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ENVIRONMENTAL MONITORING IN KAZAKHSTANI CONTEXT – STATE-OF-THE-ART AND CHALLENGES FOR INDUSTRIAL REGION

Environmental issues remain a pressing concern for Kazakhstani industrial regions. While legislative requirements for emissions into the environment permanently become increasingly stringent, the environmental monitoring system lacks several structural factors.

This article delves into the fundamental requirements for environmental monitoring systems and overviews methods and models for monitoring emissions into the environment based on sources and impact factors. The structure of classical monitoring is outlined in detail, examining methods based on international experience with existing management and control systems. The reasons and perspectives for an environmental monitoring system for industrial facilities in the Pavlodar region are discussed. The energy sector should gain the special attention due to its high density and significant environmental impact in the region.

It can be concluded that imperfections in legislation and outdated infrastructure conditions have led to the threatening ambient air pollution. While the observations based on the retrospective time-series data currently show state-of-the-art, the urgent call for implementation of industrial intelligent information-analytical system may play a pivotal role in decision-making in air quality management.

Keywords: environmental monitoring, greenhouse gases emissions, environmental pollution, Industry 4.0, air quality.

Introduction

More than half of the world's population is currently vulnerable to the consequences of climate change. One such consequence is the emergence of environmental issues resulting from and exacerbated by anthropogenic pressure. Kazakhstan is a country that has been grappling with a steadily increasing array of environmental problems. These include harmful emissions from industrial enterprises, water and soil pollution, as well as other detrimental impacts of industrial activities. Water resource challenges are escalating each year, posing a significant threat to water deficit in certain regions. Additionally, industrialized regions are experiencing contamination from radioactive, bacteriological, and chemical sources.

Sustainable development of the country in the modern world necessitates careful consideration of environmental safety. The responsibility of our generation is to safeguard nature and judiciously utilize the abundant resources of the country [1]. The government claims its commitment to the UN's urgent appeal for concrete action to preserve the environment for future generations. Kazakhstan has become the first country in the Central Asian region to ratify the Paris Agreement and embrace the Carbon Neutrality Strategy 2060.

Environmental monitoring is a part of the measures for assurance the environmental sustainability. It encompasses the processes and activities essential for evaluating the quality of the environmental objects and associated risk assessment. The regulatory framework governing these requirements focuses primarily on evaluating impact compliance and reporting industrial emissions and wastewater discharged into the environment [1–3]. Nevertheless, monitoring can be more efficient when obtained data can serve multiple objectives, such as statistical analysis for state-of-the-art evaluation and forecasting the future environmental conditions. The specific parameters to be monitored are contingent on the characteristics of the subject of a particular environmental study and the factors prevailing within it. Targeted chemical parameters for monitoring depend on the characteristics of each particular subject. Environmental monitoring system implies ecological analysis of interaction between people and nature within the biosphere. While national monitoring systems are based on such activities on the territory of one country; it is emerging and challenging to establish regional monitoring within ecosystem boundaries, which goes beyond the governmental boundaries.

This paper overviews the system of environmental monitoring in Kazakhstan under the context of worldwide experience and the recent updates in the field.

Materials and methods

The following objects are included in the environmental monitoring system of Kazakhstan:

- Environmental objects, including land, soil, water (both underground and on the surface), subsoil, air, radiation, and energy pollution levels. This scope extends to the ozone atmospheric layer and the space near Earth, crucial for creating favorable conditions for life.
- Objects of nature, which include natural ecosystems, natural landscapes, and the constituent elements within them.
- Natural-anthropogenic objects, referring to elements of nature altered due to any economic activity or objects reproduced by human intervention, serving recreational or protective purposes.
- Sources exerting anthropogenic influence on the environment, encompassing hazardous objects.

An integral component of environmental monitoring involves the formulation of a formal monitoring program. The primary objective of this program is to furnish objective information about the environmental situation, aiding in informed decision-making under current and foreseeable circumstances. Quality control and quality assurance play a pivotal role in this process to ensure the reliability and objectivity of the collected data throughout the monitoring process.

Numerous procedural manuals and standards are available to facilitate this endeavor. To discern the strengths and weaknesses of the environmental monitoring system within the Kazakhstani context, it is imperative to analyze not only the legislation of the Republic of Kazakhstan, with a specific focus on mitigation plans of industrial enterprises, but also to compare it with relevant international experiences.

The operational scheme of the intelligent informational system of environmental monitoring is presented in Figure 1.

