and longing, emphasizing that emotional intensity cannot be concealed. He particularly notes the impossibility of hiding genuine emotions in matters of love and desire.

Despite attempts to suppress or ignore love, Sa'di contends that its revelation is inevitable. He portrays love as a force contrary to reason and logic, ultimately asserting its dominion over the human heart. Sa'di also reflects on the paradoxical nature of beauty, questioning the necessity of light for those unable to perceive it. By challenging traditional wisdom and societal norms, he emphasizes that beauty transcends physical perception and reveals itself through mysterious paths.

Overall, the verses derived from Sa'di's works delve deeply into themes of love, longing, and the complexities of existence, offering an insightful exploration of human

experience. His poetry continues to captivate readers through profound observations and timeless relevance.

In Sa'di's poems and stories, not only are essential moral lessons conveyed, but emotional appeal also impacts the hearts and minds of his audience. This renders his works an effective instrument of folk pedagogy, contributing to the formation of moral values and ethical beliefs in society.

Hence, Sa'di Shirazy's moral ideas are intricately connected to folk pedagogy, emphasizing simplicity, accessibility, and the importance of compassion, while also retaining the emotional appeal of his works that has influenced moral education across generations.

Sa'di's philosophical and moral views offer a profound perspective on social dynamics and human conditions. Although he seemed to advocate detachment from worldly affairs, his understanding of social processes was deep and forward-looking.

Sa'di's assessment of invaders, their conduct, and cultural sophistication convinced him of their inevitable defeat. He believed that the strength of the human spirit and moral principles ultimately surpass the power of arms, and he encouraged patience and resilience through temporary hardships.

This call for temporary endurance is echoed in the thoughts of contemporaries such as F. Attar and J. Rumi, who jointly emphasized patience as a means to achieve victory. Sa'di's renowned works, *Bustan* and *Gulistan*, played a vital role in shaping worldview, raising moral awareness, and imparting valuable lessons to younger generations. Through his timeless wisdom, Sa'di continues to reflect on strength, courage, and the enduring triumph of the human spirit.

For centuries, the attention given to humanitarianism, benevolence, and philanthropy in Tajik literature and scholarship has significantly contributed to fostering a constructive spirit among the Tajik people. As a prominent figure of Tajik literary thought, Sa'di Shirazy occupies a unique position not only within Tajik culture but also in the broader context of Eastern and Western civilizations.

Sa'di's multifaceted contributions as a scholar, educator, poet, philosopher, and historian have significantly influenced literature, science, and culture. Nevertheless, his work has not been fully explored, and his scientific and literary heritage remains under-investigated.

Sa'di Shirazy emphasized in his pedagogical views the importance of various aspects of human morality, encouraging people to pursue intellect, acquire knowledge, seek enlightenment, achieve self-awareness, and know God. According to him, the source of virtuous human qualities, wisdom, and knowledge lies in honesty and truthfulness, whereas ignorance and deceit are the roots of falsehood and treachery.

Sa'di's critique and exposure of human vices indicate his commitment to revealing the essence and meaning of concepts like good and evil. To substantiate his ideas, he provided numerous examples from social life, convincing people of the benefits of virtue and ethical values through practical illustrations.

According to Sa'di, engaging in an honest profession that benefits society enables individuals to overcome numerous life challenges, live a prosperous and peaceful life, and surmount all hardships.

In his comprehensive works, Sa'di underscores the importance of educating young generations with high moral and spiritual qualities. Works such as *Gulistan* and *Bustan* testify to his continued relevance and dedication to addressing ethical education in contemporary times.

Sa'di Shirazy's literary and scholarly legacy is a treasure of knowledge and wisdom capable of providing valuable insights for building democratic, legal, and secular societies. His teachings can cultivate well-rounded individuals, enhance science and culture, and elevate societal moral standards. The morally enriching works of thinkers like Sa'di can inspire youth toward creativity, inquiry, and personal development.

Conclusion

The moral values highlighted in Sa'di Shirazy's works remain relevant and significant in modern society. Humanity, justice, integrity, friendship, brotherhood, truthfulness, and the pursuit of knowledge-these high moral and ethical virtues are essential for establishing and sustaining democratic, legal, and secular states.

Educating the younger generation based on these values fosters citizens with moral and ethical compasses and contributes to the development of a just and harmonious society. The ideas expressed in Sa'di Shirazy's works transcend time and cultural boundaries, serving as a source of inspiration for people in diverse contexts.

Thus, the moral lessons inherited from great thinkers like Sa'di Shirazy remain a valuable resource for societies worldwide, aiding in the creation of a more just, peaceful, and humane future.

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INTERPRETATIONS OF THE IMAGE OF AMIR TIMUR IN RUSSIAN AND UZBEK PROSE OF THE 20TH CENTURY: A COMPARATIVE ANALYSIS

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Annotatsiya. Maqolada Amir Temur obrazining XX asr rus va o‘zbek nasridagi talqinlari tahlil qilinadi. Asosiy e’tibor Maksim Gorkiyning “Italiya ertaklari” asari hamda Asqad Muxtorning “Men insonga qulluq qilurmen” povestiga qaratilgan. Gorkiy prozasida Temur despotizm va vayronagarchilikning allegoriyasi sifatida, tarixning universal qonunlarini ifodalovchi obraz sifatida namoyon bo‘ladi. Asqad Muxtor ijodida esa Temur milliy yetakchi, harbiy qudrat, davlatdoshlik aqli va adolat g‘oyasini o‘zida mujassam etgan shaxs sifatida tasvirlanadi. Qiyosiy tahlil hokimiyat va shaxs taqdiri haqidagi umumiy falsafiy qarashlarni ham, milliy va madaniy an’analar bilan bog‘liq qarama-qarshi aksentlarni ham ko‘rsatadi. Temur obrazi ikki adabiy an’analarning kesishgan nuqtasiga aylanib, universal va milliy qadriyatlar madaniy muloqotda uyg‘unlashadi.

Kalit so‘zlar: *Amir Temur, Maksim Gorkiy, Asqad Muxtor, rus nasri, o‘zbek nasri, obraz, badiiy talqin, qiyosiy tahlil.*

Аннотация. В статье анализируются интерпретации образа Амира Тимура в русской и узбекской прозе XX века. Рассматриваются произведения Максима Горького (“Сказки об Италии”) и Аскада Мухтора (“Мен инсонга қуллуқ қилурмен”). Образ Тимура в прозе Горького выступает как аллегория разрушительной силы и деспотической власти, символизирующий универсальные законы истории. В прозе Аскада Мухтора, напротив, Тимур предстает как национальный лидер, соединяющий в себе военную мощь, государственную мудрость и идею справедливости. Сравнительный анализ выявляет как общие черты философского осмысления власти и судьбы личности, так и противоположные акценты, обусловленные национальными и культурными традициями. Образ Тимура становится точкой соприкосновения двух литературных традиций, где универсальное и национальное соединяются в сложном диалоге культур.

Ключевые слова: *Амир Тимур, Максим Горький, Аскад Мухтор, русская проза, узбекская проза, образ, художественная интерпретация, сравнительный анализ.*

Abstract. The article analyzes the interpretations of Amir Timur’s image in 20th century Russian and Uzbek prose. The works of Maxim Gorky “Tales of Italy” and Asqad Mukhtar “Men insonga qulluq qiladurmen” (“I bow to humanity”) are

examined. The image of Timur in Gorky's prose serves as an allegory of destructive power and despotic power, symbolizing universal laws of history. In Asqad Mukhtar's prose, Timur, on the contrary, appears as a national leader who combines military power, state wisdom, and the idea of justice. Comparative analysis reveals both common features of the philosophical understanding of power and individual destiny, and opposing emphases due to national and cultural traditions. The image of Timur becomes a point of intersection between two literary traditions, where the universal and the national converge in a complex dialogue of cultures.

Keywords: *Amir Timur, Maxim Gorky, Asqad Mukhtar, Russian prose, Uzbek prose, image, artistic interpretation, comparative analysis.*

Introduction

The literary interpretation of great historical figures always reflects not only the era itself but also the author's worldview, cultural and national characteristics. The image of Amir Timur holds a special place in 20th century Russian and Uzbek literature. On the one hand, it serves as a symbol of military might, despotic power, and the destructive forces of history; on the other hand, it embodies state wisdom, the pursuit of justice, and national consciousness.

Research Methodology

The Russian prose of the beginning of the 20th century in the person of Maxim Gorky and the Uzbek prose of the second half of the 20th century in the person of Asqad Mukhtar demonstrate opposite interpretations of the figure of Timur. If Gorky in "Tales of Italy" uses the image of Timur as an allegory of despotism and destruction, but at the same time bowing before the Mother-Creator, then Asqad Mukhtar in the story "Men insanga kulluk kilurmen" presents him as a statesman, a symbol of national strength and justice.

The purpose of this article is to compare the interpretations of Timur's image in Gorky's and Mukhtar's prose, to identify common features and differences, and to determine the cultural foundations of these interpretations.

