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CONTENTS

S. Adilzhanova, B. Amirkhanov, G. Amirkhanova, A. Anuarbek
Innovative methods for ensuring cybersecurity of technological control systems of a digital twin of a food industry enterprise…….....11

L.A. Alexeyeva
Vibrotransport bispinors of Dirac equations in biquaternionic representation at sublight speeds and their properties…….....25

A. Amirova, B. Aldosh, A. Ibraikhan, T. Smagulov, A. Aitmagambet
A machine learning-based approach to detect malicious links on Instagram…....41

G. Argyngazin
Artificial intelligence: is alarmism justified?.....52

Zh.A. Abdibayev, **S.K. Sagnayeva**, **B.B. Orazbayev**, **M. James C. Crabbe, K.A. Dyussekeyev**
Development of an effective water accounting method for irrigation systems for automated water resource management systems…….....…….66

Zh. Bazarbek, N. Toyganbaeva, M. Mansurova, T Sarsembayeva, M. Sakypbekova
Developing a dataset for creating a Large Language model (LLM) for the Kazakh language….....….78

A. Bekarystankyzy, M. Baizakova, A. Kassenkhan, M. Iglikova
Recommendation algorithms for educational preferences: a review……...93

A. Yerimbetova, U. Berzhanova, E. Daiyrbayeva, B. Sakenov, M. Sambetbayeva
Development of a parallel corpus for Kazakh sign language translation and training of the transformer model…….....….110

Sh.P. Zhumagulova, O.Zh. Stamkulov, K. Momynzhanova
Hybrid deep learning approach for accurate ECG beat classification using ResNet18 and BiLSTM…….....132

A. Zulhazhav, G. Bekmanova, M. Altaibek, A. Omarbekova, A. Sharipbay
A personalized learning feedback system driven by a lexical semantic network…….....147

T.S. Sadykova, B.K. Sinchev, Im Cho Young, A.S. Auyezova
The application of vector space models in intelligent information retrieval systems…….....160

A. Sambetbayeva, V. Jotsov
Comparative analysis of deep learning architectures for road crack segmentation…….....176

D. Oralbekova, A. Akhmediyarova, D. Kassymova, Z. Alibiyeva
Research on linguistic analysis methods for identifying and extracting text data in the Kazakh language…….....……..188

Zh.S. Takenova
Research on expert assessment methods for determining teachers' priorities by discipline…….....204

Zh. Tashenova, A.R. Gabdullin, Zh. Abdugulova, Sh. Amanzholova, E. Nurlybaeva
Analysis of modern wireless network security protocols and prospects for their development.....……..228

A. Temirbayev, N. Meirambekuly, N. Uzbekov, A. Beisen, L. Abdizhalilova
CubeSat-based APRS digipeater: design, feasibility and mission concept……..243

N. Temirbekov, D. Tamabay, S. Kasenov, A. Temirbekov, A. Baimankulov
A web-based system for air pollution monitoring with API-integrated data sources…….....258

A.A. Tlepiyev, A. Mukhamedgali, Y.T. Kaipbayev, A.N. Kalmashova, Y.G. Mukhanbet
Surface water monitoring in Kazakhstan using NDWI and random forest: a case study of Lake Akkol…….....….271

Z. Turysbek, **O. Mamyrbayev**, **M. Abdullah**
Development of an intelligent system for detecting fake news.....286

G.S. Shaimerdenova, S.T. Akhmetova, A.N. Zhidebayeva, E.B. Mussirepova, D.A. Bibulova
The role of computer modeling in enhancing safety and efficiency in industrial facilities.....301

МАЗМҰНЫ

С. Адилжанова, Б. Амирханов, Г. Амирханова, А. Ануарбек
Тағам өнеркәсібі кәсіпорны цифрлық егізінің технологиялық басқару жүйелерінің киберқауіпсіздігін қамтамасыз етудің инновациялық әдістері.....11

Л.А. Алексеева
Сублимация жылдамдығындағы бикуатерниондық көріністегі Дирак теңдеулерінің вибротранспорттық биспинорлары және олардың қасиеттері.....25

А. Амирова, Б. Альдош, А. Ибраихан, Т. Смагулов, А. Айтмагамбет
Instagramдағы зиянды сілтемелерді анықтау үшін машиналық оқытуға негізделген тәсіл.....41

Ғ.А. Арғынғазин
Жасанды интеллект: алармистік көзқарас қалыптастыру орынды ма?.....52

Ж.А. Әбдібаев, С.К. Сагнаева, Б.Б. Оразбаев, М. Джеймс К. Крэбб, К.А. Дюсекеев
Су ресурстарының автоматтандырылған жүйелеріне суару жүйелеріндегі су есептеудің тиімді әдісін әзірлеу.....66

