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# Beyond Regulation: Integrated Governance for Effective and Sustainable Water and Air Quality Improvement

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A R T I C L E I N F O

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A B S T R A C T

Improving water and air quality is a prerequisite for public health, ecosystem sustainability, and economic productivity. However, having formal and relatively complete regulations doesn't automatically guarantee environmental quality improvements. This article aims to explain why regulations alone are not enough and to identify a combination of governance mechanisms needed to achieve effective and sustainable water and air quality improvements, with a special focus on the Indonesian context. The study uses a purposive, iterative, and thematic qualitative literature review of reputable journal articles mainly published between 2020-2026, as well as relevant official policy documents. The synthesis shows five interdependent prerequisites: the quality and coherence of regulations; institutional capacity, oversight, and enforcement; monitoring infrastructure and control technology; funding and incentives that sustain long-term operations; and stakeholder participation and behavior change. Evidence from wastewater management, air quality, low-cost sensors, collaborative governance, and the Citarum experience shows that implementation failures often stem from fragmented authority, limited data and capacity, maintenance costs, unequal participation, and weak compliance. The article proposes an integrated governance framework that links legal standards with environmental and health performance measurements, accountability, validated technology, economic instruments, and collaboration. The main implication is that the effectiveness of policies should be judged by changes in water and air quality and health risks, not just by the existence of rules or the number of programs

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## INTRODUCTION

Water and air are environmental media that directly determine human health, ecosystem function, and the sustainability of economic activities. Water contamination increases exposure to pathogens and chemical contaminants, while exposure to air pollutants—especially fine particulates—is linked to higher cardiovascular and respiratory morbidity and mortality. Recent literature emphasizes that these risks don't only appear under extreme pollution conditions; health impacts can still be detected at relatively low exposure levels, so environmental policies need to focus on prevention and continuous reduction of exposure (Owens et al., 2020; Orellano et al., 2020; Orach et al., 2021; Berman, 2024).

In Indonesia, the urgency of improving water quality is evident from the large burden of domestic wastewater and the uneven capacity to manage it. A look at domestic wastewater in Indonesia shows that untreated greywater can be a major pollution source, while on-site systems for black water still face issues with infrastructure quality, operation, and maintenance. At the same time, Indonesia's air quality literature shows limitations in monitoring networks, inconsistent data, research concentrated in the western part of Indonesia, and the need to strengthen coordination, funding, and monitoring technology. This makes water and air issues not just a matter of technical standards, but also governance capacity (Widyarani et al., 2022; Amin et al., 2025; Lukman et al., 2025).

Indonesia actually has a strong legal basis. Law Number 32 of 2009 on Environmental Protection and Management remains an important foundation, with relevant updates through Law Number 6 of 2023. On the operational level, Government Regulation Number 22 of 2021 regulates environmental approvals, protection and management of water quality, air quality, supervision, and administrative sanctions. With the enactment of GR 22/2021, GR Number 82 of 2001 on water quality management and GR Number 41 of 1999 on air pollution control are no longer the main references as they have been repealed. For providing air quality information to the public, Ministry of LHK Regulation Number 14 of 2020 regulates the Air Pollutant Standard Index. This framework shows that today's policy issue isn't the lack of rules, but rather how the rules are translated into compliance and measurable environmental outcomes (Republic of Indonesia, 2009, 2023; Republic of Indonesia, 2021; Ministry of Environment and Forestry, 2020).

Experiences across countries also show that the strictness of environmental policies can drive innovation and improve performance, but its impact depends on the design of the instruments, consistency of enforcement, and how economic actors respond. Measuring policy stringency itself isn't the same as measuring effectiveness; formal policy indicators can give a different picture than what actually happens on the ground. That's why analyzing effectiveness needs to shift from asking whether rules exist to whether rules can change incentives, behavior, technology investment, and ultimately environmental quality (Galeotti et al., 2020; Kesidou & Wu, 2020; Wang et al., 2020; Yuan & Zhang, 2020; Shen et al., 2020).

The gap between regulations and environmental outcomes is becoming more relevant when pollution sources are scattered and cross regional boundaries. River water carries pollutant loads across administrative borders, while air pollutants move according to atmospheric dynamics. In such conditions, fragmented authority can lead to collaboration gaps, program duplication, limited data sharing, and weak inter-agency accountability. Studies on watershed management and air pollution prevention show that cross-government coordination and stakeholder participation can strengthen effectiveness, but the results depend on the composition of actors, power distribution, facilitation mechanisms, and the sustainability of collaboration (Baudoin & Gittins, 2021; Hamilton et al., 2021; Wang & Zhao, 2021; Arai et al., 2021).