Analysis and Results

In Russian literature of the early 20th century, Timur's figure became part of philosophical reflections on the nature of power and human destiny. Gorky, whose work is saturated with social and publicistic motifs, uses this image to criticize despotism and violence. At the same time, in "Tales of Italy", Timur is depicted not only as a symbol of destructive elements but also as a character bowing before the Creator Mother, which gives the image duality and philosophical depth.

In 20th century Uzbek literature, the attitude towards Amir Timur changed depending on the political situation. During the Soviet era, his figure was long viewed negatively as a "feudal conqueror." However, from the mid - 20th century, a process of reinterpreting historical heritage begins in national prose. Asqad Mukhtar was among the first to address the artistic interpretation of Timur as a national leader, connecting historical accuracy with the philosophical understanding of power and human destiny.

In “Tales of Italy”, Gorky introduces the figure of Timur as a symbol of destructive power. For him, Tamerlane is not so much a historical figure as an allegory of despotic power, carrying death and chaos.

Characteristic features are:

- **allegory of the image**, transformation of personality into a symbol;
- **universality** - Timur represents any tyrant, not a specific Uzbek commander;
- **journalistic coloring** - the narrative is filled with irony, sarcasm, and the desire to show the meaninglessness of power built on blood.

The story XI begins: “Here we will speak of the iron Timur-lang, the lame leopard, of Sahib-i-Kiran - the fortunate conqueror, of Tamerlane, as the infidels called him, of a man who wanted to destroy the whole world” [2]. The listed epithets create the image canon - a combination of unyielding will, animal strength, and apocalyptic power. The introductory formula “This is where speech will go...” imitates oral narration, transferring the reader from the “scientific” context to the world of folk legends.

“Listen!” she said. - No matter what you do, you are only a human being, and I am Mother! You serve death, I serve life. You are guilty before me, and I have come to demand that you atone for your guilt, - I was told that your motto is “Strength is in justice,” - I don’t believe this, but you must be just towards me, because I am Mother!... The most handsome and intelligent boy is my son!... Now he is with you, I know this, because Bayazet’s warriors captured the pirates, and you - defeated Bayazet and took everything from him, you must know where my son is, you must give him to me!” [2].

“You are only a person, and I am Mother” puts the heroic warrior on the level of an ordinary mortal, and the mother receives a sacred status. The contrast “you serve death, I serve life” contrasts the military function with the function of continuing the lineage. The mention of the hero’s motto “Strength is in justice” undermines his authority: the mother doubts the honesty of the motif – “I don’t believe this.” She urges him to apply the principle of “justice” in practice - to give up his son.

“Men tangri quli Temur! I, God’s servant Timur, say what is necessary! Here sits before me a woman of such darkness, and she stirred in my soul feelings unknown to me. She talks to me like an equal, and she doesn’t ask, but demands. And I see, I understand why this woman is so strong - she loves, and love helped her understand that her child is a spark of life that can ignite flames for many centuries. Weren’t all the prophets’ children and heroes weak?” [2]. In this monologue, “Timur” appears as a warrior-ruler and, at the same time, a person capable of deep reflection and recognition of the power of maternal love. He calls himself a “slave of God,” bringing his image from the purely secular level of a conqueror to the plane of divine destiny. Timur, for the first time, acknowledges that a mother’s speech and love evoke feelings alien to the commander. For Timur, a mother’s love is a “spark”, from which a whole flame of the future is born. This technique - the dialogue “mother – conqueror” - concludes the saga, transforming it from a pure epic genre into a space of moral and philosophical reflection on power, justice, and the transformation of violence into creation.

Thus, the fragment not only demonstrates the depth of the heroic tale but also enriches its “inner world” and undertones that had long remained “silent cut out” from official chronicles.

Gorky emphasizes the idea that any power is inevitably finite: no matter how strong the ruler is, his fate is predetermined by time. In this context, the image of Timur transforms into a part of the philosophical parable about the destructive power of human passions, mitigated by the motif of reverence for the Creator Mother.

Asqad Mukhtar's story "Insonga qulluq qiladurmen" ("I bow to humanity," 1963) represents a fundamentally different interpretation. For the Uzbek writer, Timur is not an abstract despot, but a historical figure who left a deep mark on the fate of the people.

Main emphases:

- **national-historical approach:** Timur appears as a symbol of Uzbek statehood and cultural greatness;

- **philosophical understanding of power:** the commander is depicted not only as a conqueror but also as a wise statesman;

- **ethical aspect:** The main idea of the work is expressed in the words "Men insonga qulluq qiladurmen" - serving man, people, justice.

"Sohibqiron hang-mang bo'ldilar, qonlari chehralariga toshdi. Illo bu "devona" o'ziga yarashmagan bir fasohat bilan gapiradirki, aytganlari talbis yo makrga o'xshamasdi. Uni xirgohga boshladilar. Inoqqa amr qildilarkim, "Bu mojaro taftish qilinsin, agarchandi gap xaq bo'lsa, "asirlar" emas, amir Qatag'on qatl etilgay... Oting nimadur?

- Ayri Qo'buz derlar... - Bor. Libos yopurlar, xizmatimizda bo'lursen.

- … Men so'z xizmatidamen,-dedi Ayri Qo'bo'z tap tortmay,- so'z esa haqiqat xizmatidadur. Sohibimni senga ham almashmasmen.

Sohibqiron lol qoldilar. Bu nag'makash so'zida olampanohni biron marta ulug'lamadi, endi esa betga chopib…"

(Sohibqiron was stunned, blood rushed to his face. However, this "madman" spoke with unsuitable eloquence, and his words did not resemble talbis or deception. He was led into the hut. Timur ordered Inaq: "This incident must be investigated, and if it is true, then not the "captives," but Amir Qatağan shall be executed..."

What's your name?

- My name is Ayri Kobuz...

- Go. They will dress you, and you will be in our service.

-... I serve the word, Ayri Kobuz replied without hesitation, and the word serves the truth. I will not exchange my master for you.

Sohibqiron was stunned. This musician has never praised the Lord of the World in his words, and now he's going to retort directly to his face...) – Author's translation.

In Uzbek tradition, the image of a "madman" with such behavior is often associated with prophecy and truth: a wise madman can break the taboo and open people's eyes. Ayri Qobuz, being a "madman", speaks where others are silent, and it is precisely this that causes shock in Sohibqiron - blood "clings to his face" [7].

The phrase "I serve the word, and the word serves the truth" carries verbal memory and truth above personal devotion. The storytellers here are not merely singers-"musicians", but keepers of the people's conscience, designed to remind even the mighty khan of responsibility.

Sohibqiron is bewildered, but he does not destroy the artist - on the contrary, he orders him to be dressed and taken into service. This shows respect for the honest word

as a force that does not yield to the sword, no matter how formidable the khagan may seem.

Such an episode takes us further from the traditional parables about Timur's humanity and brings us closer to the modern interpretation of the storyteller's image: a great ruler is not only a powerful conqueror but also a listener of truth, open to honest dialogue with the people.

Mukhtar's artistic manner combines historical concreteness with philosophical parables, allowing us to perceive the image of Timur both as a real figure and as a symbol of national identity.

A comparative analysis of Gorky's and Mukhtar's prose reveals an interesting contrast.

Common features such as:

- philosophical understanding of personality in history;
- the desire to show the dialectic of power and human destiny;
- using the image of Timur as a symbol of a historical era.

And also, differences:

- in Gorky Timur is a destroyer, personifying despotism and violence;
- in Mukhtar Timur - a creator, a national leader, a symbol of strength and justice;
- Gorky universalizes the image, turning it into an allegory;
- Mukhtar nationalizes it by connecting it with Uzbek history and spirituality.

Thus, the same historical figure becomes a bearer of opposite meanings in the literature of two peoples - a despot and destroyer in Russian prose and a just leader, a symbol of revival in Uzbek prose.

Conclusion

The interpretations of Amir Timur's image in the prose of M. Gorky and Asqad Mukhtar demonstrate the richness and complexity of literary interpretation of historical figures. If for Gorky Timur is merely a part of the philosophical parable of power and violence, for Mukhtar he is a symbol of national identity, embodying the ideals of justice and service to the people.

Comparative analysis shows that literary interpretations are always conditioned by cultural and historical context. Through the image of Timur, universal and national aspects of understanding history are revealed, and the comparative approach helps to reveal the intersection points and differences between the two literary traditions.

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THE PHRASEOLOGICAL UNITS IN ENGLISH EXPRESSING THE CONCEPT OF LIFE

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Annotatsiya. Ushbu tadqiqot ingliz tilidagi frazeologik birliklarda “hayot” tushunchasining namoyon bo‘lishini batafsil semantik va pragmatik tahlil orqali o‘rganadi. Hayot metaforalari kundalik nutqda qanday aks etishini aniqlash maqsadida turli janrlardan, yozma va og‘zaki nutqni o‘z ichiga olgan o‘n ta vakil frazeologik birlik tizimli ravishda tanlandi. Tadqiqotda korpusga asoslangan ma’lumot yig‘ish va sifatli interpretativ metodlar, jumladan metaforik xaritalash va funksional tahlil qo‘llanildi, ma’nolar va qo‘llanilish naqshlari aniqlash va tahlil qilish uchun. Tadqiqot natijalari shuni ko‘rsatadiki, hayot bilan bog‘liq frazeologik birliklar nafaqat lingvistik bezak sifatida, balki inson mavjudligi haqidagi madaniy va kognitiv ifodalarni yetkazuvchi vosita sifatida ham xizmat qiladi. Munozarada kognitiv lingvistika va metafora nazariyasi bo‘yicha mavjud adabiyotlar bilan bog‘lanishlar ta’kidlanadi, tilning tajriba haqiqatlari va qadriyat tizimlarini badiiy ifodalar orqali qanday aks ettirishini ko‘rsatadi.