Ж.П. Базарбек, Н.А. Тойганбаева, М.Е. Мансурова, Т.С. Сарсембаева, М.Ж. Сакыпбекова
Қазақ тіліне арналған үлкен тіл моделін (LLM) жасау үшін Dataset әзірлеу..78

А. Бекарыстанқызы, М. Байзакова, А. Қасенхан, М. Игликова.
Білім алуды жақсарту үшін ұсыныс беретін алгоритмдерге шолу.....93

А.С. Еримбетова, У.Г. Бержанова, Э.Н. Дайырбаева, Б.Е. Сэкенов, М.А. Сэмбетбаева
Қазақ ым тіліне аудару үшін параллель корпус құру және transformer моделін оқыту.....110

Ш.П. Жұмағулова, О.Ж. Стамқұлов, К.Р. Момынжанова
RESNET18 және BILSTM қолдана отырып, ЭКГ жүрек соғысын дәл жіктеуге арналған гибридті терең оқыту тәсілі.....132

А. Зулхажав, Г.Т. Бекманова, М. Алтайбек, А.С. Омарбекова, А.А. Шәріпбай
Цифрлық білім және студенттердің академиялық жетістіктері: деңгейлер бойынша білім беруді дамыту.....147

Т.С. Садыкова, Б.К. Синчев, Im Cho Young, А.С. Ауезова
Интеллектуалды ақпаратты іздеу жүйелерінде векторлық кеңістік модельдерін қолдану.....160

А.К. Самбетбаева, В. Йоцов
Жол төсемінің жарықтарын сегментациялауда қолданылатын терең оқыту архитектураларын салыстырмалы талдау.....176

Д. Оралбекова, А. Ахмедиярова, Д. Қасымова, Ж. Алибиева
Қазақ тіліндегі мәтіндік ақпаратты анықтау және оны шығарып алу үшін лингвистикалық талдау әдістерін зерттеу.....188

Ж.С. Такенова
Пәндер бойынша оқытушылардың басымдығын бағалауға арналған сараптамалық бағалау әдістерін зерттеу.....204

Ж.М. Ташенова, А.Р. Габдуллин, Ж.К. Абдугулова, Ш.А. Аманжолова, Э.Н. Нурлыбаева
Заманауи сымсыз желінің қауіпсіздік хаттамаларын талдау және олардың даму перспективалары.....228

А.А. Темирбаев, Н. Мейрамбекұлы, Н.Ш. Узбеков, Ә.Н. Бейсен
CUBESAT негізіндегі APRS қайта таратқышы: жобалау, іске асыру мүмкіндігі және миссия тұжырымдамасы.....243

Н. Темирбеков, Д. Тамабай, С. Касенов, А. Темирбеков, А. Байманкулов
API-интеграцияланған дереккөздері бар атмосфералық ауаның ластануын бақылауға арналған веб-негізделген жүйе.....258

А.А. Тлепиев, А. Мухамедгали, Е.Т. Кайпбаев, А.Н. Калмашова, Е.Ғ. Муханбет
Қазақстандағы беткі суларды NDWI және RANDOM FOREST әдісі арқылы мониторингілеу: Ақкөл көлінің мысалында.....271

Ж. Тұрысбек, О.Ж. Мамырбаев, А. Мұхаммед
Жалған жаңалықтарды анықтайтын интеллектуалды жүйені әзірлеу.....286

Г.С. Шаймерденова, С.Т. Ахметова, А.Н. Жидебаева, Э.Б. Мусирепова, Д.А. Бибулова
Өнеркәсіптік объектілердің қауіпсіздігі мен тиімділігін арттырудағы компьютерлік модельдеудің рөлі.....301

СОДЕРЖАНИЕ

С. Адильжанова, Б. Амирханов, Г. Амирханова, А. Ануарбек
Инновационные методы обеспечения кибербезопасности технологических систем управления цифрового двойника предприятия пищевой промышленности.....11

Л.А. Алексеева
Вибротранспортные биспиноры уравнений Дирака в бикватернионном представлении при дозвуковых скоростях и их свойства.....25

А. Амирова, Б. Алдош, А. Ибрайхан, Т. Смагулов, А. Айтмагамбет
Метод на основе машинного обучения для выявления вредоносных ссылок в Instagram.....41

Г. Аргынгазин
Искусственный интеллект: оправдан ли алармизм?.....52

Ж.А. Абдибаев, С.К. Сагнаева, Б.Б. Оразбаев, М. Джеймс К. Крэбб, К.А. Дюссекеев
Разработка эффективного метода учёта воды для ирригационных систем автоматизированного управления водными ресурсами.....66

Ж. Базарбек, Н. Тойганбаева, М. Мансурова, Т. Сарсембаева, М. Сакипбекова
Создание набора данных для разработки крупной языковой модели (LLM) для казахского языка.....78