From a technology perspective, advances in water treatment, membrane-based processes, biofilms, sensors, IoT, and low-cost monitoring networks open up opportunities to improve early detection and policy response. But technology isn't a standalone solution. Cheap sensors need calibration and validation; treatment systems need energy, operators, funding, and maintenance; and real-time data is only valuable when tied to the authority to act. So, technology should be seen as enabling infrastructure within governance systems, not a replacement for institutions and enforcement (Waqas et al., 2020; Chojer et al., 2020; Liang, 2021; Kang et al., 2022; Jan et al., 2021).

Based on that background, this article raises two research questions. RQ1: Why isn't the existence of regulations enough to ensure effective and sustainable water and air remediation? RQ2: What combination of policy instruments, implementation capacity, technology, financing, and stakeholder collaboration is needed to strengthen the effectiveness of water and air remediation, especially in the context of Indonesia?

The purpose of this article is: first, to synthesize conceptual and empirical evidence regarding the limitations of approaches that rely too heavily on formal regulation; second, to identify implementation mechanisms that bridge regulation with outcomes in water quality, air quality, and health; and third, to formulate an integrated governance framework that can serve as a basis for policy and research agendas. The article's contribution lies in integrating the literature on water and air into a single implementation framework, so that both domains are not treated as separate technical issues, but as environmental governance issues that share similar failure mechanisms and prerequisites for success.

## LITERATURE REVIEW

### 1. Water and Air Sanitation as a Public Health and Sustainability Issue

The term water and air sanitation in this article is used broadly to refer to a range of efforts including pollution prevention, control of emission or discharge sources, treatment, quality recovery, exposure monitoring, and health protection. This approach views environmental quality as an outcome that must be measurable. In drinking water and water bodies, risks arise from microbiological contaminants, nutrients, metals, organic compounds, as well as changes in hydrological conditions. In air, particulates, ozone, nitrogen dioxide, sulfur dioxide, and other pollutant mixtures create health burdens through inflammation, oxidative stress, and cardiopulmonary function disruption (World Health Organization, 2021, 2022; Shah et al., 2023; Picetti et al., 2022; Chowdhury et al., 2022; Du et al., 2022).

Water and air quality are also linked to social vulnerability. Inadequate service systems can make low-income groups rely on riskier water sources, while those living or working near traffic corridors and emission sources are exposed to higher levels of air pollution. Research on water supply for urban poor communities highlights the importance of government roles in maintaining inclusive participation and service accountability, while studies on PM2.5 risks in Jakarta's public spaces emphasize the need for exposure assessment at the local level. So, improving public health should take into account not just the average environmental quality but also equity in access and risk distribution (Rana & Piracha, 2020; Pangestika & Wilti, 2021).

Climate change adds complexity because extreme rainfall, temperatures, floods, droughts, and saltwater intrusion can alter water source quality and contamination patterns. In the air, meteorological conditions interact with the formation and dispersion of pollutants. This means that quality standards and control programs need to come with adaptive capacity, long-term monitoring, and integration between environmental, health, and climate resilience policies (Nijhawan & Howard, 2022; Klompmaker et al., 2021).

### 2. Pollution Sources and Intervention Pathways

Water pollution comes from both point sources and diffuse sources, including domestic wastewater, industrial activities, agricultural runoff, waste accumulation, and land use changes. In the context of Indonesia, the large amount of untreated grey water shows that pollution control can’t just focus on big industries. Interventions need to include households, sanitation systems, area management, communal infrastructure, and operation-maintenance incentives. Participatory research in the Maros watershed also shows that changes in spatial planning, urban activities, and community behavior interact in shaping the decline in water quality (Widyarani et al., 2022; Syafri et al., 2020).

Urban air pollution is generally the result of a mix of transportation, industry, power plants, and fuel burning, construction, as well as episodic sources like forest and land fires. Recent reviews for Indonesia show a large geographical variation along with a lack of continuous data, so identifying sources and evaluating policies is often limited by the density of monitoring stations. This situation supports the need for an airshed approach and data systems that allow the government to assess cross-sector contributions, rather than relying on a single-source policy (Amin et al., 2025; Lukman et al., 2025; Feng et al., 2025).