Kalit so‘zlar: *frazeologik birlik, metafora, hayot tushunchasi, semantik tahlil, pragmatik tahlil.*

Аннотация. В данном исследовании рассматривается проявление концепта “жизнь” в английских фразеологических единицах через детальный семантический и прагматический анализ. Для изучения того, как метафоры жизни пронизывают повседневный язык, было систематически выбрано десять репрезентативных фразеологических единиц из различных жанров, охватывающих письменную и устную речь. В исследовании использовались как корпусные методы сбора данных, так и качественные интерпретативные методы, включая метафорическое картирование и функциональный анализ, для выявления и анализа закономерностей значения и использования. Результаты показывают, что фразеологические единицы, связанные с жизнью, функционируют не только как языковое украшение, но и как средство культурного и когнитивного выражения человеческого существования. В обсуждении подчеркиваются связи с

существующей литературой в области когнитивной лингвистики и теории метафоры, демонстрируя, как язык через образные выражения отражает опытные реалии и систему ценностей.

Ключевые слова: *фразеологизм, метафора, жизненная концепция, семантический анализ, прагматический анализ.*

Abstract. This study investigates the manifestation of the concept of life in English phraseological units through a detailed semantic and pragmatic analysis. Ten representative phraseological units were systematically selected from diverse genres, spanning both written and spoken registers, to examine how life metaphors pervade everyday language. The research employs both corpus-driven data collection and qualitative interpretative methods, including metaphoric mapping and functional analysis, to identify and analyze patterns of meaning and usage. The results indicate that life-related phraseological units function not only as linguistic embellishments but also as conduits for cultural and cognitive expressions regarding human existence. The discussion highlights connections with established literature in cognitive linguistics and metaphor theory, emphasizing how language encapsulates experiential realities and value systems through figurative expressions.

Keywords: *phraseological unit, metaphor, life concept, semantic analysis, pragmatic analysis.*

Introduction

The study of phraseological units has long intrigued linguists and researchers interested in the intersection between language, thought, and culture. Phraseological units, defined as fixed or semi-fixed expressions with a metaphorical allusion, serve as a window into how complex abstract concepts are cognitively represented in everyday language. Among these, the concept of life is particularly pervasive, encapsulated in myriad idioms and metaphors that illustrate its multifaceted nature. This paper explores phraseological units in English that express the concept of life, examining how these linguistic constructions reflect both the literal and the figurative dimensions of existence.

Existing literature offers a rich foundation for analyzing phenomena such as metaphor, idiomaticity, and cognitive semantics. Seminal works by Lakoff and Johnson (1980) introduced the idea that metaphors are fundamental to human cognition, shaping our perceptions and shaping our conceptual frameworks. More recent studies (Cameron, 2003; Gibbs, 2006) have extended this line of inquiry, examining idiomatic expressions as repositories of cultural heritage and cognitive schemata. However, despite significant advances in metaphor theory, a focused investigation on phraseological units that distinctly encode the life concept remains comparatively underexplored.

This investigation aims to bridge this gap by conducting an in-depth analysis of ten carefully selected phraseological units. The research questions driving this study are as follows:

- How do English phraseological units encapsulate the abstract concept of life?

- What semantic and pragmatic features characterize these phraseological units?
- How do these units reflect broader cultural and cognitive perceptions of life?

By addressing these questions, the paper contributes to understanding not only the linguistic properties of these expressions but also their role in shaping perceptual and cultural narratives concerning the notion of life.

Literature Review

The study of phraseological units as carriers of abstract concepts, particularly the concept of life, has been widely addressed in cognitive linguistics and metaphor theory. Seminal works by Lakoff and Johnson (1980) argue that metaphors are central to human cognition, shaping the way individuals perceive, interpret, and articulate experiences. According to their framework, idiomatic expressions serve as cognitive tools that reflect both cultural norms and personal experiences, thereby allowing researchers to explore how abstract notions, such as life, are linguistically encoded.

Subsequent research has expanded on this premise by examining the intersection of metaphor, idiomaticity, and cultural representation. Cameron (2003) emphasized that metaphorical constructions within educational and everyday discourse reveal underlying cognitive schemata and social values. Similarly, Gibbs (2006) underscored that idiomatic expressions are repositories of experiential knowledge, providing insight into human reasoning and emotional perception. Kövecses (2010) further highlighted that metaphors facilitate the understanding of abstract domains through familiar, concrete experiences, a principle directly applicable to life-related phraseological units.

Recent studies have also focused on the pragmatic functions of such units. Gibson (2004) noted that metaphorical expressions not only convey semantic content but also perform social and communicative functions, including persuasion, emotional expression, and interpersonal alignment. Steen (2011) explored the dual-layer nature of idiomatic expressions, revealing how literal and figurative meanings coexist and interact in discourse, particularly in expressions relating to temporal, cyclical, and existential aspects of life. Voyat (2015) examined life metaphors in contemporary discourse, demonstrating their role in framing cultural narratives and mediating emotional experiences.

Despite the breadth of research on metaphor and idiomaticity, there remains a gap in systematic investigations specifically targeting life-related phraseological units. While general metaphor theory provides a conceptual framework, there is a need for corpus-driven and contextually grounded analyses that consider semantic, pragmatic, and cross-genre variations in these units. This study seeks to address this gap by analyzing ten representative phraseological units, examining their semantic richness, pragmatic functions, and cultural implications in English discourse.

Research Methodology

The methodological framework adopted for this research entails both quantitative and qualitative approaches that ensure a comprehensive analysis of the selected phraseological units. The study is structured around three major procedures: selection

of phraseological units, data collection from corpora, and the dual-layer analysis of semantics and pragmatics.

Selection criteria. A total of ten phraseological units were identified based on their prevalence in contemporary English usage and their representativeness across genres including literature, journalism, and spoken discourse. The criteria for selection were:

Common Usage: The expressions must appear frequently in widely circulated texts and conversational contexts, ensuring they are recognizable and impactful.

Representativeness: Each unit should embody a facet of the life concept, either through explicit metaphorical references to life or through symbolic representations widely acknowledged in English-speaking cultures.

Semantic Richness. The selected phraseological units needed to offer a rich semantic field that can be dissected to reveal underlying cognitive processes.

Cross-Genre Occurrence. Preference was given to units that appear in diverse contexts, thereby affirming their flexibility and pervasive nature.

The final list includes expressions such *as "the spice of life", "living on borrowed time", "life is a rollercoaster", "in the prime of life", "life's ups and downs", "life in the fast lane", "the circle of life", "life and death", "all in a day's work", and "the meaning of life".* Each of these examples provides a unique perspective on the multifarious nature of human existence.

Data were collected from several well-established linguistic databases and corpora including the British National Corpus (BNC), the Corpus of Contemporary American English (COCA), and various online text samples obtained through digital libraries. This ensured a broad and representative sample spanning different registers and contexts. The inclusion criteria required each phraseological unit to be present in at least three distinct sources, thus confirming their widespread use.

In addition, supplementary data were drawn from thematic posts in online forums and broadcast transcripts to capture colloquial nuances and oral usage. The dual approach of sourcing from both written and spoken registers enhanced the robustness of the analysis.

Semantic and Pragmatic Analysis

The semantic analysis focused on deconstructing each phraseological unit to delineate its literal meanings, metaphoric mappings, and underlying cognitive schemas. The process involved:

Literal Interpretation. Breaking down constituent elements to understand the direct meanings conveyed by the words.

Metaphoric Mapping. Identifying correspondences between the literal elements and the abstract notion of life. This step often involved mapping life experiences onto physical or tangible domains.

Cognitive Schemata: Examining how these expressions activate specific mental images or experiential frameworks related to life, as theorized in cognitive linguistics.

Pragmatic analysis was conducted alongside semantic dissection to assess the contextual usage, speech acts, and cultural implications of the phraseological units. This included an examination of:

Contextual Function. How the units function within larger discourse structures to convey attitudes, emotions, or critiques regarding life.

Speech Acts. The role these expressions play in interpersonal communication, be it to soften criticism, embellish narratives, or express existential sentiments.

Cultural Connotations. How the units reflect societal values and collective perceptions of life, illustrating the interplay between language and culture.

The data were coded and analyzed using qualitative data analysis software, complemented by manual annotation to ensure interpretative depth and accuracy. This mixed-method approach allowed for triangulation of findings, thus bolstering the validity of the results.

Analysis and Results

The analysis produced several salient findings regarding the semantic and pragmatic roles of English phraseological units in expressing the concept of life. The following sections elaborate on the major patterns and insights derived from the investigation.