А. Бекарыстанкызы, М. Байзакова, А. Кассенхан, М. Игликова
Алгоритмы рекомендаций для образовательных предпочтений: обзор.....93

А. Еримбетова, У. Бержанова, Е. Дайырбаева, Б. Сакенов, М. Самбетбаева
Создание параллельного корпуса для перевода казахского жестового языка и обучение трансформерной модели.....110

Ш.П. Жумагулова, О.Ж. Стамкулов, К. Момынжанова
Гибридный подход глубокого обучения для точной классификации сердечных сокращений ЭКГ с использованием ResNet18 и BiLSTM.....132

А. Зулхажав, Г. Бекманова, М. Алтайбек, А. Омарбекова, А. Шарипбай
Система персонализированной обратной связи в обучении на основе лексико-семантической сети.....147

Т.С. Садыкова, Б.К. Синчев, Им Чо Ён, А.С. Ауезова
Применение моделей векторного пространства в интеллектуальных системах информационного поиск.....160

А. Самбетбаева, В. Йоцов
Сравнительный анализ архитектур глубокого обучения для сегментации трещин на дорогах.....176

Д. Оралбекова, А. Ахмедиярова, Д. Касымова, З. Алибиева
Исследование методов лингвистического анализа для идентификации и извлечения текстовых данных на казахском языке.....188

Ж.С. Такенова
Исследование методов экспертной оценки для определения приоритетов учителей по дисциплинам.....204

Ж. Ташенова, А.Р. Габдуллин, Ж. Абдугулова, Ш. Аманжолова, Е. Нурлыбаева
Анализ современных протоколов безопасности беспроводных сетей и перспективы их развития.....228

А. Темирбаев, Н. Мейрамбекулы, Н. Узбеков, А. Бейсен, Л. Абдижалилова
APRS-дигипитер на основе CubeSat: проектирование, осуществимость и концепция миссии.....243

Н. Темирбеков, Д. Тамабай, С. Касенов, А. Темирбеков, А. Байманкулов
Веб-система мониторинга загрязнения воздуха с API-интеграцией источников данных.....258

А.А. Тлепиев, А. Мухамедгали, Е.Т. Кайпбаев, А.Н. Калмашова, Е.Г. Муханбет
Мониторинг поверхностных вод в Казахстане с использованием NDWI и случайного леса: кейс озера Аккол.....271

З. Турысбек, О. Мамырбаев, М. Абдулла
Разработка интеллектуальной системы для выявления фейковых новостей.....286

Г.С. Шаймерденова, С.Т. Ахметова, А.Н. Жидебаева, Е.Б. Муссирепова, Д.А. Бибулова
Роль компьютерного моделирования в повышении безопасности и эффективности промышленных объектов.....301

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A WEB-BASED SYSTEM FOR AIR POLLUTION MONITORING WITH API-INTEGRATED DATA SOURCES

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Abstract. The developed web-based platform for atmospheric air monitoring is a multicomponent system that sequentially collects, processes, and visualizes pollution data. Its information sources are automated monitoring stations and accumulated historical records, which provide real-time access to current concentrations of $PM_{2.5}$, PM_{10}, CO, SO_2, NO_2, as well as the Air Quality Index (AQI). A key feature of the platform is the use of cartographic tools to clearly display the spread of pollutants and to analyze their spatiotemporal dynamics. Users can compare current observations with past periods, identify trends, peaks, and episodes of elevated risk without resorting to cumbersome tables. The system generates recommendations for vulnerable population groups based on World Health Organization standards, thereby increasing the practical value of the

environmental data presented. Combining up-to-date measurements with historical time series supports forecasting of changes in the environmental situation and helps to assess potential air-quality deterioration in advance. The resulting assessments, distribution maps, and time-series plots form a basis for developing effective air-quality management strategies and for making environmentally sound decisions at various levels—from the day-to-day actions of individual users to long-term planning aimed at improving urban and natural environments. In this way, the platform links observation data with applied analytics, making information delivery, short-term response, and planning processes more transparent and well-grounded. The platform focuses on air quality and its dynamics in both time and space.

