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ASIAN APPROACHES TO SMOG CONTROL: LESSONS FROM CHINA AND INDIA FOR STRENGTHENING KAZAKHSTAN'S AIR QUALITY STRATEGY

Annotation. The article supports a systematic approach to air quality management (Air Quality Management, AQM) in Kazakhstan based on a comparative analysis of Asian practices-China and India-and their adaptability to the national institutional environment.

Based on an interdisciplinary review of regulations and strategies, monitoring data, peer-reviewed studies, and industry reports, it shows that the main contribution to pollution comes from household and municipal heating with solid fuels, industry, and transport; meteorological factors (low winter boundary-layer height) and behavioral characteristics of the population intensify episodes of smog and health risks.

Deficiencies in the coverage of the observation network and in procedures for quality assurance/quality control (Quality Assurance/Quality Control, QA/QC) are identified, as well as coordination gaps between agencies and levels of government that slow the scaling of BAT (Best Available Techniques) and CEMS (Continuous Emissions Monitoring Systems).

Based on comparison with the Chinese vertical model (strict accountability, centralized monitoring) and the Indian multilevel model—the National Clean Air Programme (NCAP), the Graded Response Action Plan (GRAP), and the expansion of the National Air Quality Monitoring Programme (NAMP) / Continuous Ambient Air Quality Monitoring Stations (CAAQMS)—a hybrid framework is proposed for Kazakhstan: national standards and integrated permits with mandatory Continuous Emissions Monitoring Systems at major sources; urban plans prioritizing decarbonization of heating and fleet renewal; a coordinated system of measurement, reporting, and verification (Measurement, Reporting and Verification, MRV) and open data; inspection accountability and performance metrics.

Implementation of the framework can reduce morbidity and economic losses, increase resilience and public trust, and secure “clean air” as a national priority.

Keywords: air quality; international experience; atmospheric pollution; PM2.5; AQM; BAT; CEMS; MRV; Kazakhstan; China; India; institutional policy; comparative analysis.

Introduction

Atmospheric air quality is one of the key factors of sustainable development and public health of Kazakhstan. Clean air determines not only the duration and quality of life of the population but also directly affects economic productivity, social stability, and the international reputation of the country. According to the World Health Organization [1], air pollution remains one of the leading risk factors for premature mortality worldwide, and Kazakhstan is not an exception from this global challenge.

National strategies for air quality management already cover the main sources of pollution - energy, transport, industry, agriculture, and the household sector - and require coordinated actions of government bodies, regional authorities, and society. The goals of such strategies go beyond reducing emissions: they include protecting citizens’ health, preserving ecosystems, and creating conditions for long-term economic growth [2].

International experience shows that systemic and institutionally supported measures can significantly improve air quality within a relatively short time. Europe and North America achieved sustained reductions in key pollutant concentrations through comprehensive directives, strict standards, and transparent monitoring [3, 4, 5]. In recent years powerful programs have also been implemented by Asian countries. China applies a strict vertical regulatory model with mandatory targets, and India develops a multilevel system with national and city plans [6, 7]. These approaches demonstrate that a combination of political will, technological modernization, and public oversight can deliver tangible results even under the complex conditions of rapid economic growth. For Kazakhstan, studying and adapting such practices acquires special significance.

A combination of climatic characteristics, coal dependence, and high urbanization requires the introduction of best available techniques (BAT), modern continuous emissions monitoring systems (CEMS), and transparent mechanisms of measurement, reporting, and verification (MRV). The aim of this study is to analyze the experience of China and India in air quality management and to identify elements that can strengthen Kazakhstan’s national strategy, ensuring a transition to “clean air” as a sustainable-development priority.

Materials and research methods

The study is an interdisciplinary analytical review with elements of comparative political-institutional assessment aimed at identifying and adapting Asian air-quality management practices (Air Quality Management, AQM) to strengthen Kazakhstan’s national strategy. At the center of the analysis there are two key cases: China and India, compared with Kazakhstani realities.

As main sources, documents and studies directly reflecting the policy and practices of these three countries were used. For Kazakhstan the following were applied: the Environmental Code of the Republic of Kazakhstan (analysis in the World Bank report “Clean Air and Cool Planet,” 2021) [8], the National Air Quality Improvement

Plan until 2028, provisions of the Government of Kazakhstan on the Ministry of Ecology and Natural Resources (rev. 2023–2024) [9] and the Ministry of Energy (2014, with updates) [10], descriptions of integrated environmental permits (IEP) and implementation of best available techniques (BAT), as well as data from the national hydrometeorological service Kazhydromet [11] and results of SILAM atmospheric modeling.