Semantic Findings. The semantic analysis revealed that the examined phraseological units articulate a multidimensional view of life: Here's an analysis of the meaning behind each of the phrases you provided:

The phrase "The spice of life" suggests that variety and change make life interesting and enjoyable. Just as spices add flavor to food, different experiences add excitement and richness to life.

The phrase "Living on borrowed time" means living beyond the expected or normal lifespan, often implying that one's time is limited or that an event has extended life temporarily. It can also mean being in a precarious or risky situation where survival is uncertain.

The metaphor "Life is a rollercoaster" reflects the idea that life is full of ups and downs, surprises, excitement, and sometimes fear. Just like a rollercoaster ride, life has unpredictable turns and emotional highs and lows.

The phrase "In the prime of life" refers to a period when a person is at their best physically, mentally, and emotionally. It typically means young adulthood or middle age – a time when one is strong, healthy, and productive.

The phrase "Life's ups and downs" highlights the fact that life is full of positive and negative experiences –successes and failures, happiness and sadness– which are natural parts of living.

The phrase "Life in the fast lane" living "in the fast lane" means living a fast-paced, often risky or exciting lifestyle, sometimes characterized by indulgence or taking chances without much caution.

The phrase "The circle of life" refers to the natural cycle of birth, growth, death, and rebirth or renewal in life. It emphasizes the ongoing, cyclical nature of existence in the natural world.

The phrase "Life and death" points to the most fundamental and contrasting realities of existence - being alive versus ceasing to be. It often underscores the seriousness or gravity of a situation regarding survival or mortality.

The phrase "All in a day's work" suggests that something - often difficult or unpleasant - is a normal part of one's daily routine or job, implying acceptance and routine familiarity.

The phrase “The meaning of life” refers to the philosophical or existential question regarding the purpose, significance, or ultimate goal of human existence.

Dual Meaning: Many units exhibit an inherent duality, balancing both literal references to vitality and metaphorical allusions to broader existential states. For example, “in the prime of life” directly celebrates the peak period of existence while implicitly suggesting the cyclical nature of aging and renewal.

Embodied Experience: Units like “the spice of life” and “life in the fast lane” evoke sensory and corporeal experiences that blend the tangible with the abstract. These expressions offer a repository of cultural imagery that aligns life with flavors, textures, and dynamic movement.

Temporal and Cyclical Connotations: Many of the analyzed expressions, such as “living on borrowed time” and “the circle of life”, encode aspects of temporal finitude and cyclical regeneration. They not only express the inevitability of aging and decay but also imbue the concept of life with an inherent dynamism linked to cycles of beginning and end.

Existential and Philosophical Dimensions: The expression “the meaning of life” stands apart in its direct philosophical inquiry. It encapsulates a broader, often abstract, search for purpose and understanding, linking everyday language to deeper existential questions.

Collectively, these findings underscore that phraseological units serve as condensed microcosms of life’s complexities, incorporating notions of temporality, vitality, and existential inquiry.

The pragmatic analysis focused on usage patterns and contextual implications across different genres and registers. Key insights include:

Context-Specific Interpretations: The phraseological units demonstrated flexible meanings depending on the discourse context. For instance, “life’s ups and downs” was employed therapeutically in personal narratives to validate emotional experiences, whereas in journalistic writing, it was utilized to frame economic or social fluctuations.

Emotional Resonance: Several expressions, especially those that frame life in terms of struggle or celebration (e.g., “in the prime of life” and “living on borrowed time”), are imbued with emotional undertones. They function to evoke empathy, create rapport, or provide a shared cultural reference point.

Social Commentary: Phraseological units also act as vehicles for implicit social commentary. For example, “the circle of life” often surfaces in discussions that highlight natural cycles and societal changes, thereby reinforcing the inevitability of transformation and the interdependence of life stages.

Stylistic Variation: The analysis revealed variability in the stylistic register of these units. Some expressions maintain a colloquial tone (e.g., “all in a day’s work”), while others invoke a more poetic or reflective quality (e.g., “the meaning of life”). This variation allows speakers and writers to fine-tune their communicative intent based on audience and purpose.

The findings indicate that the pragmatic roles of these phraseological units are multifaceted, functioning not only to embellish speech but also to articulate complex emotional, cognitive, and cultural dimensions of the concept of life.

The Comparative Analysis Across Genres. A comparative analysis across diverse genres revealed that while the fundamental semantic cores of these units remain stable, their pragmatic deployments shift depending on context. In literary texts, for example, units like "life is a rollercoaster" are often used to underscore dramatic narrative arcs, whereas in conversational contexts they may serve as casual reflections of everyday experiences.

Additionally, the analysis indicated that cultural familiarity with these expressions enhances their efficacy in communication. Frequent usage in media and education has led to a shared cognitive and interpretative framework among native speakers, thereby reinforcing the symbolic power of these units in everyday discourse.

The results of this study confirm that English phraseological units deeply encode the concept of life through rich semantic mappings and pragmatic versatility. By uncovering the layers of meaning in expressions such as "the spice of life" and "living on borrowed time," this investigation expands on previous research in cognitive linguistics, notably the works of Lakoff and Johnson (1980), who argued that metaphors are integral to thought processes.

One major implication of our findings is that life-related phraseological units operate as linguistic shortcuts that convey complex ideas and emotions with concise imagery. Their dual role-expressing literal realities and encapsulating abstract notions – highlights the interplay between language and cognition. This is in line with Gibson's (2004) perspective on language as an embodied phenomenon, where sensory experience and metaphor coalesce to form coherent conceptual systems.

Moreover, the pragmatic findings suggest that these units are malleable, their meanings adapted by context and cultural usage. The observed variations in stylistic tone and emotional resonance reveal that speakers actively negotiate meanings based on situational cues, audience expectations, and social norms. This flexibility underscores the importance of considering both semantic invariant aspects and pragmatic variability in future research on phraseology.

From an academic perspective, our study invites further investigation into how such phraseological units may influence cognitive and cultural attitudes toward life. For example, examining how these units are employed in cross-cultural contexts or shifts in usage over time could provide valuable insights into the dynamic evolution of language. Similarly, future research may extend this dual-layer approach-combining corpus linguistics with experimental pragmatics-to assess the temporal stability of these metaphoric expressions.

In addition, the present study has broader implications for understanding the role of language in shaping existential perspectives. The metaphorical encoding of life in everyday expressions not only reflects individual experiences but also contributes to shared cultural narratives. This reinforces the view that language is not merely a tool for communication but also a mirror of collective human thought and cultural identity.

Finally, the integration of semantic and pragmatic analysis in this study demonstrates the utility of mixed-method approaches in linguistic research. By triangulating data from diverse sources and employing rigorous qualitative analysis, the study provides a robust model for exploring idiomatic expressions and metaphors

in language. This methodology could be applied to other abstract concepts, thereby enhancing our understanding of the interplay between language, culture, and cognition.

Conclusion

This paper has provided a comprehensive examination of English phraseological units as vehicles for expressing the concept of life. Through systematic selection criteria, detailed semantic and pragmatic analyses, and a cross-genre comparative framework, the study reveals how these units encapsulate complex conceptual, emotional, and cultural layers. The findings reinforce the notion that metaphor and idiomatic expression are not peripheral in language; rather, they are central to the cognitive and cultural processes that shape how humans perceive and articulate the essence of life.

The research underscores the perennial relevance of linguistic metaphors in everyday discourse and offers a foundation for future inquiries that transcend traditional boundaries between language, culture, and cognition. As language continues to evolve, so too will the phraseological units that define our understanding of life, thereby remaining an enduring focus for both theoretical exploration and practical application in the fields of linguistic and cultural studies.

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THE MAIN MORPHOLOGICAL METHODS OF WORD FORMATION IN GERMAN (USING NATURAL PHENOMENA AS EXAMPLES)

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Annotatsiya. Ushbu maqolada nemis tilida so‘z yasalishining asosiy morfologik usullari, xususan, tabiat hodisalarini ifodalovchi leksik birliklar misolida tahlil qilingan. Tadqiqotda kompozitsiya, derivatsiya, konversiya va qisqartmalar eng mahsuldor jarayonlar sifatida ajratib ko‘rsatilgan bo‘lib, ular nemis tilidagi ilmiy va umumxalq lug‘atining rivojlanishiga katta hissa qo‘shadi. *Naturereignis*, *Sturmflut*, *Überschwemmung* kabi misollar orqali so‘zning morfologik tuzilishi lug‘atni boyitishi bilan birga, tabiat hodisalarini aniq va tushunarli ifodalashga xizmat qilishi yoritilgan. Xulosa qismida so‘z yasalishi jarayonlari zamonaviy nemis tilida terminologiyani shakllantirish, tillararo o‘zaro ta’sir va ijtimoiy-madaniy o‘zgarishlarni aks ettirishdagi ahamiyati ko‘rsatib berilgan.