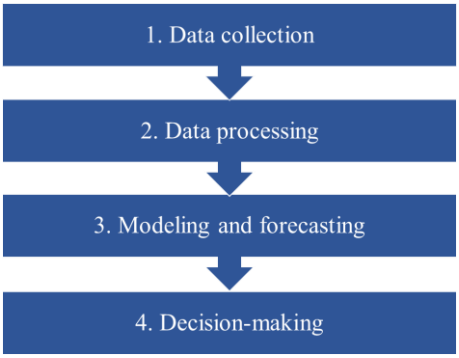

Figure 1 – Operational scheme of environmental monitoring

Data collection is the first step of the environmental monitoring. This step demands the reliability of the information obtained, as future conclusions and decisions will be derived from the processing of it. Data for intelligent information and communication systems can be acquired through two primary methods. Instrumental method, which involves direct measurements of required indicators using control and measuring devices. Data acquisition can be automated, requiring no human participation. Manual input method, which is carried out by entering available data manually. It is applied for extra statistical indicators required for calculations in risk assessment, such as population size and density, traffic intensity, number of local domestic heat sources, etc. It is essential to consider potential measurement errors or variations in the interpretation of statistical data for both methods. Overall, the requirements for the data collection stage are well-established. The legislation of the Republic of Kazakhstan, along with various normative and technical documents, outlines the scope of measurements, the composition of instrumentation, and the methods of measurement.

Data processing is directed towards acquiring comprehensive information about the state of the environment. During this stage, secondary indicators of the environmental state are computed, and the obtained data are compared with standardized values. Additionally, graphs, maps, and other visual forms of information presentation are generated. To serve as initial data for the subsequent stage of the information and communication system structure, it is crucial to establish dependencies among various parameters using statistical methods. Data analysis and processing follow various non-unified normative techniques in Kazakhstan nowadays. The list of these techniques is extensive, enabling a diverse range of calculations essential at this stage. However, the established system still follows a post-soviet approach in assessing and interpreting obtained data.

At the modeling and forecasting stage, the intelligent information-communication system should build mathematical models considering obtained data. The models aim to depict the dynamics of environmental parameters under established scenarios. This stage heavily relies on the existing research tools, which should be permanently reflected and revised in the respective regulatory framework.

As a final step, the intelligent information and communication system should facilitate the dissemination of the obtained results to various stakeholders involved in the environmental monitoring process. This procedure ensures the availability of information crucial for decision-making. The level of decision-making can range from routine consideration of the received information in day-to-day activities to the capacity for prompt intervention in processes influencing the environmental situation on the governmental and intergovernmental levels. There is a comprehensive system of responsibility for the notification of

environmental conditions on different levels in Kazakhstan. However, the administrative leverage still lacks an efficient roadmap for the improvement of environmental conditions.

There is still a space to improve the regulatory standards and guidelines for the environmental monitoring system in Kazakhstan. Directive on ambient air quality and cleaner air for Europe may be used as a reference point [4]. This document contains strict and well-established requirements for both air quality and data management, including quality assurance and quality control framework. The required data and information for reliable ambient air management are presented in Figure 2. The general obligatory requirement for implementation in all European countries is Emissions measurement systems (CEMS), aiming for monitoring of greenhouse gases (GHG) emissions. This system is based on stationary installations and equipped with high-tech devices. The level of automation in data transmission and processing renders these systems accurate and responsive to changes. Even in case any indicator surpassing established norms, an alert is activated, prompting the central point to make decision-makers [5]. The measurement is followed by a respective assessment of the impact of emitted GHGs [6].

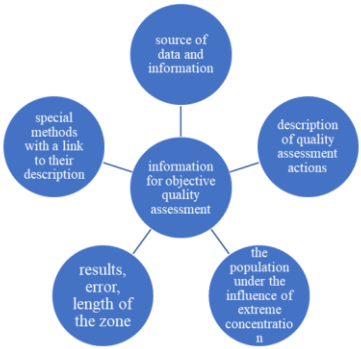

Figure 2 – Data and information required for reliable ambient air management

Contradictory, the post-soviet countries still tend to follow outdated standards and methods for environmental monitoring and risk assessment, including standards for calculation for environmental control and monitoring, the organization of state services for environmental observation, and the metrological support of control system [7].