Keywords: information and analytical platform, geographic information system, air pollution, health risk assessment, air quality index

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АРІ-ИНТЕГРАЦИЯЛАНҒАН ДЕРЕККӨЗДЕРІ БАР АТМОСФЕРАЛЫҚ АУАНЫҢ ЛАСТАНУЫН БАҚЫЛАУҒА АРНАЛҒАН ВЕБ-НЕГІЗДЕЛГЕН ЖҮЙЕ

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Аннотация. Атмосфералық ауаның ластануын бақылауға арналған әзірленген веб-негізделген платформа — бұл ауаның ластануын мониторингтеуге арналған көпқұрамды жүйе болып табылады және ластану жөніндегі деректерді рет-ретімен жинайды, өңдейді әрі көрнекілейді. Экологиялық дереккөздер ретінде автоматтандырылған мониторинг станциялары мен жинақталған тарихи жазбалар қолданылады, бұл пайдаланушыға нақты уақыт режимінде $PM_{2.5}$, PM_{10}, CO, SO_2, NO_2 концентрацияларының өзекті мәндеріне және Ауа сапасының индексіне (AQI) қолжеткізуді қамтамасыз етеді. Платформаның негізгі ерекшелігі — ластаушы заттардың таралуын көрнекі көрсету және олардың кеңістіктік-уақыттық динамикасын талдау үшін картографиялық құралдарды қолдану. Пайдаланушы ағымдағы бақылауларды өткен кезеңдермен салыстырып, үрдістерді, шыңдарды және жоғары тәуекел эпизодтарын көлемді кестелерге жүгінбей-ақ айқындай алады. Жүйе Дүниежүзілік денсаулық сақтау ұйымының стандарттарына сүйене отырып, халықтың осал топтарына арналған ұсынымдарды қалыптастырады, бұл ұсынылатын экологиялық деректердің практикалық маңызын арттырады. Өзекті өлшемдерді тарихи қатарлармен біріктіру экологиялық жағдайдың өзгерістерін болжауды қолдайды және ауа сапасының ықтимал нашарлауын алдын ала бағалауға көмектеседі. Алынатын бағалар, таралу карталары және уақыттық графиктер ауа сапасын басқарудың тиімді стратегияларын әзірлеуге және әртүрлі деңгейлерде — жекелеген пайдаланушылардың күнделікті әрекеттерінен бастап қалалық және қоршаған ортаны жақсартуға бағытталған ұзақ мерзімді жоспарлауға дейін — экологиялық негізделген шешімдер қабылдауға негіз болады. Осылайша, платформа бақылау деректерін қолданбалы аналитикамен байланыстырып, ақпараттандыру, қысқа мерзімді әрекет ету және іс-шараларды жоспарлау үдерістерін неғұрлым ашық әрі негізді етеді; ол ауа сапасына және оның уақыт пен кеңістіктегі динамикасына шоғырланады.

Түйін сөздер: ақпараттық-талдамалық платформа, географиялық ақпараттық жүйе, ауа ластануы, денсаулық тәуекелдерін бағалау, ауа сапасының индексі

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ВЕБ-СИСТЕМА МОНИТОРИНГА ЗАГРЯЗНЕНИЯ ВОЗДУХА С API-ИНТЕГРИРОВАННЫМИ ИСТОЧНИКАМИ ДАННЫХ

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Аннотация. Разработанная веб-платформа для мониторинга атмосферного воздуха представляет собой многокомпонентную систему, которая последовательно собирает, обрабатывает и визуализирует данные о загрязнении. Источниками информации служат автоматизированные станции мониторинга и накопленные исторические записи, что обеспечивает доступ к актуальным значениям концентраций $PM_{2.5}$, PM_{10}, CO, SO_2, NO_2, а также к индексу качества воздуха (AQI) в режиме реального времени. Ключевая особенность платформы — применение картографических средств для наглядного отображения распространения загрязняющих веществ и анализа их пространственно-временной динамики. Пользователь может сопоставлять текущие наблюдения с прошлыми периодами, выявлять тенденции, пики и эпизоды повышенного риска без обращения к громоздким таблицам. Система формирует рекомендации для уязвимых групп населения, ориентируясь на стандарты Всемирной организации здравоохранения, что повышает практическую значимость представляемых экологических данных. Объединение оперативных измерений с историческими рядами

поддерживает прогнозирование изменения экологической обстановки и помогает заранее оценивать возможные ухудшения качества воздуха. Получаемые оценки, карты распределения и временные графики служат основой для выработки эффективных стратегий управления качеством воздуха и принятия экологически обоснованных решений на различных уровнях — от повседневных действий отдельных пользователей до долгосрочного планирования мер по улучшению городской и окружающей среды. Тем самым платформа связывает данные наблюдений с прикладной аналитикой, делая процессы информирования, краткосрочного реагирования и планирования мероприятий более прозрачными и обоснованными. Разработанная платформа фокусируется на качестве воздуха и его динамике во времени и пространстве.