The empirical base consisted of peer-reviewed studies on Kazakhstan: trends and health under exposure to major pollutants [12], episodic analysis of $PM_{2.5}$ in Astana and Almaty [13], influence of planetary boundary-layer height (PBLH) on particle concentrations [14], research on industrial emissions and biomonitoring of heavy metals [15, 16, 17], atmospheric modeling of photochemical processes [18, 19], chemical characterization and source apportionment of $PM_{2.5}$ [20], behavioral aspects of pollution perception [21], and economic costs of particulate exposure [22].

For China, the analysis covered materials of the Ministry of Ecology and Environment (MEE) [23] and the World Bank report on the implementation of the Hebei Air Pollution Prevention and Control Program [24]; in addition, the present review also used relevant academic studies assessing CEPI's effectiveness and recent trends in $PM_{2.5}$ concentrations [6, 25, 26, 27, 28].

For India, sources included the National Clean Air Program (NCAP) of the Ministry of Environment, Forest and Climate Change [29], National Ambient Air Quality Standards (NAAQS) [30] and materials of the Central Pollution Control Board [31], data from the national monitoring networks NAMP and CAAQMS [32], as well as studies on the Graded Response Action Plan (GRAP) and on the national implementation of the Bharat Stage VI (BS-VI) vehicle standard [33, 34, 35, 35].

The methodology included: (1) content analysis of national regulatory acts and programs of China, India, and Kazakhstan to identify key objectives, instruments (standards, economic incentives, technological solutions) and performance metrics (reductions of $PM_{2.5}$/PM_{10}, SO_2, NO_2 concentrations, health indicators, economic costs); (2) synthesis of epidemiological and atmospheric data on Kazakhstan to assess risks and factors (including correlation of pollutant levels with meteorological conditions such as PBLH); (3) comparative institutional analysis of the Chinese vertical model with strict accountability and centralized monitoring and the Indian multilevel model with city plans and operational response mechanisms; (4) integration of results into a systemic framework "standards → monitoring (Measurement, Reporting and Verification, MRV) → enforcement (IEP/BAT, continuous emissions monitoring systems, CEMS) → effect evaluation → policy adjustment," which made it possible to develop recommendations for strengthening Kazakhstan's AQM strategy taking into account the most effective mechanisms of China and India.

Such an approach ensured the comprehensiveness of the analysis, combining qualitative and quantitative data and providing practical applicability of the conclusions for the development of Kazakhstan's air-quality management policy.

Scientific results and discussion

The Current State of Air Pollution in Kazakhstan: Facts and Risks

Kazakhstan continues to be one of the most polluted regions of Eurasia according to several key air-quality indicators and benchmarks. In global comparisons, the country ranks thirty-fifth worldwide for the level of atmospheric air-pollution overall among peer nations [19, 12]. The main emission sources—industry, energy, transport, and household coal heating—produce a complex mixture of airborne priority pollutants: CO, SO_2, NO_2, $PM_{2.5}$, PM_{10}, NH_3, and volatile organic compounds (VOC). These substances originate both from large metallurgical and petrochemical industries and from the private sector, where solid fuel remains the main heating type today [12, 37].

The largest industrial centers—Almaty, Astana, Pavlodar, Ust-Kamenogorsk, Karaganda, Temirtau, Ekibastuz, Zhezkazgan, and Petropavlovsk—show consistently high concentrations of pollutants which repeatedly exceed WHO recommendations (5 µg/m³ annual and 15 µg/m³ daily for $PM_{2.5}$) [1]. In Almaty and Ust-Kamenogorsk, annual average $PM_{2.5}$ concentrations range from 20–35 µg/m³, and winter peaks reach 200–500 µg/m³, which is four to seven times higher than annual and up to thirty-three times higher than daily limits [13, 38]. In Pavlodar, peak PM_{10} levels reach 40–60 µg/m³, exceeding WHO daily recommendations, and chronic $PM_{2.5}$ exposure in the industrial centers of Karaganda and Temirtau is associated with health-care economic losses of about 12 billion US dollars per year in total [39, 40].