Theoretically, the presence of heterogeneous pollution sources requires a policy mix. Command-and-control instruments are needed to set quality standards and minimum obligations, but they can be complemented by economic instruments, disclosure, technology monitoring, innovation support, and behavioral interventions. Empirical studies show that the impact of environmental policies on innovation and emissions varies depending on the strictness, type of instrument, and quality of enforcement. Therefore, coherence between instruments is more important than having more stand-alone rules (Kesidou & Wu, 2020; Shen et al., 2020; Yuan & Zhang, 2020; Feng et al., 2025).**2.3**

**3.Regulations, Implementation Capacity, and the Enforcement Gap**

Regulations provide a legal mandate, performance standards, a division of responsibilities, permit/approval mechanisms, and a basis for sanctions. However, regulatory effectiveness only happens when legal norms are transformed into inspection activities, measurements, enforcement, remediation, and consistent behavior change. Environmental policy stringency literature shows that formal strictness indices don't always match air quality results or innovation levels; implementation and institutional context influence that relationship (Galeotti et al., 2020; Wang et al., 2020).

Enforcement gaps happen when institutions lack staff, budget, labs, data, operational authority, or coordination mechanisms. Gaps can also appear when the cost of non-compliance is lower than the cost of compliance, when violation information comes in late, or when shared authority causes people to wait on each other. Evidence shows that government investment, legislation, enforcement, and public participation can actually strengthen each other in improving environmental quality. This shows that effectiveness isn't really an inherent feature of the rules themselves, but the result of the interaction between rules, capacity, accountability, and how actors respond (Wu et al., 2020; Li, 2022). In the context of Indonesia, the update towards PP 22/2021 is important because it integrates water and air quality regulations with environmental permits, guidance and supervision, information systems, and administrative sanctions. However, normative integration still requires the ability of central and local governments to translate quality standards into monitoring targets, risk-based inspections, follow-ups to violations, and public communication. In other words, regulations are a necessary condition but not a sufficient one for effective environmental improvement.

**4. Collaborative Governance, Participation, and Behavior Change**

Water and air pollution are a collective-action problem because environmental benefits are widespread while compliance costs are borne by specific actors. Collaborative governance makes sense when the government, industry, communities, academia, and civil organizations have complementary resources. But collaboration isn't automatically effective: the mix of actors, interest representation, trust, facilitation mechanisms, and power distribution all shape the quality of the process and ecological outcomes (Baudoin & Gittins, 2021; Arai et al., 2021).

Institutional fragmentation can create collaboration gaps between actors who actually depend on each other. For cross-regional air pollution, regional collaboration helps overcome the limitations of administrative jurisdictions. For water, effective quality management requires coordination across scales and consistency between national goals, local practices, and land use. Because of that, governance design needs to build decision-making forums, data-sharing protocols, task distribution, and clear conflict resolution mechanisms (Hamilton et al., 2021; Wang & Zhao, 2021; Wuijts et al., 2021).

Public participation also serves as a source of information and a mechanism for accountability. Evidence shows that participation can support environmental enforcement when there are institutional channels that make public reports actionable. However, symbolic or unbalanced participation risks reinforcing actors who are already dominant. On the behavioral side, environmental knowledge needs to be translated into norms, behavior control, and practical incentives; environmental education tends to be more effective when it provides concrete experiences and opportunities for action, not just information transfer (Li, 2022; Rezaei-Moghaddam et al., 2020; van de Wetering et al., 2022).

**5.Data Processing Technology and Infrastructure as an Enabler**

In water treatment, the development of integrated fixed-film activated sludge, anaerobic membrane bioreactor, reverse osmosis, and nanofibrous membranes has expanded treatment options for organic loads, pathogens, and more complex contaminants. These technologies have high potential, but choosing the right one needs to take into account influent quality, energy requirements, fouling, operator skills, spare parts, residue management, and lifecycle costs. So, technology decisions need to be set within realistic institutional and financing models (Waqas et al., 2020; Ji et al., 2020; Liu et al., 2021; El-Aswar et al., 2022; Abdulhamid & Muzamil, 2023).