Ключевые слова: информационно-аналитическая платформа, геоинформационная система, загрязнение воздуха, оценка риска для здоровья, индекс качества воздуха

Introduction. In the early 1960s, with the development of technology and increased attention to environmental issues, large-scale introduction of sensors for monitoring atmospheric air quality began. The environmental monitoring system had to quickly detect sudden significant releases of radioactive materials for operational activities, as well as regularly measure the levels of hazardous substances. It should detect radiation and radioactivity levels before the surrounding population is exposed to exposure exceeding established limits.; This means that the higher the dose, the earlier the detection should be performed. It also implies the need for prompt notification and appropriate measures to protect the public and the environment. The research results (Ishihara, 1967) showed that this monitoring system functioned in the following three ways: (1) centralized continuous automatic monitoring; (2) regular surveys of radiation levels; and (3) environmental sample analysis, especially for use as biological indicators. The selection of suitable biological indicators for monitoring environmental pollution and the development of methods for measuring changes in low dose levels, for example, 10^{-6} rad × hr^{-1}, were important before designing an effective environmental monitoring system. Three different centralized continuous monitoring systems for nuclear installations were presented in the work.

The paper (Mukaro et al., 1999) describes a battery-powered, microcontroller-based DAS for remote solar radiation monitoring. It uses an ST62E20 microcontroller and a SolData pyranometer, operating in low-power mode with 10-minute data sampling. Data is stored in EEPROM and transferred via RS232 for offline analysis. The system prioritizes efficiency and cost-effectiveness, showing ±13 W/m^2 accuracy in field tests.

A study (Lodwick et al., 1981) at the University of New South Wales has shown that changes in the environment can be effectively measured using LANDSAT images. A set of programs has been developed for the CYBER 72/171 system that process data from MSS tapes provided by NASA. The results were used to monitor

droughts, predict forest fires, and evaluate crops. Programs written in Fortran used minimal memory requirements and provided image processing in five hours of processor time.

The work (Morita et al., 1983) is devoted to monitoring the environment of the Japanese Tokai and Oarai regions, where there were seventeen enterprises related to nuclear energy, varying in size and type of activity. Environmental monitoring was carried out with the cooperation of the Government, local authorities and enterprises in accordance with plans developed by the prefectural monitoring Committee. The main monitoring objectives included: 1) assessment of the dose to the public based on data on environmental radioactivity and emissions of radioactive substances; 2) determination of the accumulation of radioactive materials over long time intervals. 3) Early detection of abnormal emissions from enterprises.

As can be seen from papers above, the importance of environmental monitoring and the development of tracking systems was recognized back in the early 1960s. This time became the starting point for the implementation of systems that made it possible to monitor the state of the environment and respond promptly to changes in it. Today, thanks to advances in high technology, environmental monitoring has become more efficient and accurate. Modern sensors allow for round-the-clock monitoring without having to worry about data storage. The received data can be processed using cloud computing and transmitted over long distances without obstacles.

The study (Lee et al., 2024) uses geoinformation system and isochronous mapping to assess air quality risks for vulnerable populations in Gangseo, Seoul, South Korea. It identifies underserved areas with limited monitoring, proposing strategic sites for air quality stations. Findings offer policymakers recommendations for better environmental protection and monitoring infrastructure.

The article (Chen et al., 2008) highlights the importance of information systems as a key technological factor capable of contributing to environmental sustainability. The presented conceptual model and the proposed provisions reveal the potential roles of IP in sustainable development strategies, providing a scientific basis for future research in this area.

The article (Ghaemi et al., 2009) presents a web platform for interactive environmental planning in Southern California's Green Visions Plan. It helps municipalities identify project sites for parks, biodiversity, and watershed improvements. Featuring a site-level park analysis tool, it estimates user demographics. A client-server model ensures efficient geospatial data processing.

The article (Paynter et al., 1998) examines the process of developing web-based information systems, including the stages of design, implementation and security. The study highlights the importance of using modern web technologies to effectively manage data and improve information exchange processes in various fields.

The article (Giglione et al., 2022) is devoted to the development of an integrated Geographic Information System-based web platform (GIS) for monitoring the environmental status associated with industrial emissions. The paper presents

an approach to the use of modern technologies for the collection, analysis and visualization of air pollution data related to the activities of industrial enterprises. The main focus is on the functionality of the platform, which provides users with access to real-time data and allows them to analyze pollution levels and their dynamics.

The article (Culshaw et al., 2006) describes a web platform designed to support decision-making in planning in the UK. It provides access to environmental information by integrating data from URGENT and ODPM research. The system covers key planning functions and includes 11 thematic areas such as air quality, groundwater protection and flood risk. The use of geoinformation technologies and modular architecture make it possible to take into account new legal requirements and local data. The study demonstrates the effectiveness of e-governance principles, offering economic and operational benefits to planners and developers.

In summary, it can be stated that information ecology is a newly emerging field that has been actively developing in recent years, and research in this area represents a multidisciplinary subject (Wang et al., 2017). Studies on information ecology primarily focus on information ecosystems, information ecology in e-commerce, and information ecology in networks.