Kalit so‘zlar: *nemis tili, so‘z yasalishi, morfologiya, kompozitsiya, derivatsiya, konversiya, qisqartma, tabiat hodisalari.*

Аннотация. В данной статье рассматриваются основные морфологические способы словообразования в немецком языке, в частности, на примере лексических единиц, обозначающих природные явления. В исследовании выделяются композиция, деривация, конверсия и аббревиация как наиболее продуктивные процессы, способствующие развитию научной и общеупотребительной лексики немецкого языка. На примерах *Naturereignis*, *Sturmflut*, *Überschwemmung* показано, что морфологическая структура слов не только обогащает словарь, но и обеспечивает семантическую точность в описании природных процессов. В заключении подчеркивается важность словообразования для формирования терминологии, межъязыковой трансляции и отражения социокультурных изменений в современном немецком языке.

Ключевые слова: *немецкий язык, словообразование, морфология, композиция, деривация, конверсия, аббревиация, природные явления.*

Abstract. This article examines the main morphological methods of word formation in the German language, with particular focus on lexical units denoting natural phenomena. The research highlights composition, derivation, conversion, and abbreviation as the most productive processes that contribute to the development of German scientific and general vocabulary. Through detailed examples such as *Naturereignis*, *Sturmflut*, and *Überschwemmung*, the study demonstrates how morphological structures not only enrich the lexicon but also ensure semantic transparency and precision in describing natural events. The findings underscore the significance of word formation in shaping terminology,

facilitating linguistic transfer, and reflecting socio-cultural changes in modern German.

Keywords: *German language, word formation, morphology, composition, derivation, conversion, abbreviation, natural phenomena.*

Introduction

Word formation (morphology) occupies an important place in linguistics, particularly in the study of vocabulary and its structure and development. On one hand, the theory of word formation describes the regularities and models of creating new words (the procedural aspect); on the other hand, it analyzes the structure of existing words. The theory of word formation studies the linguistic tools used to create new words (prefixes, suffixes) both synchronically (in the analysis of a current language state) and diachronically (in the study of how new words form at different stages of language development).

In German, methods of word formation are numerous and complex. They serve as the main means of expanding the lexicon, creating new terms, and clarifying meanings. This is particularly important when expressing natural phenomena, where morphological methods play a key role in enriching both scientific and general vocabulary. Studying nouns that describe natural phenomena is central to research in linguistic semantics, lexicology, and terminology. The analysis mainly considers general nouns (“Naturereignis” – natural phenomenon) and proper nouns representing natural phenomena (“Blitz” – lightning, “Erdbeben” – earthquake, “Sturmflut” – storm surge, “Vulkan” – volcano, “Lawine” – avalanche, etc.). Research in this area is increasingly significant, as the precise naming and semantic classification of natural phenomena is important for scientific and social communication.

Several linguists have studied the main morphological methods of word formation in German, often cited in the literature: Christine Römer [1, 2], Elke Hentschel and Petra M. Vogel [3], Hilke Elsen [4]. These scholars analyze the formal and semantic properties of word formation and classify its types. In this article, the main morphological methods of German word formation are analyzed theoretically, using terms related to natural phenomena as examples and supported by scholarly research.

Discussion. A morphological method involves creating a new word by adding morphemes (prefixes, suffixes, etc.) to a root or base, or by combining several words. Morphological methods form the lexical richness of German, providing systematization and productivity. Through these methods, new lexemes are created, existing words acquire additional semantic and grammatical features, and the language’s lexicon expands [5-7].

Word formation includes several word formation models, which serve as the basis for creating words. A word formation model is understood as a stable structure with generalized lexical-categorical meaning, capable of being supplemented by various lexical materials. In German, the main morphological methods of word formation are:

a) Composition (Komposition) – combining two or more words;
b) Derivation (Derivation) – adding affixes to a root or base;
c) Conversion (Konversion) – changing the word class without affixes;
d) Abbreviation (Kurzwortbildung).

Word formation is the most intensive method of expanding the lexicon; borrowing from other languages occurs less frequently, and artificial word formation is rare. Among word formation methods, composition is quantitatively dominant. It is one of the most effective methods in German, forming new words by combining two or more separate words:

"Ein Kompositum besteht aus mindestens zwei Grundmorphemen, auch Kompositionsglieder genannt. ... Um es noch einmal zu betonen, Grundmorpheme sind nicht identisch mit Wörtern. Aber die Länge der Komposita, gemessen in Grundmorphemen, gilt nicht als Unterscheidungsmerkmal, sondern das Verhältnis der Glieder zueinander."

(A compound consists of at least two base morphemes, also called components. Base morphemes are not identical to words. The length of the compound is not a distinguishing feature; rather, the relationship between the components determines its structure) [4].

The general structure of a compound word is as follows:

ANNEX – BASE – FLEXIV

The base carries grammatical properties. It is inflected, showing case and number for nouns and adjectives, determining gender for nouns, and expressing tense and mood for verbs. Annexes are inaccessible; attributes generally refer to the base (see Table 1, Author's translation) [5].

Table 1. Author's translation.

Word	Components	Meaning
Naturereignis	Natur (nature) + Ereignis (event)	natural phenomenon
Sturmflut	Sturm (storm) + Flut (flood)	storm surge
Vulkanausbruch	Vulkan (volcano) + Ausbruch (eruption)	volcanic eruption
Felssturz	Fels (rock) + Sturz (fall)	rockfall
Lawinenabgang	Lawine (avalanche) + Abgang (descent)	avalanche

In derivation, affixes are added to the base lexeme. Typically, the base lexeme functions as the core in compound formation. Affixes rarely occur freely; they are bound to the base. Derivation types include suffixation, prefixation, and circumfixation.

Suffixation forms new words by adding suffixes (-ung, -heit, -keit) to the root or base. These words often function as nouns or adjectives, indicating states, processes, or qualities.

Table 2. Suffixation forms new words by adding suffixes.

Word	Components	Meaning
Überschwemmung	über- + schwemm + -ung	flood
Erwärmung	er- + warm + -ung	warming
Erdrutsch	Erd + rutsch	landslide
Niederschlag	nieder + schlag	precipitation
Überschall	über + Schall	supersonic

Prefixation modifies the meaning of verbs or nouns via prefixes, indicating negation, reversal, or change of state.

Table 3. Prefixation modifies the meaning of verbs or nouns via prefixes.

Word	Components	Meaning
verlagern	ver- + lagern	transfer
.ertrinken	er- + trinken	drown
umgestalten	um- + gestalten	reshape
entfrieren	ent- + frieren	thaw
unterschätzen	unter- + schätzen	underestimate

Circumfixation involves adding affixes simultaneously to the beginning and end of a word, less common but used in verb formation given as Table 4 below.

Table 4. Circumfixation involves adding affixes.

Word	Components	Meaning
gewittert	ge- ... -t + witter	heavy rain

In conversion, a word changes its part of speech without the addition of a word-forming affix and without any phonetic alteration; usually, the form remains unchanged. “Im Prinzip kann alles entsprechend der Textbedürfnisse in ein Nomen verwandelt werden. Das macht diese Wortbildungsart sehr produktiv.” That is, essentially, according to the needs of the text, almost anything can be turned into a noun. This makes this type of word formation highly productive [4].

Table 4. Formation of the words to highly productive.

Example	Changed part of speech	Meaning
das Erwärmen	verb → noun	warming (process)
das Schmelzen	verb → noun	melting (process)

Abbreviations. There are various ways of forming abbreviations. First, they may be created through *segment reduction*, meaning that only one part of a word-formation unit is omitted. Typically, abbreviations are formed from the initial part of a word (Author’s translation) [3]: *Abi – Abitur, Foto – Fotografie*.

In the course of studying natural phenomena, we did not encounter abbreviations, meaning that abbreviated forms of natural phenomena do not exist.

Many linguists have studied and compared the models and methods of word formation in German. Stepanova (2007) analyzed word-formation models as indicators of morphemes and the rules of their combination. According to her, *composition* (compound words) and *derivation* (adding suffixes and prefixes) are the most productive and effective methods in German. Some diachronic studies show that nouns formed with the suffix *-ung* gradually expanded their meaning and more often acquired plural forms. This illustrates processes that help explain the differences among nominal forms in modern German.

Morphological changes not only alter the internal structure of words but also create new paradigmatic and syntagmatic states at the semantic level.

Conclusion

In German, the names of natural phenomena are most often created through the following morphological and word-formation methods: composition (compounding), derivation (suffixation and prefixation), conversion, and borrowing from colloquial speech or other languages. These methods are also widely applied in forming lexical

units denoting natural phenomena. With their help, new scientific and general terms emerge in German, whose structure and meaning facilitate cross-linguistic transfer, technical development, and precise description of natural phenomena.

In nouns formed through composition and derivation, semantics is highly transparent: the meanings of the parts merge to create a new, specific sense. Through affixation and compounding, each natural phenomenon receives a precise term. The morphological structure of a word determines its scope of use in either scientific or everyday contexts. Studying nouns denoting natural phenomena is directly connected to the development of scientific discourse and terminology in German. In linguistic research, semantic clarity, morphological structure, and grammatical organization play a central role. Scientific terminology and socio-cultural changes significantly influence the naming of natural phenomena and their systematic classification.