For air, low-cost sensor networks can boost the spatio-temporal resolution of monitoring and expand citizen science. However, the literature consistently warns that cheap sensors face issues like drift, cross-sensitivity, humidity, device-to-device variation, and the need for calibration against reference instruments. Therefore, the value of sensors doesn't lie in the number of devices, but in quality assurance, field calibration, metadata, integration with reference networks, and transparent interpretation protocols (Chojer et al., 2020; Liu et al., 2020; Liang, 2021; Giordano et al., 2021; Kang et al., 2022; Singh et al., 2021).

IoT systems for water quality can provide basic parameter data almost in real-time, help detect changes in conditions, and reduce data collection costs for dispersed locations. However, sensor limitations, data security, connectivity, energy consumption, and maintenance need to be considered. Digital data must be linked to action thresholds, who receives alerts, who has the authority to respond, and how verification results are recorded. Without this decision chain, digitalization risks just producing more data without improving compliance or environmental quality (Pasika & Gandla, 2020; Jan et al., 2021).

Green infrastructure also mainly helps control air exposure on a micro scale, but its effectiveness really depends on the layout of the space, the type of vegetation, street aerodynamics, and pollutant sources. So, greening shouldn't be seen as a substitute for cutting emissions at the source; it's more like an extra piece in city design and environmental health policies (Tomson et al., 2021).

**6. Kerangka Konseptual: Lima Pilar Implementasi**

The literature synthesis resulted in five pillars that bridge regulation with outcomes. The first pillar is clear, coherent, adaptive, and risk-based regulation. The second pillar is implementation capacity, including organization, personnel, supervision, enforcement, and coordination. The third pillar is validated data and technology to measure environmental conditions and support interventions. The fourth pillar is financing and incentives that cover investment, operation, and maintenance costs, and encourage compliance. The fifth pillar is stakeholder participation and behavior change, which expand legitimacy, information, and social oversight. The five pillars are complementary; weaknesses in one pillar can reduce the effectiveness of the others (Wu et al., 2020; Hamilton et al., 2021; Feng et al., 2025).

Table 1. Conceptual Framework of the Five Pillars For Implementing Water and Air Sanitation

| Pillar | The gap if we only rely on regulations | Amplifier mechanism | Example indicator |
|---|---|---|---|
| Regulations & targets | There are rules, but the targets aren't operational or they overlap | Risk-based standards, division of authority, periodic evaluation | Quality standards, target outcomes, instrument consistency |
| Institutions & enforcement | Violation not detected or not acted upon | Risk-based inspections, laboratories, consistent sanctions, coordination | Compliance rate, response time, follow-up on violations |
| Data & technology | Late decisions; technology not validated/maintained | Reference monitoring, QA/QC sensor, fit-for-purpose treatment, interoperability | Coverage data, uptime, valid data rate, removal/emission reduction |
| Financing & incentives | There was initial investment, but operations and maintenance failed | Life-cycle financing, polluter-pays, tariff/incentive design | O&M coverage, cost per unit outcome, compliance investment |
| Participation & behavior | Low compliance; symbolic collaboration forum | Open data, complaint channels, facilitation, education, and co-monitoring | Meaningful participation, complaint resolution, behavior change |

## METHODOLOGY

This article uses a qualitative literature review, not a systematic literature review. The search was done purposively and iteratively to build a conceptual understanding and an argumentative synthesis regarding the relationship between regulation, implementation, technology, and collaboration in water and air sanitation. The qualitative approach allows for combining evidence with diverse research designs and emphasizes depth of interpretation, while the integrative review provides a basis for connecting empirical findings, theory, and policy implications. This procedure is not intended to produce aggregated effect estimates or claim an exhaustive coverage of the literature like an SLR (Busetto et al., 2020; Dhollande et al., 2021; Barry et al., 2022).

Sources are prioritized from peer-reviewed journal articles in Indonesian or English published between 2020-2026 and can be verified through DOI or the publisher's website. Legal documents and official policies are used to establish the current regulatory status, even if their publication year falls outside this range, as long as they are primary legal sources that are still relevant. Articles are selected based on relevance sampling: sources must contribute to at least one theme, such as health impacts and pollution sources; environmental regulation and enforcement; collaborative governance and participation; treatment technologies; digital/sensor monitoring; financing and incentives; or the Indonesian empirical context. Bibliographic details and DOIs are double-checked before being included in the reference list.