The overall goal of environmental monitoring is to formulate economic and political solutions grounded in environmental safety, achieving a precise diagnosis, forecasting negative scenarios, and proposing respective measures. Unfortunately, this goal is barely visible in Kazakhstan, where the environmental

monitoring does not reflect the abovementioned objectives and exists by itself. The system of various types of observations conducted at both stationary, organized posts and in expeditionary conditions is not implemented into the decision-making and may not offer reliable predictions, particularly in fluctuating conditions or during facility planning. Consequently, one of the most viable approaches to managing risks and making optimal decisions involves the mathematical modeling of processes, enabling the exploration of different scenarios. This approach can be considered, as one of the priority directions to achieve environmental sustainability in Kazakhstan.

Pavlodar region is one of the most important industrial actors of Kazakhstan, which accounts for more than one-third of emissions within the whole country. Therefore, the system of environmental monitoring fails significantly. Industry has taken advantage of loopholes in environmental legislation for a long time to emit significantly high levels of GHGs. The data collection stage has limitations in several parameters, such as spatial and temporal boundaries, which may not offer reliable predictions, particularly in fluctuating conditions or during facility planning. Mathematical modeling of processes, enabling the exploration of different scenarios are not implemented for managing risks and making optimal decisions, particularly in establishing fair target indicators of environmental quality. The energy sector, represented by Aksu GRES, Ekibastuz GRES, Pavlodar CHPs, oil refining cluster, etc., contributes significantly to the environmental issues of the region. The situation worsens due to outdated obsolete infrastructure, which does not meet the modern requirements for environmental safety.

Thus, achieving carbon neutrality is a questionable challenge, demanding a systematic multitask approach. One of the urgent parts for the region is the development of a comprehensive set of intelligent information and communication systems for monitoring emissions into the environment to facilitate decision-making within the framework of the carbon neutrality concept.

Results and discussion

National Air Quality Monitoring Network (NAQMN) by the RSE «Kazhydromet» comprise 140 environmental posts spread across 45 settlements in the country. These posts are equipped with automated gas analyzers designed for monitoring pollutants. An interactive map is in place to depict the real-time condition of the atmospheric air, considering factors such as the concentration of harmful substances and pollution levels. The existence of these automated monitoring systems results in the generation of extensive datasets, offering opportunities for the application of intelligent processing methods and tools. However, the reliability of the data generated by the NAQMN has been questioned by the number of authors. As an alternative, the «Airkaz» public air quality monitoring network (www.airkaz.org) uses Pms5003 PM2.5 sensors (Plantower, China) to measure the concentrations of $PM_{2.5}$ every minute. These

monitoring systems can serve as a basis for stochastic modeling and implementation of the Industry 4.0 concept, as the tool for forecasting and decision-making for each particular settlement.

Unfortunately, the number of air quality research in Kazakhstan is limited by a few publications, and is absent for Pavlodar. The existing publications show the threatening situation, where air pollution is extremely dangerous for the population. In 2021 annual $PM_{2.5}$ concentrations in Astana (22.5 μg m^{-3}) and Almaty (35.3 μg m^{-3}) exceeded the annual WHO limit by 4.5 and 7.1 times, respectively [8]. The daily limits surpassed 151 days in Astana and 217 days in Almaty. $PM_{2.5}$ levels were highest in winter averaging 35.3 μg m^{-3} (Astana) and 76.0 μg m^{-3} (Almaty) over the heating season, with coal combustion as a main contributor. The dangerous concentrations of NO_2 and SO_2 exceeded the limits by 2–3 and 1.5–2 times, independently of the seasonality in Ust-Kamenogorsk [9]. Averaged concentrations of TSP slightly exceeded the established limits for the most industrialised part of the city. In the wintertime, some cities of Kazakhstan (e.g., Astana, Almaty, Karagandy) are frequently among the top ten polluted cities globally, with $PM_{2.5}$ concentration levels ranging between 100 – 200 μg/m^3 [10]. Annual average (2015-2017) population-weighted concentrations were Kazakhstan cities was 157, 51, 29, and 41 μg m^{-3} for TSP, NO_2, SO_2, and O_3 respectively. We estimated a total of 8134 adult deaths per year attributable to $PM_{2.5}$ (average over 2015–2017) in the selected 21 cities of Kazakhstan [11].

All the available research attempts to analyze state-of-the-art air pollution with some suggestions for stakeholders. The implementation of intelligent information and communication systems can become the next step in efficient and preventive forecasting and developing respective measures to improve ambient air quality.