The purpose of this research is to develop an information and analytical platform for monitoring the atmospheric air of industrial cities in Kazakhstan, which receives and analyzes air condition data from automated monitoring systems (AMS). This system provides the collection, transmission and processing of information in real time, which allows you to quickly monitor changes in the level of pollution in the atmosphere and provide recommendations to the public. Developed website *https://aipol.kz/* is an integrated platform that combines data on meteorological conditions and pollutants such as $PM_{2.5}$, PM_{10}, NO_2, SO_2 and CO with the calculation of the Air Quality Index (AQI).

Materials and Methods. Information and analytical systems are an important tool for monitoring the environment and supporting decision-making. They provide environmental data analysis to identify trends, anomalies, and forecast changes, which contributes to a deeper understanding of ecosystem processes and reduces risks to public health.

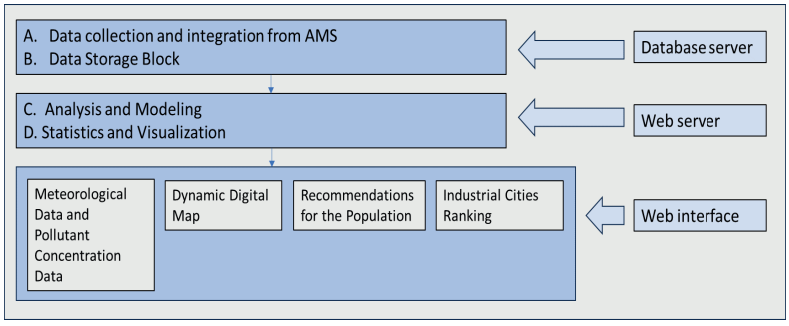


Figure 1. The structure of the information and analytical platform

Platforms increase the availability of environmental information by contributing to information and environmental education for citizens, as well as providing government agencies with informed data for environmental policy development.

The integration of GIS technologies enables comprehensive visualization and spatial representation of environmental data, significantly enhancing the ability to analyze patterns, trends, and anomalies in air pollution distribution. By leveraging GIS-based spatial analysis, researchers and decision-makers can identify high-risk areas, assess pollution sources, and evaluate the effectiveness of mitigation strategies with greater accuracy.

In the context of scientific research, web-based platforms that incorporate GIS technologies facilitate access to extensive datasets collected from various automated monitoring systems, remote sensing technologies, and open-source databases (Figure 1). This integration supports interdisciplinary collaboration by enabling researchers from different fields - such as environmental science, meteorology, public health, and urban planning - to utilize shared geospatial data for developing predictive models, conducting impact assessments, and formulating evidence-based policies. Furthermore, the ability to integrate real-time and historical data enhances the capacity for temporal analysis, enabling a deeper understanding of pollution dynamics and long-term environmental changes.

Data collection and integration. The air pollution data integration module, located in the database server, includes several key components, each of which performs important functions to ensure efficient information collection and processing. Its structure includes an Application Programming Interface (API) client, a data processing unit, and a storage interface.

The API client is responsible for executing HTTP requests to the pollution data API from AMS of Ecoservice-S LLP, managing authentication, and configuring request parameters. It provides reliable and secure data transfer between the platform and an external information source. The data processing unit accepts the received responses in JSON format, cleans them of unnecessary information and converts them into a format suitable for future use. In addition, this component performs error checking and data validation, which guarantees the accuracy and integrity of the information.

From a functional point of view, the module periodically sends API requests to get up-to-date pollution data. It is configured to collect information on key indicators such as $PM_{2.5}$, NO_2 concentrations, and AQI values. To ensure the timely receipt of data, a query planning mechanism is used via cron or special tasks, which allows you to regularly update information about the state of atmospheric air.

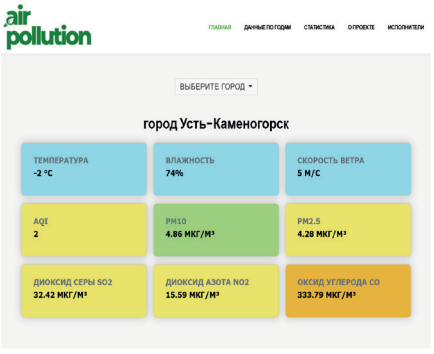
After processing, all data is stored in a database for further analysis and visualization. The module also includes notification and reporting functions: in case of missing data from the remote server or other problems, the system sends notifications. This integration automates the data collection and analysis process, ensuring real-time monitoring of air quality with minimal delays and maximum accuracy.

Data storage block. The created atmospheric pollution database for the industrial city of Ust-Kamenogorsk is designed to generate long-term historical records of the state of the atmosphere, identify the most dangerous pollutants and accumulate metadata from various sources. The system allows you to securely store and process information on server hosted in the LLP Akademset data center. The developed geoinformation system provides access to up-to-date and archived data from mobile and stationary automated sensors installed in the most polluted areas of cities.

