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Манаш Қабашұлы Қозыбаевтың
95 жылдығына арналған «ҚОЗЫБАЕВ ОҚУЛАРЫ - 2026:
БОЛАШАҚ ЭКОЖҮЙЕСІ, ТЕХНОЛОГИЯЛАР МЕН АДАМ
КАПИТАЛЫН ДАМУДЫҢ СИНЕРГИЯСЫ»
ХАЛЫҚАРАЛЫҚ ҒЫЛЫМИ-ТӘЖІРИБЕЛІК КОНФЕРЕНЦИЯСЫНЫҢ

МАТЕРИАЛДАРЫ

МАТЕРИАЛЫ

МЕЖДУНАРОДНОЙ НАУЧНО-ПРАКТИЧЕСКОЙ КОНФЕРЕНЦИИ
«КОЗЫБАЕВСКИЕ ЧТЕНИЯ - 2026: ЭКОСИСТЕМА БУДУЩЕГО,
СИНЕРГИЯ ТЕХНОЛОГИЙ И РАЗВИТИЯ ЧЕЛОВЕЧЕСКОГО КАПИТАЛА»,
посвящённой 95-летию выдающегося казахстанского учёного-историка,
академика Манаша Кабашевича Козыбаева



Петропавловск, 2026

ҚАЗАҚСТАН РЕСПУБЛИКАСЫ ҒЫЛЫМ ЖӘНЕ ЖОҒАРЫ БІЛІМ МИНИСТРЛІГІ
М. Қозыбаев атындағы Солтүстік Қазақстан университеті

**Манаш Қабашұлы Қозыбаевтың 95 жылдығына арналған
«Қозыбаев оқулары - 2026: болашақ экожүйесі, технологиялар
мен адам капиталын дамытудың синергиясы» халықаралық
ғылыми-тәжірибелік конференциясының**

МАТЕРИАЛДАРЫ

(10 сәуір)

МАТЕРИАЛЫ

**Международной научно-практической конференции
«Козыбаевские чтения - 2026: экосистема будущего, синергия
технологий и развития человеческого капитала», посвященная
95-летию выдающегося казахстанского ученого-историка,
академика Манаша Козыбаева**

(10 апреля)



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2026**

Based on the above information, the data obtained from the existing observation network cannot fully and accurately describe the current development and changes. Therefore, further hydrogeological research work must be carried out in the following areas:

- collection of data on the state of groundwater resources by conducting seasonal and long-term observations of groundwater levels and hydrochemical changes;
- collection of information on the state of groundwater resources and the main natural and man-made factors contributing to their pollution by collecting information on climatic factors and economic conditions;
- it is advisable to study the quality of underground water resources influenced by the natural ecosystem, urbanized areas, reservoirs, main canals, large collectors, the processes of salinization around them, and the effects of technogenesis, including flooding.

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SYNTHESIS AND COMPARATIVE CHARACTERIZATION OF METAL–ORGANIC FRAMEWORKS AND ZEOLITIC IMIDAZOLATE FRAMEWORKS: EFFECT OF SYNTHESIS CONDITIONS ON STRUCTURE AND YIELD

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Андатпа: Бұл жұмыста цирконий негізіндегі металлоорганикалық қаңқалардың (UiO-66, UiO-66-NH₂) және цеолиттәрізді имидазолаттық қаңқалардың (ZIF-8, ZIF-67) синтезі мен салыстырмалы бағасы ұсынылған. Зерттеуде синтез шарттары, құрылымның қалыптасу механизмдері және өнім шығымы арасындағы байланыс қарастырылған. Сольвотермиялық кристалдану және ерітіндіден тұндыру әдістері координация кинетикасы, процестің тиімділігі және құрылымдық сипаттамалар тұрғысынан жүйелі түрде талданды. Нәтижелер көрсеткендей, UiO-66-NH₂ шығымы (76,6%) UiO-66-ға (71,2%) қарағанда жоғары, бұл лиганд функционализациясының оң әсерін дәлелдейді. Сонымен қатар, ZIF-8 және ZIF-67 сәйкесінше 78,6% және 81,2% жоғары шығым көрсетеді, бұл тұндыру әдісінің тиімділігін растайды. ZIF жүйелерінің жоғары тиімділігі металл–лиганд координациясының жылдам жүруімен және нуклеацияның төмен энергия тосқауылдарымен түсіндіріледі. Жалпы алғанда, синтез әдісі құрылым мен өнім шығымына шешуші әсер етеді: ZIF материалдары синтез тиімділігі бойынша MOF-тен жоғары, ал MOF құрылымды басқаруда артықшылыққа ие.