The analysis was done through comparative reading and iterative thematic coding. The findings were grouped into cause-and-effect mechanisms: regulation sets standards and mandates; institutional capacity determines oversight and enforcement; data and technology determine observability and intervention capabilities; financing determines the sustainability of operations; while participation and behavior determine legitimacy, compliance, and social monitoring. These themes were then synthesized to answer two research questions and form a five-pillar implementation framework. The credibility of the interpretations was maintained by comparing findings across contexts and not equating the number of regulations with environmental success; principles of narrative transparency and reflexivity were used in drawing inferences (Andrews, 2021; Oermann & Knafl, 2021).

## RESULTS AND DISCUSSION

### 1. Updates to the Regulatory Framework and Their Implications

Indonesia's legal framework shows a shift from separate regulations towards a more integrated approach. Law 32/2009 provides principles for environmental protection and management, while changes under Law 6/2023 need to be considered when looking at the applicable provisions. Government Regulation 22/2021 serves as an important operational reference because it covers water and air quality, environmental approvals, supervision, and administrative sanctions all in one framework. As a result, old references in literature and practical documents to Government Regulation 82/2001 for water quality management or Government Regulation 41/1999 for air pollution need to be updated since both have been repealed by Government Regulation 22/2021. Updating these legal references is important so that policy analysis doesn't make recommendations based on norms that are no longer valid (Republic of Indonesia, 2021).

In the air domain, LHK Regulation 14/2020 provides the ISPU framework for communicating air quality. However, the public communication index isn't the same as a compliance monitoring system. Daily information can help individual decisions and raise awareness, but enforcement requires a validated measurement network, source identification, relevant emission or ambient standards, as well as follow-up mechanisms. Sensor literature shows that expanding networks using cheap devices is promising, but the results need to be calibrated and placed within a quality assurance system (Ministry of Environment and Forestry, 2020; Liang, 2021; Kang et al., 2022).

In the water sector, the Citarum case shows that pollution problems may require special coordination across ministries, local governments, businesses, and the community. Presidential Regulation 15/2018 sets up a framework to accelerate the control of pollution and damage in the Citarum watershed. Studies in Indonesia show that governance innovation and collaborative governance have grown, but they also emphasize the need for consistent industry supervision, stronger coordination, building trust, and improving shared understanding among actors (Republic of Indonesia, 2018; Fridayani, 2020; Zakiah & Suprayogi, 2020; Prayoga et al., 2022; Diavano, 2022).

### 2. Why Regulation Alone Isn't Enough: Answer to RQ1

First, regulations create obligations, but they don't automatically create the capacity to detect violations. Water pollution can change depending on time, flow, and location, while air pollution is very dynamic and crosses regions. Without sufficient data density, the government faces information asymmetry: the actors know their production processes, while regulators only observe a portion of emissions or waste. Limited monitoring then reduces the probability of detection and the effectiveness of sanctions. Indonesian literature on pollution management also shows that infrastructure limitations and data inconsistencies remain significant challenges (Amin et al., 2025; Lukman et al., 2025).

Second, regulations don't automatically solve organizational capacity issues. Oversight needs labs, technical staff, risk-based inspection systems, data interoperability, budgets, and escalation procedures. In fragmented governance, even clear rules can lead to poor outcomes when no one can coordinate action across jurisdictions. Environmental governance literature shows that collaboration gaps actually emerge when actors depend on each other but working relationships and information flows are weak (Hamilton et al., 2021; Wuijts et al., 2021).

Third, regulations don't solve the issue of economic incentives. Waste treatment installations, emission control equipment, sensor calibration, filter media replacement, energy, and operator labor all come with recurring costs. When financing mechanisms only support the initial investment without ensuring operation and maintenance, the technology can underperform. This can be seen in Indonesia's domestic wastewater systems, which face issues with infrastructure quality and operation and maintenance. Therefore, enforcement needs to be backed by tariff schemes, incentives, sustainable financing, or credible polluter-pays mechanisms (Widyarani et al., 2022).

Fourth, regulations don’t automatically change behavior. Compliance by households, farmers, vehicle users, or business actors is influenced by values, norms, perceived cost-benefit, ease of action, and the belief that others are also complying. Evidence on pro-environmental behavior shows that perceived behavioral control and economic factors can be obstacles, while environmental education is more effective when it encourages actual involvement. Therefore, communication and education strategies need to be accompanied by feasible action choices and aligned incentives (Rezaei-Moghaddam et al., 2020; van de Wetering et al., 2022).