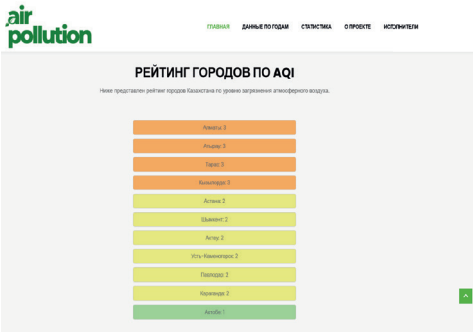
The data repository of the information-analytical platform stores spatiotemporal analysis of pollution, providing regulatory authorities with tools for informed decision-making in environmental safety and sustainable development. The data are available for scientific research on environmental conditions and facilitate ecological monitoring and natural resource management.

Real-time displayed data. The site is integrated with external APIs that provide real-time data on weather conditions and air pollution levels. One of these sources is the Pollution Data API of Ecoservice-S LLP, which aggregates data from automated air quality monitoring stations operated by the company. Additionally, data from other organizations' monitoring stations are collected and made available via API of the OpenWeatherMap platform. This integration enables comprehensive environmental monitoring by ensuring access to accurate and up-to-date atmospheric data.

The website interface provides the following information: on the main page of the platform, meteorological parameters, concentrations of pollutants ($PM_{2.5}$, PM_{10}, CO, SO_2, NO_2) and AQI are presented, which makes it possible to assess the level of pollution and its impact on human health (Figure 2 (a)-(c)). It also displays recommendations for the population (Temirbekov et al., 2023, (a)), in accordance with World Health Organization (WHO) global air quality standards, an AQI rating of cities, and a frequently asked questions section to improve navigation and accessibility of information.



(a)



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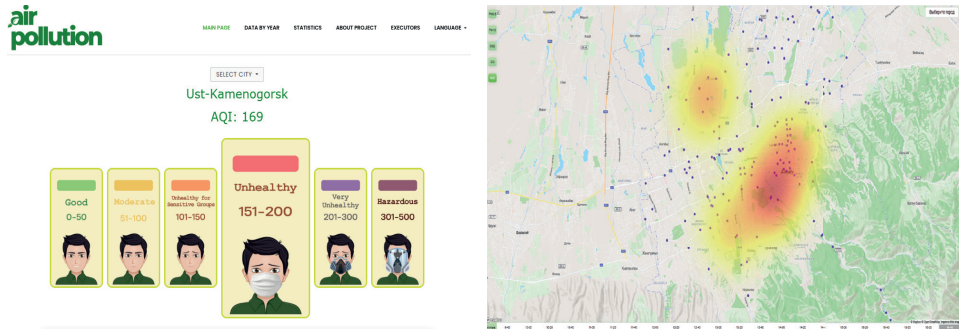

(c) (d)

Figure 2. The website interface of the information and analytical system

Figure 2(c) presents recommendations aimed at informing citizens about possible health risks at different levels of atmospheric air pollution and providing adapted precautions for different population groups.

The recommendation system for the population, implemented within the developed platform, is designed in accordance with internationally recognized air quality standards. It is based on a comprehensive analysis of environmental parameters and aligns with the global guidelines established by the WHO. This system ensures the provision of scientifically grounded recommendations aimed at mitigating the adverse effects of air pollution on public health, thereby enhancing environmental awareness and promoting informed decision-making among users.

Visualization of pollutant dispersion. The cartographic section is a key tool for visualizing environmental data in real time, including the location of automated monitoring stations, their current indicators and dynamic maps of the dispersion of pollutants in industrial zones of Kazakhstan, which allows for spatial analysis and assessment of local sources of pollution.

For visualization of spread of harmful substances in city, a model of the transport of pollutants in the atmospheric air of industrial cities is used with an accurate determination of the concentration of emissions from manufacturing enterprises, as in (Temirbekov et al., 2023 (b), Temirbekov et al., 2024 (a), Temirbekov et al., 2023 (c), Temirbekov et al., 2024 (b)).

The transport equation is examined, where the initial urban area is transformed into a dimensionless region. Within this dimensionless computational domain $0 \le x \le 1,\ 0 \le y \le 1,\ 0 \le t \le T$:

$$\frac{\partial \varphi_q}{\partial t} + u\frac{\partial \varphi_q}{\partial x} + v\frac{\partial \varphi_q}{\partial y} = \Delta\varphi_q + \alpha_q\varphi_q + \beta_q + f_q \quad (1)$$

$$\varphi_q(x,y,0) = \varphi_0(x,y),\ \varphi_q(0,y,t) = 0, \varphi_q(1,y,t) = 0, \quad (2)$$

$$\varphi_q(x,0,t) = 0,\ \ \varphi_q(x,1,t) = 0, \quad (3)$$

where φ_q is the concentration of the impurity, u, v are components of wind speed, f_q is the power of the pollution sources, $\Delta\varphi_q = \frac{\partial}{\partial x}\left(\frac{\partial\varphi_q}{\partial x}\right) + \frac{\partial}{\partial y}\left(\frac{\partial\varphi_q}{\partial y}\right)$, in terms of the concentration of the harmful substance in the impurity, the coefficient β_q is the constant of the rate of formation of the substance, α_q is the constant of the rate of decrease.