According to World Bank estimates, air pollution leads to 10,000 premature deaths annually and economic losses of 10.5–12 billion US dollars, which equals 6–7 percent of the country's GDP [40, 41, 12]. A direct link has been established between elevated $PM_{2.5}$ concentrations and cardiovascular diseases, strokes, and chronic obstructive pulmonary disease. During the heating season, when coal consumption increases, a rise in respiratory and cardiovascular diseases is recorded [21].

Geography and climate intensify the problem. In Almaty, the mountainous surroundings contribute to a low winter planetary boundary-layer height (PBLH), leading to pollutant accumulation: with an average winter PBLH of about 392 m, the $PM_{2.5}$ concentration reached 94 µg/m³, whereas in summer with a PBLH around 1969 m it was only 9.9 µg/m³ [14]. In Ust-Kamenogorsk, winter spikes of NO_2 and SO_2 are caused by coal combustion at thermal power plants and metallurgy, and in Semey, significant SO_2 exceedances are intensified by cement production [15].

Metallurgical districts are marked by chronic accumulation of heavy metals: in Ust-Kamenogorsk and Aksu, biomonitoring detected elevated levels of lead, zinc, and cadmium in residents' blood [16, 17].

The national Kazhydromet network covers seventy cities (127 automatic and 43 manual stations) yet remains insufficient: many stations fail to provide 90 percent data completeness, and rural and industrial areas are poorly studied [20]. Numerical models of photochemical processes partly compensate for the lack of observations and show strong agreement with the data from automatic stations [18, 19], however improvement of emission inventories and data quality control (QA/QC) remains a priority.

The institutional system of AQM in Kazakhstan

Air-quality management (AQM) policy in Kazakhstan is framed as a comprehensive mechanism to cut pollution and protect public health while aligning fully with national climate goals; its legal foundation is the 2021 Environmental Code, which integrates the National Air Quality Improvement Plan to 2028 and the Paris Agreement's provisions [8].

Implementation relies on the national monitoring network: 170 stations (127 automatic operating continuously and 43 manual taking measurements three to four times daily) across seventy settlements throughout the country, also supplemented by mobile laboratories; monitoring covers $PM_{2.5}$, PM_{10}, SO_2, NO_x, O_3, CO, H_2S, NH_3, HF, HCl, VOCs (including benzene), priority organics (formaldehyde, benzo[a]pyrene), methane, and heavy metals [11].

The institutional architecture ensures decentralized implementation coordinated by the Ministry of Ecology and Natural Resources, which sets the AQM regulatory framework, implements both the Environmental Code and the National Plan, administers integrated environmental permits (IEP) through the Committee for Environmental Regulation and Control, approves BAT reference documents and requirements for their application, and organizes effective interagency coordination [9].

The national hydrometeorological service Kazhydromet deploys and maintains the monitoring network, provides data collection, QA/QC, and analytical processing, and publicly publishes indicators (API5, pollution classes I–IV) in real time on the kazhydromet.kz platform [11].

The Ministry of Energy sets national fuel-and-energy policy and programs, and tools for transitioning to cleaner fuels and efficiency, including subsidies for corresponding technologies across sectors [10]. Akimats translate national requirements into urban air-quality management plans and ensure implementation of measures at the local level.

International partners (World Bank, IIASA, and others) provide expertise, modeling support (GAINS), and financing, creating a closed loop of “standards → monitoring → enforcement” that enables prioritizing measures, evaluating their effectiveness, and adjusting policy on the basis of data [42].

AQM policy spans industry, transport, and the residential sector: for major sources, integrated environmental permits (IEP) and best available techniques (BAT) are applied; in transport, Euro-4/5 standards and fleet-renewal programs are implemented; in the residential sector, a shift from coal to gas and energy-efficient heating is encouraged through subsidies; the toolkit is complemented by payments for negative impact and greenhouse-gas emissions trading [43].

China and India: Smog Control Mechanisms

Air-quality management in China operates through a strict vertical hierarchy extending from the central government to local executive bodies there. This system, often described as “authoritarian environmentalism,” is marked by centralized decision-making, mandatory targets, and rigorous accountability mechanisms at all levels [6]. At the central level, the State Council sets overall directives, while the Ministry of Ecology and Environment (MEE, formerly MEP) develop national standards, coordinates policy instruments and provides worldwide oversight, and designs priority control zones—including Beijing–Tianjin–Hebei, the Yangtze River Delta, and the Pearl River Delta—where stricter air-quality norms apply [27]. National programs such as the Air Pollution Prevention and Control Action Plan and the Blue-Sky Protection Campaign highlight the center’s leading role in setting national policy goals [24].