Fifth, just having rules doesn't guarantee legitimacy and social accountability. Communities are often the first to notice changes in the color or smell of water, dust, smoke, or health problems. Complaint channels that can be verified and followed up on can boost the government's monitoring capacity. Studies on public participation in enforcement show that institutionalized participation can increase enforcement pressure, while regional studies indicate there’s a coordinating effect between government governance and community participation (Wu et al., 2020; Li, 2022).

**3. Processing and Monitoring Technology: From Devices to Governance Systems**

For wastewater, advancements in technology allow for better removal and reuse, but the choice of technology should follow a fit-for-purpose principle. Integrated fixed-film activated sludge can boost biological process capacity; anaerobic membrane bioreactors offer a combination of treatment and separation; reverse osmosis is effective for certain contaminants but faces fouling and requires pretreatment; nanofibrous membranes offer promising separation characteristics. Since technologies come with trade-offs in energy, cost, residues, and maintenance, investment decisions should be based on total cost of ownership and operator skills, not just lab efficiency (Waqas et al., 2020; Ji et al., 2020; Liu et al., 2021; El-Aswar et al., 2022; Abdulhamid & Muzamil, 2023).

IoT-based water monitoring can shorten the time between changes in water quality and corrective actions. Systems that measure pH, turbidity, temperature, and other parameters can support early warnings, especially for source points or distribution networks. However, sensor reliability, connectivity, power, cybersecurity, drift, and verification procedures still determine whether the data is suitable for regulatory decisions. Therefore, the data architecture needs to include sensors, gateways, storage, validation, thresholds, alerts, verification, and audit trails (Pasika & Gandla, 2020; Jan et al., 2021).

For air quality, low-cost sensors have the potential to fill spatial gaps that reference stations can't reach. Long-term studies show that device performance can be affected by humidity, temperature, aerosol type, and changes in response over time. Methodological reviews also indicate that calibration models, testing environments, and reference instruments influence performance. The implication is that community sensor networks should be used as a complementary network and linked with collocation and regular quality assurance, rather than automatically being considered equivalent to reference-grade monitoring (Liu et al., 2020; Chojer et al., 2020; Liang, 2021; Kang et al., 2022).

Good data use can change the way enforcement is carried out. Longitudinal data allows for identifying hotspots, setting inspection priorities, evaluating the before-and-after impact of a policy, and ensuring transparency to the public. However, abundant data without defined performance indicators can blur accountability. A monitoring system should lead to a few simple and traceable outcomes: frequency of exceedances, pollutant load, exposure reduction, response time to violations, facility compliance rates, and relevant health indicators. This perspective aligns with the shift towards system-based air-quality governance and policy synergy, rather than just administrative compliance (Feng et al., 2025; Lukman et al., 2025).

## 4. Challenges for Effective and Sustainable Water and Air Treatment

The first challenge is scale mismatch. Sources of pollution, ecological impacts, and health exposure don't always follow administrative boundaries. Watersheds need upstream-downstream coordination; airsheds can cover multiple regions. When targets, budgets, and accountability are only set per organization or per region, there's no strong incentive to optimize outcomes across boundaries. Evidence from river basin collaboration and cross-regional air control shows that coordination mechanisms can improve outcomes, but they require a stable working structure and a clear sharing of costs and benefits (Baudoin & Gittins, 2021; Wang & Zhao, 2021).

The second challenge is the heterogeneity of sources and actors. Large industries are relatively easy to identify, but domestic wastewater, agriculture, transportation, open burning, and informal sources are scattered across millions of daily decisions. An enforcement model based only on facility inspections isn't enough. A mix of standards, public services, economic incentives, infrastructure design, education, and community monitoring is needed. In water management, community involvement can boost local relevance, but the government still needs to maintain quality standards and inclusivity (Syafri et al., 2020; Rana & Piracha, 2020).

The third challenge is the sustainability of operations. Many environmental projects succeed during the construction phase but decline once program support ends due to a lack of operators, spare parts, electricity, chemicals, calibration, or funding. Therefore, technology appraisal needs to require an operation and maintenance plan, reliability indicators, financing mechanisms, and asset responsibility. Lessons from water treatment systems and sensors show that maintenance and quality control are just as important as the technical capability of the devices (Widyarani et al., 2022; Liu et al., 2021; Kang et al., 2022).