Түйін сөздер: MOF, ZIF, UiO-66, координациялық химия, синтез, шығым, нуклеация.

Аннотация: В работе представлен синтез и сравнительная оценка цирконийсодержащих металлоорганических каркасов (UiO-66, UiO-66-NH₂) и цеолитоподобных имидазолатных каркасов (ZIF-8, ZIF-67) с акцентом на взаимосвязь между условиями синтеза, механизмами формирования и выходом продукта. Проведено систематическое сравнение двух подходов - сольвотермальной кристаллизации и осаждения из раствора - с точки зрения кинетики координации, эффективности процесса и структурных характеристик. Показано, что UiO-66-NH₂ характеризуется более высоким выходом (76,6%) по сравнению с UiO-66 (71,2%), что свидетельствует о положительном влиянии функционализации лиганда.

В то же время ZIF-8 и ZIF-67 демонстрируют более высокие выходы - 78,6% и 81,2% соответственно, что подтверждает эффективность метода осаждения. Повышенная эффективность ZIF-систем обусловлена быстрой координацией металл-лиганд и низкими энергетическими барьерами нуклеации. В целом установлено, что метод синтеза играет определяющую роль в формировании структуры и выходе продукта: ZIF-материалы превосходят MOF по эффективности синтеза, тогда как MOF обеспечивают более высокий контроль структуры.

Ключевые слова: MOF, ZIF, UiO-66, координационная химия, синтез, выход, нуклеация.

Annotation: This study presents the synthesis and comparative evaluation of zirconium-based metal-organic frameworks (UiO-66, UiO-66-NH₂) and zeolitic imidazolate frameworks (ZIF-8, ZIF-67), with a focus on the relationship between synthesis conditions, formation mechanisms, and product yield. Two distinct synthetic approaches-solvothermal crystallization and solution-phase precipitation-were systematically analyzed in terms of coordination kinetics, process efficiency, and structural outcomes. The results show that UiO-66-NH₂ exhibits a higher yield (76.6%) compared to UiO-66 (71.2%), indicating the positive effect of ligand functionalization. In contrast, ZIF-8 and ZIF-67 demonstrate significantly higher yields of 78.6% and 81.2%, respectively, confirming the greater efficiency of precipitation-based synthesis. The enhanced performance of ZIF systems is attributed to rapid metal-ligand coordination and lower nucleation energy barriers. Overall, the findings confirm that the synthesis route plays a decisive role in determining both yield and structural organization, with ZIF materials outperforming MOFs in terms of synthesis efficiency, while MOFs provide greater control over framework formation.

Keywords: MOF, ZIF, UiO-66, coordination chemistry, synthesis, yield, nucleation.

Metal-organic frameworks (MOFs) and zeolitic imidazolate frameworks (ZIFs) constitute an important class of porous coordination materials characterized by high surface area, tunable porosity, and adjustable chemical functionality. These features enable their application in adsorption, catalysis, and separation technologies [1-3].

Despite substantial progress in this field, the relationship between synthesis parameters and structural formation remains insufficiently understood. In particular, comparative studies addressing the influence of different synthesis routes on both yield and crystallization mechanisms are still limited [3,4].

The aim of this work is to synthesize UiO-66, UiO-66-NH₂, ZIF-8, and ZIF-67 and to comparatively evaluate how synthesis conditions affect yield, structural characteristics, and formation mechanisms [1,5].

Materials and Methods

In this study, MOF and ZIF materials were synthesized using solution-based methods in a DMF medium.

MOF Synthesis

The synthesis of zirconium-based frameworks was carried out using a solvothermal method in dimethylformamide (DMF). The reaction system included a zirconium precursor, terephthalic acid or 2-aminoterephthalic acid, and benzoic acid as a modulating agent[4,5].