At the provincial level, authorities and environmental agencies function under a "dual leadership" arrangement: they report to both regional administrations and to the Ministry of Ecology simultaneously [6]. Mandatory targets for key pollutants, such as $PM_{2.5}$ and SO_2, are issued from the top, and compliance directly influences the career prospects of officials across regions. This mechanism of personal responsibility has remained a key policy instrument since 2013 [6, 44]. Municipal and county bodies at ground level are responsible for practical policy implementation: they tighten control over sources, restrict coal use, promote cleaner heating options, and take measures in transport and traffic management [45]. Over the last decade, seasonal smog-control plans were introduced, and a color-alert system now informs the population about risks [46].].

A special place in the vertical system is held by the Central Environmental Protection Inspection (CEPI), which dispatches inspection teams to evaluate the work of provincial and local authorities [26]. Studies show that CEPI's introduction contributes to reductions in SO_2 and PM_{10} emissions and significantly increases the speed of responses to environmental violations, notably [6, 25]. Transparency is ensured through the national monitoring network, which includes more than 1,500 centrally managed stations that publish data in real time [25], reducing opportunities for manipulation on the ground and strengthening public oversight [47]. Interregional cooperation is also advancing within the Chengdu–Chongqing economic circle, the governments of Chongqing and Sichuan build joint coordination and information-sharing mechanisms, issue interprovincial documents, and shift from fragmented measures to an institutionalized model, underscoring the rising importance of interprovincial management of transboundary pollution [28]. Overall, China's vertical model combines national-level policy development, fixed targets, campaign-style enforcement, and real-time monitoring, which has significantly reduced $PM_{2.5}$ concentrations over the last decade, although limitations still persist regarding short-term campaigns and the balancing of environmental and economic goals national today [26].

India has built a multilevel air-quality management system centered on the National Clean Air Program (NCAP), launched by the Ministry of Environment, Forest and Climate Change (MoEF&CC) in 2019 [48]. The program sets national targets—reducing $PM_{10}/PM_{2.5}$ by 20–30 percent by 2024–2025 relative to 2017–2018—and is implemented through city air-quality management plans for "non-attainment cities," where standards are systematically violated annually [48, 16–17, 45–46]. Its foundation is the National Ambient Air Quality Standards (NAAQS), adopted in the 2009 version, which establish annual limit levels—$PM_{2.5}$ = 40 µg/m³, PM_{10} = 60 µg/m³—as well as binding standards for SO_2, NO_2, O_3, CO, Pb, and other pollutants generally [49, 97–98].

Institutionally, the NCAP rests on the Central Pollution Control Board (CPCB) and, at the state level, on the State Pollution Control Boards (SPCB) [50]. The CPCB coordinates two national monitoring networks: the manual National Air Quality Monitoring Program (NAMP) and the automatic Continuous Ambient Air Quality Monitoring Stations (CAAQMS), which feed the national Air Quality Index (AQI) and public dashboards [51, 2–3]. The national monitoring network expanded three- to fourfold during 2019–2023: the number of automatic stations in NCAP cities grew from 155 to 340, and nationwide from 220 to 530; priority was given to covering the Indo-

Gangetic Plain, while low-cost sensors are simultaneously deployed for rural areas [51, 6–7].

A key “accelerator” of enforcement in the Delhi agglomeration and neighboring National Capital Region (NCR) has been supraregional tools around the Environment Pollution (Prevention and Control) Authority (EPCA) and the Graded Response Action Plan (GRAP) [34, 329–330]. GRAP represents a preapproved set of escalating measures by AQI category—from “moderate” to “severe”—including restrictions on truck entry, suspension of construction, closure of kilns and crushers, strengthening of public transport, up to an odd–even scheme for private vehicles and school closures when $PM_{2.5}$ exceeds 250–300 μg/m³ or PM_{10} exceeds 430–500 μg/m³ [34, 383–386]. These measures are applied cumulatively and tightened as air quality deteriorates.