Additional information for solving this problem is p_q – data on the values of pollutants of AMS. For this problem, the inverse problem is considered, in which it is required to determine the source based on the data received from the monitoring system. The essence of the inverse problem is to minimize the following Lagrange functional

$$L(f_q) = \int_0^T dt \int_\Omega \left[\frac{\partial\varphi_q}{\partial t} + u\frac{\partial\varphi_q}{\partial x} + v\frac{\partial\varphi_q}{\partial y} - \Delta\varphi_q - \alpha_q\varphi_q - \beta_q - f_q\right]\varphi^* d\Omega + \sum_{i=1}^{n}\lambda_i \int_0^T dt \int_\Omega (p_q - \varphi_q)^2 \delta(\vec{r} - \vec{r}_i)\, d\Omega, \quad (4)$$

where r_j is the radius vector of the location of pollution sources and AMS, $\delta(x)$ is the Dirac delta function, λ_i – the coefficient of preference.

This model takes into account the inaccuracy of data on the concentration and volume of emissions, as well as their changes during photochemical reactions. The proposed approach solves this problem as an inverse problem using the theory of conjugate equations. This provides a more accurate understanding of the impact of industrial facilities on air quality and provides a basis for decision-making in the field of regional environmental policy.

For data visualization, Mapbox and OpenStreetMap maps are used, which allows to track environmental information in real time (Figure 2(d)).

Results and discussion. The study of atmospheric pollution monitoring has gained significant attention in recent years due to the increasing anthropogenic impact on air quality and public health (Okabayashi Miyaji et al., 2021). Numerous specialized platforms provide real-time data on pollutant concentrations, leveraging automated monitoring systems to facilitate continuous observation and early detection of environmental risks. These platforms, including AirKaz.org, IQAir, AQI India, AirNow, SmartEco, etc. serve as valuable tools for public access to air quality indices and pollutant concentrations ($PM_{2.5}$, PM_{10}, CO, SO_2, NO_2). However, they primarily focus on data aggregation and visualization without advanced spatial analysis or predictive capabilities.

The developed platform (Air pollution, 2024) introduces a more advanced analytical approach by integrating automated monitoring data with meteorological parameters, enabling spatiotemporal modeling of pollutant dispersion. This methodological framework enhances the ability to identify emission hotspots, track

pollution sources, and assess the impact of atmospheric dynamics on pollutant transport. The visualization module employs dynamic geospatial mapping techniques to represent real-time pollution levels and historical trends, offering an in-depth perspective on environmental fluctuations.

The integration of computational algorithms allows for the real-time assessment of pollution dynamics and the generation of adaptive recommendations for vulnerable population groups, including individuals with respiratory conditions, children, and the elderly. By providing health-oriented advisories and exposure minimization strategies, the platform bridges the gap between environmental science and public health management.

Conclusion. The development of a platform for monitoring atmospheric air quality and informing the public represents a significant step in the field of environmental management and environmental protection. The proposed solutions are based on modern information technologies that ensure the collection, processing and analysis of large amounts of data on air pollution. The integration of automated monitoring stations and the use of historical data allows not only to assess the current state of the environment, but also to identify long-term trends and predict environmental changes.

One of the key features of the platform is the accessibility and visibility of the information provided. Users can monitor the concentrations of pollutants ($PM_{2.5}$, PM_{10}, CO, SO_2, NO_2) and the Air quality Index in real time, which helps to raise environmental awareness. An important component of the platform is a recommendation system based on WHO international standards, which offers tailored precautions for various population groups, including children, the elderly, and people with chronic diseases.

Visualization of data using cartographic tools provides a deeper understanding of the spatial distribution of pollutants and allows you to quickly identify problem areas. This is especially important for industrial regions, where the concentration of emissions from production facilities significantly affects air quality. The ability to track the spread of pollution and localize sources of emissions supports informed decision-making to develop measures to reduce anthropogenic impact.

Thus, the developed platform becomes an important tool for air quality management and making environmentally significant decisions. Its implementation contributes to improving environmental monitoring, increasing the level of environmental safety and public health. Further development of the platform is expected in the future, including expansion of functionality, integration of additional data sources and improvement of forecasting algorithms, which will increase its efficiency and accuracy of environmental analysis.

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