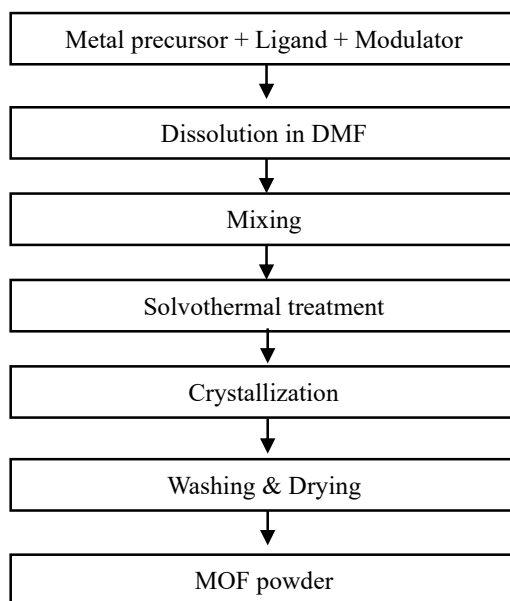
The molar ratios of the components were as follows:

UiO-66: 1 : 0.66 : 16.7

UiO-66-NH₂: 1 : 0.55 : 16.7

The reaction mixture was homogenized in DMF to ensure uniform distribution of reactants, followed by solvothermal treatment in a sealed autoclave, where nucleation and crystal growth occurred under controlled temperature conditions [4]. The presence of the modulator played a key role in regulating the crystallization kinetics and particle size by competing for coordination sites [5].

After synthesis, the solid products were isolated and subjected to repeated washing with organic solvents to remove unreacted species and residual modulator. The materials were then dried under controlled conditions to obtain fine crystalline powders.



Scheme 1 – Scheme of MOF synthesis (UiO-66 and UiO-66-NH₂)

The yields of the synthesized materials were:

UiO-66 — 71.2%

UiO-66-NH₂ — 76.6%

ZIF Synthesis

ZIF materials were synthesized via a precipitation method involving rapid coordination of Zn²⁺ and Co²⁺ ions with imidazolate ligands. [6,7].

The molar ratios of the reactants were as follows:

ZIF-8: 1 : 16

ZIF-67: 1 : 36

The synthesis procedure included mixing of metal salt and ligand solutions under continuous stirring, leading to rapid nucleation and formation of a crystalline precipitate. The resulting suspension was subjected to an aging process to ensure complete crystallization [6].

The obtained solids were separated by centrifugation, followed by repeated washing with DMF and ethanol to remove unreacted species and residual solvent. The purified materials were then dried under controlled conditions to obtain fine powder products [7].

The yields of the synthesized materials were:

ZIF-8 — 78.6%

ZIF-67 — 81.2%

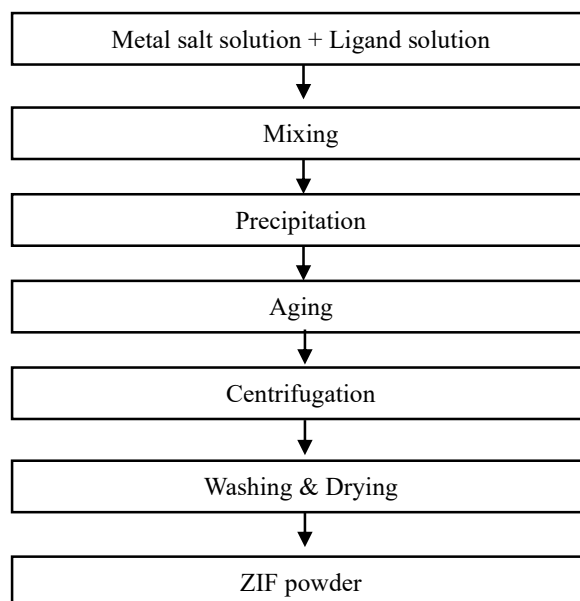
Theoretical Background and Formation Mechanisms

MOF formation is based on coordination interactions between zirconium clusters and carboxylate groups of the ligand, resulting in a three-dimensional framework.

The formation of Zr₆O₄(OH)₄ clusters plays a key role in the structural stability of UiO-66. The presence of a modulator controls crystal growth and defect formation.

In ZIF synthesis, rapid coordination between metal ions (Zn²⁺, Co²⁺) and imidazolate ligands leads to nucleation and crystal growth.

The M–N coordination bonds form structures analogous to zeolites, providing high chemical and thermal stability.



Scheme 2 – Schematic representation of ZIF synthesis (ZIF-8 and ZIF-67)

Results and Discussion

The synthesis resulted in crystalline powder materials with well-defined morphology.

The yield of UiO-66-NH₂ (76.6%) is higher than that of UiO-66 (71.2%), which may be attributed to the presence of amino groups enhancing coordination interactions.