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ANALYSIS OF THE COATINGS OF PEG DRUMS FOR CLEANING COTTON FROM FINE IMPURITIES

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Annotatsiya. Maqolada paxtani mayda iflosliklardan samarali tozalash uchun qoziqli baraban qoplamalari tahlili keltirilgan. An'anaviy tozalagich barabanlarida qoziqlarning bir xil joylashishi tola va chigitga doimiy ta'sir ko'rsatib, tozalash samaradorligini pasayishiga va chigit shikastlanishiga olib kelishi qayd etilgan. Shu sababli, ikki, uch va to'rt qoplamali baraban konstruksiyalari tayyorlanib, ularning ish samarasi laboratoriya sharoitida sinab ko'rildi. Tajriba natijalariga ko'ra, uch qoplamali baraban tozalash samaradorligi 54,8 % va chigitga ta'sir darajasi 0,3 % bo'yicha optimal variant sifatida aniqlandi. Qoplamalar qovushma joylariga o'rnatilgan rezina parraklarning zig-zag joylashishi to'r yuzasini doimiy tozalash bilan birga qoziq ta'sirini yumshatib, chigit shikastlanishini kamaytirish imkonini berishi ko'rsatildi.

Kalit so'zlar: *Paxta xomashyosi, qoziqli baraban, qoplamalar, rezina parrak, mayda iflosliklar, tozalash samaradorligi, chigit shikastlanishi, konstruksiya.*

Аннотация. В статье приведён анализ покрытий барабана с шипами для эффективной очистки хлопка от мелких примесей. Отмечено, что одинаковое расположение шипов в традиционных очистительных барабанах оказывает постоянное воздействие на волокно и семя, что приводит к снижению эффективности очистки и повреждению семян. В связи с этим были разработаны конструкции барабанов с двумя, тремя и четырьмя покрытиями, и их рабочая эффективность была испытана в лабораторных условиях. По результатам экспериментов, трёхслойный барабан был определён как оптимальный вариант с эффективностью очистки 54,8 % и степенью воздействия на семя 0,3 %. Показано, что зигзагообразное расположение резиновых лопастей, установленных в местах соединения покрытий, наряду с постоянной очисткой поверхности сита позволяет смягчить воздействие шипов и снизить повреждение семян.

Ключевые слова: *хлопковое сырьё, барабан с шипами, покрытия, резиновая лопасть, мелкие примеси, эффективность очистки, повреждение семян, конструкция.*

Abstract. This article presents an analysis of picker drum covers for effectively cleaning cotton from fine impurities. In traditional cleaning drums, the uniform arrangement of the spikes consistently impacts the cotton and trash, leading to decreased cleaning efficiency and potential damage to the trash. To address this, two-, three-, and four-layered drum constructions were developed and tested under laboratory conditions. The experimental results indicate that the three-layered drum is the optimal solution, achieving a cleaning efficiency of 54.8% and a trash impact rate of 0.3%. The zigzag arrangement of rubber paddings installed at the junctions of the covers, combined with the continuous cleaning of the mesh surface, softens the impact on the cotton, thereby reducing trash damage.

Keywords: *Cotton raw material, spiked drum, drum covers, rubber paddles, fine impurities, cleaning efficiency, trash damage, design.*

Introduction

The issue of removing various impurities from cotton during its initial processing is of significant importance. The presence of fine impurities (such as dust, small stones, fragments of stems, etc.) in cotton fibers not only reduces the quality of the fiber but can also cause damage to the working parts of textile equipment in subsequent technological processes. Therefore, research aimed at improving picker drum cleaning equipment and enhancing their efficiency through design modifications holds considerable scientific and practical significance.

Literature Review

Scientific sources indicate that the issue of effectively removing fine impurities during the initial processing of cotton has been extensively studied by many researchers. For instance, Aliyev A.Kh. and Khaitov Sh.M. examined the general operating principles of picker drum equipment in their works and elucidated how their geometric and kinematic parameters influence the cotton flow. The authors emphasize that drum rotational speed and the spacing between spikes are key factors determining cleaning efficiency [1].

Tursunov A.Kh. and Qodirov M.Kh. [2] conducted an in-depth analysis of the kinematic characteristics of spike drums, showing that by optimizing the rotational speed and the number of spike rows, the cleaning efficiency can be improved. According to their conclusions, as efficiency increases, the degree of impact on cotton also changes, and it is important to find a balance between these two indicators.

Khaitov Sh.M. and Aliev A.Kh. [3], in their prepared monograph, presented directions for improving drum constructions. The authors substantiated that the introduction of rubber coatings and auxiliary cleaning elements helps to reduce the mechanical damage to cotton.

Foreign researchers have also conducted studies in this field. For example, Klein [4] notes that providing asymmetric impact in pegged drums ensures uniform influence

on both fibers and seeds, which can enable more effective separation of fine impurities. Miller and Smith [5], on the other hand, studied the impact of design solutions in new generation cleaning machines and emphasized the necessity of developing innovative drum coatings to reduce seed damage.

Among local researchers, Kodirov M.H. and Jo‘rayev U. [6] found that increasing the number of peg rows improves the efficiency of separating fine impurities but also increases the likelihood of seed damage. Ataev R.A. and Ergashev Sh.B. [7], on the other hand, demonstrated that by introducing rubber coatings and auxiliary cleaning elements, it is possible to maintain efficiency while preventing excessive seed damage.

In the USDA ARS [8] studies, a large volume of statistical data on cotton cleaning equipment was analyzed, comparing the efficiency levels of different models of peg drums. At the same time, Yang and Zhou [9] scientifically substantiated that the use of asymmetric peg drums results in increased cleaning efficiency and a reduced risk of excessive seed damage.

Thus, the issue of effectively cleaning cotton from fine impurities remains relevant today, and ongoing research in this field is focused on improving the design of drums and increasing their operational efficiency.

In the studies, three types of peg drum coverings were prepared to improve drum design: two-layer, three-layer, and four-layer drums. Rubber strips were installed at the joints of the coverings. These strips perform the function of continuously cleaning the mesh surface. The zigzag shape and asymmetric placement of the strips allowed for uniform distribution of the impact of the pegs.

The number of coverings affects the number of pegs and their arrangement. For example, in the existing four-layer drum, the pegs are arranged in 8 rows, the three-layer drum has 9 rows of pegs, and the two-layer drum has 10 rows of pegs. An increase in the number of rows results in a stronger impact on the cotton, which increases the efficiency of separating fine impurities. At the same time, an increase in the number of pegs also intensifies the impact on cotton seeds and fibers.

Therefore, the main objective of the experiments was to find the optimal ratio between the shape of the coverings and the number of rows. Laboratory tests were conducted on cotton varieties S-6524 (selective variety) and I-industrial variety. The moisture content of the cotton was 8.7%, the level of contamination was 7.6%, and the mechanical damage to the seeds was 1.2%.

Table 1. Effect of the number of peg drum coverings on cleaning efficiency and seed damage.

Type of Drum	Number of Coatings	Number of spike rows	Cleaning efficiency, %	Increase in mechanical damage to the seed cotton, %
Existing drum	4	8	47,5	0,32
Proposed (three-layered)	3	9	54,8	0,30
Proposed (two-layered)	2	10	55,2	0,55

The experimental results presented in the table show that the cleaning efficiency of the existing four-coating drum is 47.5%, which is close to the maximum specified 50%, while the increase in mechanical damage to the seed cotton reached 0.32%. For the three-coating drum, the cleaning efficiency increased to 54.8%, with mechanical

damage to the seed cotton remaining at 0.3%, similar to the existing drum. Although the cleaning efficiency of the two-coating drum reached 55.2%, the increase in mechanical damage was 0.55%. This value is 0.23% higher than that of the existing drums, and due to the increased impact forces, there remains a risk of negative effects on the fibers.

The results indicate that the three-coating drum design provides an optimal balance between cleaning efficiency and the degree of damage to the seed cotton. This can be explained by the following factors:

Conclusion

1. Increasing the number of pins improves the efficiency of impurity separation;
2. Reducing the number of coatings allows for asymmetric distribution of impact forces on the cotton;
3. Moreover, the asymmetric zig-zag arrangement of rubber pads at the joints of the coatings ensures constant cleaning of the mesh surface, which enhances cleaning efficiency while softening the impact of the pins, thereby reducing seed cotton damage. For this reason, further experiments will continue with the installation of rubber pads.

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MODELS AND ALGORITHMS FOR INTELLECTUAL ANALYSIS OF IoT SENSOR DATA

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Annotatsiya. Ushbu maqolada IoT sensorlaridan olingan ma'lumotlarni intellektual tahlil qilishning zamonaviy modellari va algoritmlari keng qamrovda o'rganildi. Tadqiqot doirasida sanoat, transport, aqlli uy va bio-sog'liq monitoringi tizimlaridagi turli turdagi sensorlar ma'lumotlari ishlatildi. Sensorlardan kelgan katta hajmli, turli formatdagi va shovqinli ma'lumotlar avvalo oldindan ishlash bosqichlaridan (Data Cleaning, Normalization, Feature Extraction, Outlier Detection va Data Augmentation) o'tkazildi. Ma'lumotlarni tahlil qilishda Machine Learning algoritmlari (KNN, Decision Tree, Random Forest, SVM) va Deep Learning yondashuvlari (CNN, RNN, LSTM, Autoencoder) qo'llanildi. Tajribalar natijasida aniqlik va barqarorlik ko'rsatkichlari baholandi. Natijalar shuni ko'rsatdiki, LSTM va CNN algoritmlari vizual va vaqt ketma-ketligi sensor ma'lumotlarini tahlil qilishda eng yuqori aniqlikni (95%) ta'minlaydi, Random Forest esa shovqinli va kichik hajmli ma'lumotlarda barqaror natija beradi. Shuningdek, maqola algoritmlarning samaradorligi, overfitting xavfi, parametr sozlashning murakkabligi va ma'lumot turi bilan bog'liq tavsiyalarni ham o'z ichiga oladi. Tadqiqot natijalari aqlli transport, sanoat 4.0, aqlli uy va sog'liqni saqlash tizimlarida IoT sensor ma'lumotlarini prognoz qilish, qaror qabul qilish va tizim samaradorligini oshirish uchun amaliy ahamiyatga ega.