The fourth challenge is uncertainty and climate change. The baseline quality of water and air can change due to city growth, energy shifts, mobility, fires, extreme rainfall, and rising temperatures. Static regulations risk falling behind risk patterns. Because of this, governance needs to have adaptive management mechanisms: periodic evaluation of standards and targets, updating emission or pollutant inventories, adjusting strategies based on data, and climate scenarios (Nijhawan & Howard, 2022; Feng et al., 2025).

The fifth challenge is fairness and trust. Policies that impose compliance costs without offering alternatives can lead to resistance; on the other hand, vulnerable groups often have the least capacity to reduce exposure. Therefore, policy design needs to consider affordability, access to information, representation, and benefit distribution. Facilitating ways to reduce power imbalances and inclusive participation mechanisms is important to avoid collaborative governance that is only formal (Arai et al., 2021; Rana & Piracha, 2020).

**5. Critical Role of Stakeholders**

The central government plays a role in setting standards, methodologies, national data systems, minimum requirements, and enforcement mechanisms, while local governments have an important role in local monitoring, waste and wastewater services, controlling local sources, and risk communication. Their relationship needs to be based on data interoperability and a clear division of tasks. The Citarum case shows that complex problems require orchestration across government levels and sectors, not just normative instructions (Fridayani, 2020; Zakiah & Suprayogi, 2020; Diavano, 2022).

Business actors are not just subjects of regulation, but also sources of technology investment, process innovation, and emissions data. Policies need to create incentives so that improving environmental performance becomes part of business decisions. Evidence on environmental policy stringency and eco-innovation shows that credible policy design can drive innovation, but its effect depends on the context and enforcement. Performance transparency, audits, and economic incentives can strengthen that signal (Kesidou & Wu, 2020; Galeotti et al., 2020; Yuan & Zhang, 2020).

Communities and civil organizations act as both users of the environment, partial contributors to pollution, and co-monitors. Effective participation requires access to understandable data, reporting channels, protection from power imbalances, and feedback on follow-up actions. The role of academics and research institutions is to provide method validation, source apportionment, impact evaluation, policy experiment design, and analytical independence. Collaboration becomes productive when each party has a clear function, not just when everyone is present in a forum (Li, 2022; Arai et al., 2021; Hamilton et al., 2021).

In practice, collaborative platforms should come with an accountability matrix: who sets the targets, who measures, who verifies, who funds, who enforces, and who receives public information. Without this matrix, collaborative governance can easily turn into consultation without operational consequences. The Citarum study shows that dialogue, trust, commitment, and shared understanding are important, but they still need to be translated into monitoring mechanisms and repeated actions (Prayoga et al., 2022).

**6. Analysis and Synthesis to Answer Research Questions**

The answer to RQ1 is that regulations only provide the rules of the game, while the outcome is determined by the system's ability to observe conditions, detect deviations, incentivize compliance, offer technical solutions, and coordinate actors. Gaps can occur at any link: standards may be unmeasurable; data may be insufficient; violations may go undetected; sanctions may be inconsistent; technology may not be maintained; compliance costs may be unaddressed; or the public may lack effective participation channels. Therefore, the number of regulations cannot be used as a direct proxy for governance quality (Galeotti et al., 2020; Wu et al., 2020; Hamilton et al., 2021).

The answer to RQ2 is the need for a policy mix built on five pillars. First, coherent rules, measurable targets, and clear division of authority. Second, enforcement capacity through risk-based inspections, laboratories, personnel, audits, and cross-region coordination. Third, validated technology and data infrastructure, including treatment systems, reference monitoring, additional sensors, IoT, and open data. Fourth, financing and incentives to maintain operations, maintenance, net investments, and behavior change. Fifth, collaborative accountability connecting the government, industry, communities, academics, and civil organizations with clear roles and performance indicators. The synergy of these five pillars is more consistent with the evidence compared to strategies that only tighten regulations or buy technology (Feng et al., 2025; Widyarani et al., 2022; Kang et al., 2022).