ZIF materials showed higher yields overall, with ZIF-67 (81.2%) exhibiting the highest value, likely due to stronger coordination of Co²⁺ ions.

Comparison of synthesis methods shows that:

the solvothermal method provides better structural control;

the precipitation method is simpler and yields higher product output.

The novelty of this work lies in the comparative analysis of synthesis methods and the relationship between synthesis conditions, structure, and yield of MOF and ZIF materials.

The formation of UiO-type frameworks involves a multi-step assembly of zirconium oxo-clusters followed by coordination with dicarboxylate linkers. The presence of a modulator introduces competitive coordination, slowing down crystal growth and enabling structural control. In UiO-66-NH₂, amino functional groups enhance donor–acceptor interactions, leading to more efficient nucleation and increased yield. In contrast, ZIF formation proceeds through direct metal–nitrogen coordination, resulting in rapid framework construction and reduced sensitivity to synthesis conditions

Table 1 — Comparative Characteristics

Material	Type	Ratio	Method	Color	Yield
UiO-66	MOF	1:0.66:16.7	Solvothermal	White	71.2%
UiO-66-NH ₂	MOF	1:0.55:16.7	Solvothermal	Light yellow	76.6%
ZIF-8	ZIF	1:16	Precipitation	White	78.6%
ZIF-67	ZIF	1:36	Precipitation	Purple	81.2%

The data demonstrate a clear advantage of ZIF systems in terms of synthesis efficiency.

Microscopic Analysis of MOF and ZIF Structures

Microscopic analysis was performed to evaluate the morphology, particle size distribution, and structural uniformity of the synthesized materials (Figure 1). Observations

were carried out at a magnification of $\times 100$, which allowed for the assessment of general particle morphology and aggregation behavior.

The UiO-66 and UiO-66-NH₂ samples exhibited relatively uniform but aggregated structures. The particles were predominantly irregular polyhedral in shape, forming loosely packed clusters. This morphology is consistent with the solvothermal synthesis mechanism, where crystal growth occurs gradually through the formation of zirconium oxo-clusters. The presence of a modulator contributed to partial control of crystal growth; however, aggregation was still observed. In the case of UiO-66-NH₂, slightly improved dispersion and reduced aggregation were noted, which can be attributed to the presence of amino functional groups enhancing interparticle interactions and stabilization.

In contrast, ZIF-8 and ZIF-67 samples demonstrated more homogeneous particle distribution and clearer crystalline features even at $\times 100$ magnification. ZIF-8 appeared as finely dispersed particles with relatively smooth morphology, whereas ZIF-67 exhibited well-defined faceted polyhedral structures. The observed uniformity is associated with the rapid nucleation characteristic of precipitation synthesis, which limits excessive crystal growth and promotes the formation of smaller particles.

The differences in morphology between MOF and ZIF systems can be explained by their distinct formation mechanisms. The multi-step assembly of zirconium-based clusters in MOFs leads to slower nucleation and crystal growth, resulting in larger particles and aggregation. In contrast, the fast coordination between metal ions and imidazolate ligands in ZIF systems accelerates nucleation and restricts crystal growth, leading to finer and more uniformly distributed particles.

Overall, microscopic analysis confirms that the synthesis method significantly influences particle morphology and structural homogeneity. ZIF materials exhibit higher dispersion and uniformity, while MOF systems demonstrate more controlled but slower crystal growth, resulting in larger structural domains.

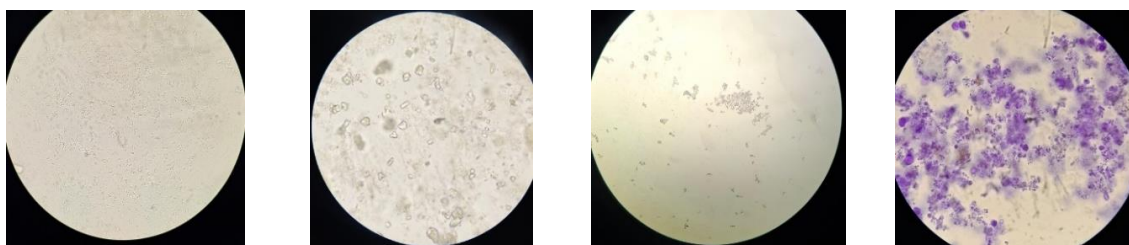


Figure 1 –Microscopic images of synthesized materials at $\times 100$ magnification: (a) UiO-66, (b) UiO-66-NH₂, (c) ZIF-8, (d) ZIF-67

MOF and ZIF materials were successfully synthesized using solvothermal and precipitation methods. The higher yield of UiO-66-NH₂ can be attributed to the presence of electron-donating amino groups, which enhance coordination interactions and stabilize intermediate species. The precipitation method ensures higher yield and operational simplicity.