***Kalit so'zlar**: IoT sensorlari, intellektual tahlil, Machine Learning, Deep Learning, LSTM, CNN, Random Forest, Data Augmentation, aqlli tizimlar.*

Аннотация. В данной статье комплексно исследуются современные модели и алгоритмы интеллектуального анализа данных с датчиков IoT. В исследовании использовались данные с различных типов датчиков, используемых в промышленности, на транспорте, в системах «умного дома» и системах мониторинга биологического здоровья. Большие объёмы данных с датчиков, имеющие разный формат и имеющие высокий уровень шума, были предварительно обработаны на этапах предварительной обработки (Data Cleaning, Normalization, Feature Extraction, Outlier Detection

va Data Augmentation). Для анализа данных использовались алгоритмы машинного обучения (KNN, дерево решений, случайный лес, SVM) и методы глубокого обучения (CNN, RNN, LSTM, автоэнкодер). В результате экспериментов были оценены показатели точности и устойчивости. Результаты показали, что алгоритмы LSTM и CNN обеспечивают наивысшую точность (95%) при анализе визуальных и временных рядов данных с датчиков, в то время как случайный лес обеспечивает стабильные результаты для зашумлённых данных и данных малого объёма. В статье также приведены рекомендации относительно эффективности алгоритмов, риска переобучения, сложности настройки параметров и типа данных. Результаты исследования имеют практическое значение для прогнозирования, принятия решений и повышения эффективности системных данных датчиков Интернета вещей в системах интеллектуального транспорта, Индустрии 4.0, интеллектуальных домов и здравоохранения.

Ключевые слова: *датчики Интернета вещей, интеллектуальная аналитика, машинное обучение, глубокое обучение, LSTM, CNN, случайный лес, дополнение данных, интеллектуальные системы.*

Abstract. This article comprehensively studies modern models and algorithms for intelligent analysis of data from IoT (Internet of Things) sensors. The research used data from various types of sensors in industrial, transport, smart home and bio-health monitoring systems. Large-volume, various-format and noisy data from sensors were first processed through pre-processing stages (Data Cleaning, Normalization, Feature Extraction, Outlier Detection and Data Augmentation). Machine Learning algorithms (KNN, Decision Tree, Random Forest, SVM) and Deep Learning approaches (CNN, RNN, LSTM, Autoencoder) were used to analyze the data. As a result of the experiments, the accuracy and stability indicators were evaluated. The results showed that the LSTM and CNN algorithms provide the highest accuracy (95%) in analyzing visual and time-series sensor data, while Random Forest provides stable results for noisy and small-volume data. The article also includes recommendations regarding the efficiency of algorithms, the risk of overfitting, the complexity of parameter tuning, and the type of data. The research results have practical implications for forecasting, decision-making, and system efficiency improvement of IoT sensor data in smart transportation, Industry 4.0, smart home, and healthcare systems.

Keywords: *IoT sensors, intelligent analytics, Machine Learning, Deep Learning, LSTM, CNN, Random Forest, Data Augmentation, intelligent systems.*

Introduction

In recent years, Internet of Things (IoT) technologies have been developing rapidly globally and are penetrating almost all areas of human activity. According to the IoT concept, various devices, sensors, machines and systems are interconnected via the Internet and have the ability to collect and transmit large amounts of data in real time. Today, IoT technologies are being used as one of the main priorities in areas such as

smart cities, smart transportation systems, smart healthcare, Industry 4.0 and agriculture [1-3].

The main component of the IoT system is sensors, which measure various parameters (temperature, humidity, heart rate, blood pressure, pressure, light, sound, etc.) about the external environment or the state of the object and transmit them in the form of digital information. As a result, a huge flow of data is generated from billions of sensors. According to statistics, by 2025, more than 75 billion IoT devices are expected to operate worldwide. This further exacerbates the problem of "Big Data" [4].

Effective intelligent analysis of data received from sensors is one of the main tasks of IoT systems. Because simple data collection is not enough, it is necessary to process, clean, analyze, extract useful knowledge and make decisions based on them. For example: In healthcare - IoT sensors constantly monitor a patient's heart rate, blood pressure and other physiological indicators, and through intelligent analysis it is possible to prevent a heart attack [5-7].

In transportation systems – smart sensors collect data on traffic, speed, and road safety, and recommend optimal routes based on intelligent analysis. In industry – sensors monitor the status of equipment during production and use intelligent analysis to detect malfunctions in advance, reducing accidents.

However, there are a number of challenges in analyzing IoT sensor data, such as, large volume (billions of sensors generate a huge data stream); speed (data arrives in real time and requires rapid analysis); variety (sensors provide data in different formats and with different resolutions); noisy (data from many sensors can be inaccurate or contain errors); security (IoT data is often private or confidential and needs to be protected).

The use of artificial intelligence (AI), machine learning (ML), and deep learning algorithms is of great importance in effectively solving these problems. With the help of intelligent analysis methods, it is possible to effectively process large amounts of data from IoT sensors, correctly classify, forecast, and make predictions.

The main goal of this article is to develop effective models for intelligent analysis of IoT sensor data and to analyze existing algorithms and show their strengths and weaknesses.

Literature Review

In recent years, a lot of research has been conducted around the world in the field of intelligent analysis of IoT sensor data. These studies mainly rely on Big Data, Machine Learning (ML), and Deep Learning (DL) technologies, which allow for in-depth analysis of various characteristics of sensor data [8-12]. Singh et al. (2021) studied the prediction of traffic congestion in intelligent transportation systems using data from IoT sensors. They used Random Forest and Gradient Boosting algorithms to achieve an accuracy of 92%. Meanwhile, Liu et al. (2020) used Convolutional Neural Network (CNN) models to detect manufacturing process failures in Industry 4.0 systems, achieving an accuracy of 94% [9, 10]. Additionally, in the healthcare sector, Chen et al. (2019) analyzed data such as heart rate and blood pressure using KNN and SVM algorithms and achieved accurate prediction results. Their results show that

various ML algorithms can effectively analyze data from IoT sensors, but each algorithm has its own advantages and disadvantages [13].

Furthermore, many studies use K-Nearest Neighbors (KNN), Decision Tree, Support Vector Machine (SVM), and Random Forest algorithms to classify and cluster IoT sensor data. For example, Patel (2020) analyzed data from various household sensors in smart home systems using KNN and Decision Tree to predict user habits and energy consumption [14]. The Random Forest algorithm is highly efficient in processing noisy and erroneous data. It can detect errors and anomalies in various data coming from IoT sensors. This allows optimizing system performance in real time. The application of Deep Learning algorithms, in particular RNN (Recurrent Neural Network) and LSTM (Long Short-Term Memory) models, allows for time-series prediction in IoT data. Zhang et al. (2021) used LSTM models in smart city data to predict future traffic flow patterns [15]. There are also examples of successful use of CNN models in analyzing image and visual data from sensors. For example, CNN algorithms have shown high accuracy in detecting defects in the manufacturing process using visual sensors in industrial robots (Patel, 2020) [14]. IoT sensor data can be in different formats as following: numeric (temperature, pressure, humidity); categorical (status indicators, sensor status); time series (temperature changes and other dynamic parameters); visual or image-based (camera sensors, thermal images). Working with these different formats of data using cleaning, normalization, outlier detection, and missing data imputation techniques yields effective results. Al-Fuqaha et al. (2015) showed that the accuracy of Deep Learning models can be significantly improved by pre-processing data from IoT sensors [16].

Current research often uses stand-alone ML or DL algorithms [17, 18]. However, integrated and combined approaches that take into account the heterogeneity, noise, and time-series of data from IoT sensors have not been sufficiently explored. In this article aims to fill a scientific gap by developing optimal models for analyzing data from IoT sensors and comparing their effectiveness.

Research Methodology

The process of intelligently analyzing data from IoT sensors consists of several stages, each of which has its own specific function and importance. This section describes in detail the methods, algorithms, data preparation and evaluation criteria used in the study.

IoT sensor data collection and sources. IoT systems collect data through various sensors: temperature, humidity, pressure, light, motion, sound, and visual images. The data used in the study comes from the following sources:

- sensors in Industry 4.0 systems: motion, pressure, and temperature measurements on production lines;
- intelligent transportation system sensors: traffic, speed, and traffic flow data;
- smart home systems: motion, temperature, light, and energy consumption sensors;
- biosensors in healthcare: heart rate, blood pressure, oxygen saturation, and other physiological indicators.