The sectoral design of the NCAP covers transport, industry and energy, construction, dust, agriculture, and the household sector. In transport, a central step was the introduction of the Bharat Stage VI (BS-VI) standard on 1 April 2020, expansion of gas-motor fuel, and development of electric transport; this also includes fleet-renewal and old-vehicle scrappage programs [34, 359–364]. In industry and energy, standards for diesel generators and thermal power plants are strengthened, and certification of measuring instruments and QA/QC standards for monitoring are implemented [35, 30967–30979]. For control of urban dust, NCAP and GRAP provide mechanized cleaning, dust-suppression regulations, and restrictions on construction during unfavorable conditions [36, 30976–30977].

The air-monitoring system is closely linked to forecasting and health protection: CAAQMS stations transmit hourly data for AQI calculation and rapid response [52], while the long-term NAMP program tracks air-quality dynamics [52]. NCAP also uses satellite data on aerosol optical depth (AOD), deploys low-cost sensors and expands the network of stations in villages, creates a pollution-forecasting system, and engages research teams from IIT and CSIR-NEERI to analyze sources and mitigation measures [36].

Thus, the Indian model combines a national strategy (NCAP), institutional control (CPCB/SPCB), a broad monitoring network (NAMP/CAAQMS), and rapid-response mechanisms (GRAP), forming a multilevel air-quality management system capable of adapting to regional characteristics and ensuring reductions in pollutant concentrations.

Asian Experience: Guidelines for Kazakhstan

The experience of China and India demonstrates that even in countries with a heavy industrial load it is possible to achieve sustainable reductions of $PM_{2.5}$ and other pollutants when air-quality management relies on clear targets, a robust monitoring system, and strict institutional accountability supported by transparent enforcement and public reporting. Kazakhstan has already taken significant steps: the 2021 Environmental Code is in effect, the National Air Quality Improvement Plan until 2028 is being implemented, integrated environmental permits (IEP) and best available techniques (BAT) are introduced, the network of automatic Kazhydromet stations is expanding, and regional ecology departments, as subdivisions of the Committee for Environmental Regulation and Control of the Ministry of Ecology and Natural Resources, directly report to the Committee and operate according to its regulatory acts. These elements already create a foundation for comprehensive air-quality management, yet Asian experience makes it possible to strengthen institutional control and governance mechanisms significantly.

China demonstrates the effectiveness of a strict vertical of responsibility in which the State Council and the Ministry of Ecology and Environment set general directives, assign mandatory quantitative indicators for reducing key pollutants, and oversee their fulfillment through the Central Environmental Inspection (CEPI). Provincial authorities and municipalities bear personal responsibility for achieving the targets, and a centralized network of more than 1,500 automated stations publishes data in real time, eliminating manipulation and reinforcing public oversight.

For Kazakhstan such a practice could become the basis for stricter institutional control: it is advisable to fix quantitative targets for reducing $PM_{2.5}$ and SO_2 for each region and link them to the performance evaluation of regional ecology departments and akimats, and also to consider creating an unscheduled inspection mechanism similar to CEPI, ensuring direct accountability of local authorities to the Committee.

The Indian model, by contrast, shows the value of multilevel planning and rapid response measures. The National Clean Air Program (NCAP) links national targets to specific urban plans for “non-attainment cities,” where standards are systematically violated, and uses a monitoring network that has expanded rapidly in recent years through automatic CAAQMS stations and low-cost sensors. Of particular importance is the Graded Response Action Plan (GRAP) - a pre-approved package of escalating measures that is triggered automatically when pollution thresholds are reached: from restricting truck entry and suspending construction work to temporarily closing schools and enterprises. For Kazakhstan, where winter smog in Almaty, Ust-Kamenogorsk, and other industrial centers recurs every year, implementing a unified emergency-response protocol modeled on GRAP would improve the predictability and speed of actions, and city air-quality management plans under the coordination of regional ecology departments would strengthen the implementation of the National Plan at the regional level.

Both countries also offer lessons in data control and economic incentives. India has developed mandatory certification of monitoring equipment and QA/QC procedures, which has improved the reliability of the national air-quality index and can be directly adapted to the Kazhydromet system. China’s experience with targeted subsidies and a gradual phase-out of coal heating, integrated into municipal decarbonization plans, can accelerate Kazakhstan’s ongoing transition to gas and renewable energy. Alongside this, Indian measures for fleet renewal, the switch to gas-powered vehicles, and the development of electric transport (BS-VI standard) provide ready guidelines for modernizing the transport sector.