The observed differences in yield are governed by coordination chemistry: Zr–O cluster formation is a multi-step process with slower kinetics, whereas Zn–N and Co–N bond formation occurs rapidly. Thus, ZIF systems demonstrate higher kinetic efficiency, while MOFs provide greater structural tunability.

Microscopic analysis at $\times 100$ magnification confirmed that MOF samples are characterized by larger, aggregated polyhedral particles formed under controlled but slower crystal growth conditions, while ZIF materials exhibit finer, more uniformly distributed particles with well-defined crystalline morphology due to rapid nucleation. These

observations are consistent with the proposed formation mechanisms and further support the relationship between synthesis method and structural organization.

The study confirms that the synthesis method significantly influences both yield and structural properties of MOF and ZIF materials. Ligand functionalization improves MOF formation efficiency, whereas ZIF systems offer higher productivity due to rapid coordination-driven assembly.

These findings highlight the importance of integrating coordination chemistry principles with process engineering strategies for the development of advanced porous materials.

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ҚҰЗЫРЕТТІЛІК ТӘСІЛДІ ЖҮЗЕГЕ АСЫРУДАҒЫ ПӘНАРАЛЫҚ БАЙЛАНЫСТАРДЫҢ РӨЛІ

Абилов К.М.

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Аңдатпа: Мақалада қазіргі білім беру жүйесінде құзыреттілік тәсілді жүзеге асырудағы пәнаралық байланыстардың рөлі қарастырылады. Білім алушылардың негізгі және кәсіби құзыреттерін қалыптастыру шарты ретінде әртүрлі оқу пәндеріндегі білімді ықпалдастырудың қажеттілігі негізделеді. Пәнаралық ұғымның теориялық тәсілдері талданып, оның сыни ойлауды дамытуға, кешенді мәселелерді шешу қабілетіне және білімді практикалық қызметте қолдануға ықпалы көрсетіледі. Оқу үдерісін пәнаралық байланыстар негізінде ұйымдастырудың әдістемелік аспектілеріне, соның ішінде жобалық қызметке, кейс-әдістерге және проблемалық оқытуға ерекше назар аударылады. Білім беру тәжірибесіне пәнаралық тапсырмаларды тиімді енгізудің мысалдары келтіріледі. Пәнаралық байланыстарды жүйелі қолдану білім сапасын арттыруға және құзыреттілік тәсілді толық жүзеге асыруға ықпал ететіні туралы