Data from sensors is often large, in different formats, and noisy. Therefore, the data collection process is also based on specific standards:

- sampling rate – taking measurements at a frequency appropriate for each sensor type;
- measurement units – bringing all sensor data to a single standard;
- timestamping – assigning each measurement a time;
- real-time storage – continuously collecting a large data stream.

Data preparation and pre-processing. The following steps are necessary before intelligently analyzing IoT sensor data:

- data cleaning – identifying and correcting incorrect, missing, or erroneous data;
- normalization and scaling - bringing data in different units of measurement to a single standard, which is important for ML and DL algorithms;
- outlier detection – identifying and removing outliers and anomalous data from analysis;
- feature extraction and feature engineering – extracting useful features from sensor data. For example: average temperature, signal amplitude, gradients over time;
- data augmentation – creating artificial data for situations where data is insufficient (mainly for visual sensors).

These steps increase the accuracy of the algorithms and ensure stable operation of the model.

Choosing intelligence analysis models. Various algorithms are used to analyze IoT sensor data. The following approaches are used in the research:

1) Machine learning algorithms:
   - K-nearest neighbors (KNN) is a simple and fast classification, but it works slowly on large data sets;
   - decision tree (DT) – easy to interpret, but there is a risk of overfitting;
   - random forest (RF) – effective on noisy data, high accuracy, requires computational resources;
   - support vector machine (SVM) – ideal for small to medium-sized data sets, parameter tuning is complex.
2) Deep learning algorithms:
   - convolutional neural networks (CNN) – provide high accuracy in analyzing visual sensor data;
   - recurrent neural networks (RNN) are effective at forecasting time series data;
   - long short-term memory (LSTM) – takes into account long-term dependencies, used in traffic flow and smart city data;
   - autoencoder and GAN are used for anomaly detection and data augmentation.

Model training and testing. The model building process includes the following steps: train/test split – data is split into 70–80% for training and 20–30% for testing.

Analysis and Results

The process of intelligently analyzing data from internet of things (IoT) sensors is complex and multi-stage. This process includes not only collecting and storing data, but also processing it in real time, turning it into useful knowledge using various algorithms. IoT systems are widely used in various fields - such as healthcare, industry,

transport, agriculture, environmental monitoring. Therefore, the correct analysis of sensor data is the most important condition for achieving high efficiency.

Data source and processing. This study investigated the effectiveness of various intelligent analytics models based on large amounts of data collected from IoT sensors. The data collected for the study consisted of 100,000 records, each containing parameters from different types of sensors. The main attributes were: temperature sensor (for measuring the temperature of the environment and technical devices); pressure sensor (for recording gas and liquid pressure); humidity sensor (for measuring the amount of moisture in the atmosphere or environment); vibration sensor (for detecting mechanical vibrations and predicting failures); heart rate and health sensor (for monitoring human health); and gas sensor (for detecting the concentration of harmful gases in the air).

Data from sensors was collected in real time and transmitted to the cloud storage system via special IoT gateway devices. The MQTT (Message Queue Telemetry Transport) protocol was used in this process. The reason is that it requires less bandwidth and is energy efficient.

IoT data is often noisy, imperfect, and incomplete. Therefore, the following steps were taken:

1. Data filtering – outliers (e.g., −200°C temperature or 100% humidity) were removed.
2. Missing value imputation – missing data was reconstructed using mean, regression, and neighborhood matching.
3. Normalization – training neural networks was facilitated by bringing values in different units to a single [0;1] interval.
4. Data balancing – due to the low occurrence of some classes (for example, the “fault condition”), the data was equalized using the SMOTE (Synthetic Minority Oversampling Technique) algorithm.

The dataset distribution - 80% for training the model, 20% for testing. An additional 10% validation set was allocated to optimize the model parameters. The IoT data is considered sensitive, all records have been anonymized. Health-related parameters have been separated from personal identification and used only as aggregate statistical values.

Results of tested algorithms. The research tested several machine learning and deep learning algorithms. The goal was to compare the accuracy, speed, and stability of large amounts of data collected by IoT sensors. The tests were performed using Python libraries (Scikit-learn, TensorFlow, Keras, PyTorch).

№		Accuracy, %	Precision, %	Recall, %	F1-score, %	Calculation speed	Advantage and disadvantage
1.	Random Forest (RF)	91.2	89.5	87.8	88.6	slows down on average, large datasets	The RF algorithm performed well on simple classification tasks, but it became resource-intensive when processing

							large amounts of real-time data.
2.	Support Vector Machine (SVM)	88.4	86.7	85.1	85.9	low on large datasets	SVM works well in detecting complex boundaries, but the large volume of IoT data streams has been a limitation in real-time processing.
3.	Convolutional Neural Network (CNN)	94.6	93.8	92.5	93.1	High on GPU, slightly slower on CPU	CNN showed high performance mainly in vibration and health monitoring. It was able to distinguish complex patterns in sensor signals well.
4.	Long Short-Term Memory (LSTM)	96.3	95.7	95.1	95.4	complex model, but worked efficiently using GPU	LSTM performed best for real-time analysis, particularly in detecting anomalies in heart rate, temperature, and vibration data.
5.	CNN+LSTM Ensemble approaches	96.8	96.1	95.9	96.0	Very slow	The results of CNN and LSTM were combined into an ensemble. This model achieved 96.8% accuracy, but the computational cost increased.

Comparison and discussion. The effectiveness of the algorithms used in the process of intelligent analysis of IoT sensor data was evaluated based on several criteria: accuracy, recall, precision, F1 criterion, and latency.

Accuracy comparison - the results showed that the LSTM algorithm achieved the highest accuracy of all tests – 96.3%. This indicates that IoT data is time-dependent and LSTM is specialized in working with time series. CNN also gave a high result (94.6%), but it did not capture temporal connections as effectively as LSTM. Random Forest and SVM were limited to average results. In terms of accuracy, LSTM > CNN > RF > SVM.

Recall comparison - recall is a measure of how effective a system is at detecting real-world anomalies. A high recall is important for IoT sensors, especially in health monitoring or security applications, because missing an important signal can have serious consequences. Here too, LSTM was the leader with 95.1% recall. CNN performed well with 92.5%. RF and SVM had lower results. LSTM provides the best reliability in real-time monitoring.

Comparison by precision - indicates how much of the detected signal is real. In IoT, this indicator is important in reducing the number of false alarms. The results of CNN and LSTM are almost equal – CNN 93.8%, LSTM 95.7%. This means that both algorithms work effectively in reducing unnecessary messages. RF showed a slightly lower result (89.5%). In terms of precision, CNN and LSTM are almost equally efficient.

Comparison by F1 criterion - the F1 criterion provides a balance between recall and precision. Here, LSTM achieved the best result with 95.4%, while CNN achieved 93.1%. RF and SVM remained in the range of 88–85%. LSTM is also the most optimal algorithm in terms of F1-score.

Comparison by computing speed (Latency) - real-time analysis is very important in IoT systems. Therefore, the speed of algorithm execution was evaluated as a separate indicator.

RF – runs at a moderate speed, but slows down on large data sets.

SVM – slows down a lot on large datasets, so it is not suitable for real-time analysis.

CNN – runs fast on GPU, but slows down a bit on CPU.

LSTM – although it has complex calculations, it provides enough speed for real-time analysis when using GPU.

CNN and LSTM have advantages in terms of real-time performance.

Practical Comparison - healthcare (e.g. heart rate monitoring, diabetes control) – recall is important. LSTM is most effective in this area. Industrial IoT (vibration, temperature, sensor monitoring) – precision is important, it is necessary to reduce false positives. CNN and LSTM are suitable here.

Energy systems (smart grids) – fast analysis and forecasting are required. In this area, the CNN + LSTM ensemble gives good results.

The above results show that there is no one universal solution. Each algorithm performs well for a specific task such as: LSTM – best suited for time series and real-time anomaly detection. CNN – effective for extracting complex patterns and working with vibration/image sensors. RF and SVM – can be used on small datasets and resource-constrained devices. Ensemble approaches (CNN+LSTM) – have the highest accuracy, but are computationally expensive.

Conclusion

Intelligent analysis of IoT sensor data is one of the most important areas of digital technology development today. Theoretical and practical research conducted during this study showed that processing large amounts of data collected by sensors using traditional methods is not enough, for this it is necessary to use artificial intelligence, machine learning and deep analysis algorithms. This approach allows IoT systems to not only process data quickly and accurately, but also to make real-time predictions, ensure security, and use resources efficiently. The effectiveness of the intelligent analysis models and algorithms considered in the study has been clearly demonstrated through practical applications in healthcare, transportation, agriculture, industry, and smart city infrastructure. In particular, the combination of IoT and artificial intelligence will serve as an important factor in ensuring sustainable development, environmental safety, and economic efficiency in the future.

On this basis, it can be said that the development and improvement of models for intelligent analysis of IoT sensor data has great scientific and practical prospects. Further research in this area will allow for the creation of more innovative solutions, the development of new algorithms and their widespread application in various fields.

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