Thus, Kazakhstan, while maintaining its own achievements and regulatory framework, can draw from Asian experience primarily the mechanisms for institutional control and governance: fixing quantitative targets and directly linking them to the personal responsibility of regional authorities; centralized and independent monitoring with mandatory data publication; development of flexible city plans with predefined emergency measures; implementation of strict MRV and QA/QC procedures; and economic and technological incentives for the decarbonization of heating and transport.

Strengthening the role of regional ecology departments as a link between the Committee, the akimats, and Kazhydromet, granting them the functions of coordinators of city plans and operators of regional MRV systems, will establish a sustainable vertical of responsibility and ensure more effective implementation of Kazakhstan's air-quality management strategy, drawing on the best practices of China and India.

Conclusion

The analysis indicates that Kazakhstan already possesses core elements of a modern air-quality management system: the 2021 Environmental Code is in force, the National Plan through 2028 is being implemented, integrated environmental permits and best available techniques (BAT) are introduced, the network of automatic Kazhydromet stations is expanding, and an administrative control vertical is established through the Committee for Environmental Regulation and its regional departments. At the same time, high levels of air pollution in industrial centers and recurring winter smog episodes persist, requiring further strengthening of institutional mechanisms and improvements in management practice.

Comparative analysis of Asian experience shows that China and India, despite comparable scales of industrial burden, have achieved significant progress through a combination of strict vertical accountability, transparent and independent monitoring, multilevel planning, and flexible emergency-response protocols. For Kazakhstan, especially valuable are the Chinese practice of setting quantitative targets and personal responsibility for regional authorities, centralized automated monitoring with real-time data publication, and the mechanism of unscheduled inspections, as well as the Indian approach to "non-attainment city" plans, the Graded Response Action Plan (GRAP), and the large-scale expansion of low-cost sensors and CAAQMS stations.

Integrating these elements into Kazakhstan's existing AQM architecture will create a durable vertical of institutional control, significantly increase the accountability of regional authorities, speed the transition to low-carbon energy sources, and ensure faster responses to episodes of high pollution. Strengthening the role of regional ecology departments as a link between the Committee, the akimats, and Kazhydromet will be key to adapting the best Asian practices, ultimately ensuring reduced morbidity over time, greater public trust, and the achievement of the strategic goal-clean air as Kazakhstan's national priority.

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ТҰМАНМЕН КҮРЕСУДЕГІ АЗИЯЛЫҚ ТӘСІЛДЕР: ҚАЗАҚСТАННЫҢ АУА САПАСЫ СТРАТЕГИЯСЫН НЫҒАЙТУ ҮШІН ҚЫТАЙ МЕН ҮНДІСТАННЫҢ САБАҚТАРЫ

Аннотация. Мақалада Қазақстанда атмосфералық ауаның сапасын жүйелі басқарудың (Air Quality Management, AQM) қажеттілігі негізделеді: Азия тәжірибелері — Қытай мен Үндістан — салыстырмалы талдауы негізінде олардың ұлттық институционалдық ортаға бейімделуі бағаланады.

Нормативтік актілер мен стратегияларға, мониторинг деректеріне, рецензияланған зерттеулер мен салалық есептерге жүргізілген пәнаралық шолу негізінде, ластануға ең көп үлес қосатындар – тұрмыстық және коммуналдық қатты отынмен жылыту, өнеркәсіп және көлік екені көрсетілді; метеорологиялық факторлар (қыс мезгілінде шекаралық қабаттың төмен болуы) мен халықтың мінез-құлық ерекшеліктері смог эпизодтарының жиілеуіне және соған байланысты денсаулыққа төнетін қауіптердің артуына ықпал етеді.

Мониторинг желісін қамтудағы және сапаны қамтамасыз ету/сапаны бақылауда (QA/QC бойынша сапаны қамтамасыз ету/сапаны бақылау) олқылықтар бары анықталды, сондай-ақ агенттіктер мен үкімет деңгейлері арасындағы үйлестірудегі кемшіліктер бар екені байқалды, бұл жағдайлар BAT (ең үздік қолжетімді технологиялар) және үздіксіз эмиссияларды бақылау жүйелерінің (CEMS) ауқымын кеңейтуде бәсеңдетуші факторлар екені анықталды.