For Indonesia, the most important implication is shifting the measure of success from administrative output to outcomes. The number of permits, inspections, sensors, wastewater treatment plants, campaigns, or coordination meetings are useful as process indicators, but the final indicators should include trends in pollutant concentrations, pollutant loads, exceedances, compliance rates, facility reliability, response times, exposure reduction, and, if possible, health indicators. An outcome-based governance framework will also make it easier to evaluate whether public investments and private obligations truly deliver environmental and health benefits that are worth it (Berman, 2024; Lukman et al., 2025).

**Table 2. Synthesis of Research Question Answers and Policy Implications**

| Fokus | Temuan sintesis | Implikasi kebijakan | Outcome utama |
|---|---|---|---|
| RQ1 | Regulation is a necessary condition, but its effectiveness is limited by enforcement gaps, fragmentation, data limitations, O&M costs, and behavior. | Audit of implementation capacity and the regulation-monitoring-enforcement-remediation chain. | Reduction of exceedance/pollutant load and exposure |
| RQ2 | Effectiveness requires a combination of five complementary pillars. | Use a policy mix; integrate technology with QA/QC, financing, and collaborative accountability. | Compliance, reliability, response time, environmental quality, and health. |
| Indonesia | Government Regulation 22/2021 provides a basis for integrating air and water quality, monitoring, and sanctions; its implementation needs to be outcome-based.. | Strengthen center-region relations, open/interoperable data, risk-based inspections, O&M financing, and participation channels. | Outcomes that can be compared across regions and over time. |

## CONCLUSIONS AND RECOMMENDATIONS

This article shows that improving water and air quality needs to be treated as a sociotechnical governance issue, not just a matter of having regulations or technology. Regulations are still fundamental because they set standards, mandates, rights, obligations, and penalties. However, the effectiveness of regulations only appears when there is the capacity to monitor environmental conditions, identify pollution sources, enforce obligations, fund operations, maintain technology, and change behavior. So, having rules is a necessary condition, but not enough to guarantee effective and sustainable outcomes.

Regarding RQ1, the synthesis found five main sources of the implementation gap: limited institutional capacity and enforcement; fragmented authority across regions and sectors; weaknesses in data and quality assurance; misalignment of costs and incentives; and weak or unequal participation. These five factors explain why an increase in the number of regulations can happen alongside persistently high pollution. The quality of governance should be looked at in terms of whether the regulation-monitoring-enforcement-remediation chain produces measurable changes in water quality, air quality, exposure, and health.

Regarding RQ2, the article proposes a five-pillar framework: coherent regulation; implementation and enforcement capacity; technology and validated data infrastructure; sustainable financing and incentives; and collaborative accountability and behavior change. These pillars need to be designed as mutually reinforcing systems. Sensors without action protocols aren't enough; wastewater treatment plants without operation and maintenance aren't enough; collaboration forums without shared responsibilities aren't enough; and penalties without a sufficient probability of detection aren’t enough either.

In the context of Indonesia, updating legal references towards PP 22/2021 is important to ensure policy discussions follow the applicable framework. Its implementation needs to be translated into transparent target outcomes, data interoperability, risk-based supervision, and operational center-regional role sharing. The Citarum experience shows the value of coordination and collaborative governance, but also reinforces the need for continuity, monitoring, shared understanding, and consistent enforcement. For air quality, expanding monitoring needs to be accompanied by quality assurance and more even coverage beyond well-established research centers.

Future research needs to move from descriptive studies towards causal and longitudinal evaluations of the most effective combination of instruments. Key agenda items include: comparing enforcement performance across regions; evaluating the cost-benefit of hybrid sensor networks; studying the total cost of ownership of treatment technologies; the relationship between data transparency and compliance; designing incentives for domestic wastewater and diffuse pollution sources; and measuring the impact of collaborative governance on ecological and health outcomes. Research also needs to examine environmental justice issues, including who bears the cost of policies and who benefits from reduced exposure.

As a qualitative literature review, this article doesn't aim to calculate effect sizes or give a universal ranking of interventions. Its main value lies in integrating literature on water, air, policy, technology, and participation into a framework for implementation that can be tested further. This framework can serve as a working hypothesis for empirical research in Indonesia: the stronger the complementarity between regulation, enforcement, data-technology, financing, and participation, the higher the likelihood that policies will lead to real and lasting improvements in environmental quality.

**FURTHER STUDY**

This research still has limitations, so further studies on the topic of Beyond Regulation: Integrated Governance for Effective and Sustainable Water and Air Quality Improvement are needed to refine this study and add insights for both the author and readers.

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