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Conclusions

Establishing a monitoring system necessitates a methodological foundation in the realm of risk and uncertainty management, coupled with the utilization of intelligent information technologies. These technologies are designed to process a diverse range of information, including inaccurate, incomplete, and fuzzy data, presented in the form of data and various knowledge. The pivotal components of the information-analytical system involve the processing of varied information, including inaccurate, incomplete, and fuzzy data, as well as the incorporation of advanced Industrial Internet of Things (IIoT) technologies.

It is noteworthy that the Republic of Kazakhstan currently lacks indigenous developments in the field of Industrial Internet of Things (IIoT), highlighting a reliance on foreign technologies. This underscores the importance of promoting research and development in the realm of IIoT at the national level to enhance technological transferability and innovation processes, especially within the Kazakhstani energy sector industry.

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ЭКОЛОГИЧЕСКИЙ МОНИТОРИНГ В КОНТЕКСТЕ КАЗАХСТАНА – СОВРЕМЕННОЕ СОСТОЯНИЕ И ВЫЗОВЫ ДЛЯ ПРОМЫШЛЕННОГО РЕГИОНА

Экологические проблемы остаются актуальной проблемой для промышленных регионов Казахстана. В то время как законодательные требования к выбросам в окружающую среду постоянно становятся все

более жесткими, в системе экологического мониторинга отсутствует несколько структурных факторов.

В этой статье рассматриваются фундаментальные требования к системам экологического мониторинга и рассматриваются методы и модели мониторинга выбросов в окружающую среду на основе источников и факторов воздействия. Подробно описывается структура классического мониторинга, рассматриваются методы, основанные на международном опыте использования существующих систем управления и контроля. Обсуждаются причины и перспективы внедрения системы экологического мониторинга промышленных объектов в Павлодарской области. Особое внимание требуется уделить энергетическому сектору в связи с высокой плотностью расположения крупных предприятий и значительным воздействием на окружающую среду.

Можно сделать вывод, что несовершенство законодательства и устаревшие условия инфраструктуры привели к угрожающему загрязнению атмосферного воздуха. Хотя наблюдения, основанные на ретроспективных данных временных рядов, в настоящее время позволяют оценить статус-кво, следующим этапом является необходимость внедрения промышленной интеллектуальной информационно-аналитической системы, которая может сыграть ключевую роль в принятии решений по управлению качеством воздуха.

Ключевые слова: экологический мониторинг, выбросы парниковых газов, загрязнение окружающей среды, Индустрия 4.0, качество воздуха

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ҚАЗАҚСТАН КОНТЕКСТІНДЕГІ ЭКОЛОГИЯЛЫҚ МОНИТОРИНГ-ИНДУСТРИАЛДЫ АЙМАҚ ҮШІН ЗАМАНАУИ ЖӘНЕ СЫН-ҚАТЕРЛЕР

Экологиялық проблемалар Қазақстанның өнеркәсіптік өңірлері үшін өзекті мәселе болып қала береді. Қоршаған ортаға шығарындыларға қойылатын заңнамалық талаптар үнемі қатайып келе жатқанымен,

экологиялық мониторинг жүйесінде бірнеше құрылымдық факторлар жоқ.

Бұл мақалада экологиялық мониторинг жүйелеріне қойылатын негізгі талаптар және әсер ету көздері мен факторларына негізделген қоршаған ортаға шығарындыларды бақылау әдістері мен модельдері қарастырылады. Классикалық мониторингтің құрылымы егжей-тегжейлі сипатталған, қолданыстағы басқару және бақылау жүйелерін қолданудың халықаралық тәжірибесіне негізделген әдістер қарастырылған. Павлодар облысында өнеркәсіптік объектілердің экологиялық мониторингі жүйесін енгізудің себептері мен перспективалары талқыланады. Энергетика секторы жоғары тығыздығы мен аймақтағы қоршаған ортаға айтарлықтай әсер етуіне байланысты ерекше назар аударуы керек.

Заңнамадағы кемшіліктер мен инфрақұрылымның ескірген жағдайлары қоршаған ауаның ластану қаупіне әкелді деген қорытынды жасауға болады. Уақыт қатарларының ретроспективті деректеріне негізделген бақылаулар қазіргі уақытта ең заманауи технологияларды көрсеткенімен, өнеркәсіптік интеллектуалды ақпараттық-аналитикалық жүйені енгізуге шұғыл шақыру ауа сапасын басқару саласында шешім қабылдауда шешуші рөл атқаруы мүмкін.

Кілтті сөздер: экологиялық мониторинг, парниктік газдар шығарындылары, қоршаған ортаның ластануы, Өнеркәсіп 4.0, ауа сапасы

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