Қытайдың вертикалды үлгісі (қатаң есептілік және орталықтандырылған мониторинг) мен Үндістанның көпдеңгейлі тәсілдерін (NCAP - Ұлттық таза ауа

бағдарламасы, GRAP - Деңгейлендірілген әрекет ету жоспары, NAMP - Ауа сапасын бақылаудың ұлттық бағдарламасы /CAAQMS - Қоршаған ауаның сапасын үздіксіз бақылау станциялары) салыстыру негізінде Қазақстан үшін аралас модель ұсынылады. Нақтырақ айтсақ: негізгі нысандарда міндетті үздіксіз эмиссияларды бақылау жүйелерін (CEMS) орнату талап ететін ұлттық стандарттар мен біріктірілген рұқсаттарды беру; жылыту жүйесін декарбонизациялауға және автопаркті жаңартуға басымдық беретін қалалық жоспарлар; өлшеу, есеп беру және верификация жүйесі (MRV) жүйесін үйлестіру және ашық деректерді кеңейту; инспекцияның есептілігі мен нәтиже көрсеткіштерін жақсарту.

Осы үлгіні жүзеге асыру халық денсаулығын жақсартуға, экономикалық шығындарды азайтуға, тұрақтылық пен қоғамдық сенімді арттыруға және таза ауаны ұлттық басымдық ретінде бекітуге мүмкіндік береді.

Кілт сөздер: ауа сапасы; халықаралық тәжірибе; атмосфералық ластану; PM2.5; AQM; BAT; CEMS; MRV; Қазақстан; Қытай; Үндістан; институционалдық саясат; салыстырмалы талдау.

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АЗИАТСКИЕ ПОДХОДЫ К БОРЬБЕ СО СМОГОМ: УРОКИ КИТАЯ И ИНДИИ ДЛЯ УКРЕПЛЕНИЯ СТРАТЕГИИ КАЗАХСТАНА ПО КАЧЕСТВУ ВОЗДУХА

Аннотация. В статье обосновывается необходимость системного управления качеством атмосферного воздуха (Air Quality Management, AQM) в Казахстане на основе сравнительного анализа азиатских практик — Китая и Индии — и оценки их адаптируемости к национальной институциональной среде.

На основе междисциплинарного обзора нормативных актов и стратегий, мониторинга данных, рецензируемых исследований и отраслевых отчетов показано, что основной вклад в загрязнение вносят бытовое и коммунальное отопление твердым топливом, промышленность и транспорт; метеорологические факторы (низкая высота приземного слоя зимой) и поведенческие особенности населения увеличивают эпизоды смога и связанные с ними риски для здоровья.

Выявлены недостатки в охвате сети наблюдений и процедур обеспечения и контроля качества (обеспечение качества/контроль качества, QA/QC), а также пробелы в конкуренции между ведомствами и уровнями власти, которые замедляют масштабирование NDT (наилучших современных технологий, BAT) и систем непрерывного мониторинга выбросов (CEMS).

На основе сравнения с китайской вертикальной моделью (строгая подотчетность, централизованный мониторинг) и индийской многоуровневой моделью — Национальной программой чистого воздуха (NCAP), Планом действий по градуированному реагированию (GRAP) и расширением Национальной программы мониторинга качества воздуха (NAMP)/Станциями непрерывного мониторинга качества окружающего воздуха (CAAQMS) — для Казахстана предлагается гибридная структура: национальные стандарты и комплексные разрешения с обязательными системами непрерывного мониторинга выбросов (системы непрерывного мониторинга выбросов, CEMS) на крупных источниках;

городские планы, отдающие приоритет декарбонизации отопления и обновлению автопарка; согласованная система измерений, отчетности и верификации (Measurement, Reporting and Verification, MRV) и открытые данные; подотчетность инспекций и метрическая эффективность.

Реализация этой модели позволит снизить заболеваемость и тяжелые потери, повысить устойчивость и общественную безопасность и закрепить «чистый воздух» в качестве национального приоритета.

Ключевые слова: качество воздуха; международный опыт; загрязнение атмосферы; PM2.5; AQM; BAT; CEMS; MRV; Казахстан; Китай; Индия; институциональная политика; сравнительный анализ.