AVEZOV M.M., DOSKENOVA B.B., IBRAGIMOVA R.A. RESEARCH ON THE INFLUENCE OF TECHNOGENIC FACTORS ON THE HYDROGEOLOGICAL CONDITIONS OF THE RIVER BASIN IN INDUSTRIAL AREAS (ON THE EXAMPLE OF THE AHANGARAN RIVER BASIN OF UZBEKISTAN).....	310
AVEZOV M.M., IMRANI Z.T., ISMATULLAEV K.M., ELMUROTOVA A.M. PHYSICO-GEOGRAPHICAL OPPORTUNITIES FOR THE DEVELOPMENT OF TOURISM AROUND WATER BODIES IN SOUTHERN UZBEKISTAN (ON THE EXAMPLE OF THE TUPALANG RESERVOIR).....	314
BORISSOVA K.A., SAGANDYK A.I., TLEGENOVA A.S., ZUCCOLO A. FEATURES OF FORMATION AND DEVELOPMENT OF ROOT ARCHITECTURE OF <i>CUCUMIS SATIVUS</i>	320
NURKAN ZH.A., SUVOROV N.A. ISOLATION AND IDENTIFICATION STRAIN TO BIODEGRADE CRUDE OIL HYDROCARBONS.....	324
RAKHIMOV N.N., AVEZOVA A.M. RESEARCH OF THE STATE OF GROUNDWATER IN THE ARID CLIMATE REGIONS OF UZBEKISTAN IN THE CONTEXT OF CLIMATE CHANGE (ON THE EXAMPLE OF BUKHARA REGION).....	328
YANEVICH A.V., BERILLO D.A. SYNTHESIS AND COMPARATIVE CHARACTERIZATION OF METAL-ORGANIC FRAMEWORKS AND ZEOLITIC IMIDAZOLATE FRAMEWORKS: EFFECT OF SYNTHESIS CONDITIONS ON STRUCTURE AND YIELD.....	333
АБИЛОВ К.М. ҚҰЗЫРЕТТІЛІК ТӘСІЛДІ ЖҮЗЕГЕ АСЫРУДАҒЫ ПӘНАРАЛЫҚ БАЙЛАНЫСТАРДЫҢ РӨЛІ.....	338
АВЕЗОВ М.М., МИРАКМАЛОВ М.Т. ПРИМЕНЕНИЕ МЕЖДУНАРОДНОГО ОПЫТА В ПРОЦЕССЕ СОВЕРШЕНСТВОВАНИЯ СОДЕРЖАНИЯ ГЕОГРАФИЧЕСКОГО ОБРАЗОВАНИЯ В УЗБЕКИСТАНЕ НА ОСНОВЕ ПРИНЦИПА КРАЕВЕДЕНИЯ.....	342
АМАНГЕЛЬДИНОВ Ж.К ВЛИЯНИЕ ПРАКТИКО-ОРИЕНТИРОВАННЫХ ЗАДАЧ НА УЧЕБНУЮ МОТИВАЦИЮ УЧАЩИХСЯ ОСНОВНОЙ ШКОЛЫ.....	347
АМАНЖОЛОВА А.Ж., КАБИДЕНОВ М.Е., ТАЛАСБАЙ Д.А. ФИЗИКА САБАҒЫНДА ОҚУШЫЛАРДЫҢ АКАДЕМИЯЛЫҚ АДАЛДЫҒЫ МЕН ТАНЫМДЫҚ БЕЛСЕНДІЛІГІН КӨПНҮСҚАЛЫ ТАПСЫРМАЛАР АРҚЫЛЫ АРТТЫРУ.....	351
АМАНЖОЛОВА А.Н. НЕГІЗГІ МЕКТЕПТЕ МӘТІНДІК ЕСЕПТЕРДІ ШЕШУ ДАҒДЫЛАРЫН СКАФФОЛДИНГ ТЕХНОЛОГИЯСЫН ҚОЛДАНА ОТЫРЫП КЕЗЕҢ-КЕЗЕҢІМЕН ҚАЛЫПТАСТЫРУ ӘДІСТЕМЕСІ.....	355
АННЕНКОВ В.С. ОЛИМПИАДЫ УЧИТЕЛЕЙ КАК ИНСТРУМЕНТ ФОРМИРОВАНИЯ ПРОФЕССИОНАЛЬНЫХ ИНТЕРЕСОВ ПО БИОЛОГИИ У ШКОЛЬНИКОВ.....	361
АХМЕТОВА А.Е., БАЙМАТОВА А.А., КАРАМГУЖИНОВА А.Е., МАЖИТОВА Г.З. МЕТОДОЛОГИЧЕСКИЕ ОСНОВЫ СОЗДАНИЯ АТЛАСА ПРИРОДНО-ОЧАГОВЫХ БОЛЕЗНЕЙ (ЗООНОЗОВ) СЕВЕРО-КАЗАХСТАНСКОЙ ОБЛАСТИ В СРЕДЕ ГИС.....	366
ӘКІН Т.С., БАЗАРБАЕВА С.М. АСҚАЗАН-ШЕК ЖОЛДАРЫ АУРУЛАРЫНЫҢ СТУДЕНТТЕР МЕН ОҚУШЫЛАР АРАСЫНДАҒЫ ТАРАЛУЫ ЖӘНЕ ОЛАРДЫҢ ДАМУ СЕБЕПТЕРІ.....	372
БАЛАШОВ Д.А. ДИАГНОСТИКА ЛОГИСТИЧЕСКОГО ПОТЕНЦИАЛА ВОЛГОВЯТСКОГО РАЙОНА.....	377
БЕКЕТАЕВА Г.Н., БОГОЯВЛЕНСКИЙ А.П. ДЕНСОВИРУСТАР ГЕНОМЫНДАҒЫ МУТАЦИЯЛЫҚ ӨЗГЕРГІШТІК ЖӘНЕ ЭВОЛЮЦИЯЛЫҚ БЕЙІМДЕЛУ.....	380