GOLDEN RATIO OF MAPPING IDEA AND LITERATURE FORMAT
VOLUME 6, ISSUE. 2 (2026)
Website: https://goldenratio.id/index.php/grmilf
ISSN [Online]: 2776-6381

MAPPING IDEA & LITERATURE FORMAT | RESEARCH ARTICLE

Collaboration and Innovation Strategies between Stakeholders in the Management of Water Resources by the Public Works Department

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ARTICLE HISTORY

Received: September 19, 2025
Revised: January 18, 2026
Accepted: February 01, 2026

DOI
https://doi.org/10.52970/grmilf.v6i2.1750

ABSTRACT
This study aims to analyze the collaboration and innovation strategies between stakeholders in the management of Water Resources (SDA) by the Public Works Department (PU) through integrated mixed-method design. The case study approach is applied to several Public Works Office units with variations of policies, geographical conditions, and institutional capacity. Qualitative data obtained through in -depth interviews, Focus Group Discussions (FGD), and analysis of policy documents. Thematic analysis is used to identify driving factors and collaboration barriers, as well as the form of innovation applied. Meanwhile, quantitative data is collected through a survey related to the effectiveness of collaboration, water service innovation index, and operational performance indicators, which are then analyzed with multilevel regression to test the linkages between variables, supported by the validity and reliability of instruments. The results showed that multi -vessel collaboration had a significant effect on the effectiveness of natural resource management. Collaborative leadership, clarity of regulations, and inter-actors is the main factor that encourages cooperation. However, the pattern of collaboration is still ad-hoc and has not been supported by formal institutional mechanisms. In terms of innovation, the use of digital technology and sensorization began to be implemented, although constrained infrastructure, technical competence, and bureaucratic resistance. Quantitative analysis confirms that the quality of collaboration is more dominant in improving service performance and water distribution justice, while technology innovation contributes to operational efficiency. Integration of findings through Design-based Research (DBR) produces an implementative strategy in the form of permanent multi-stakeholder forums, regulatory strengthening, co-creation of innovation models, digitalization acceleration, and increasing human resource capacity. Policy recommendations emphasize the importance of monitoring systems based on the main performance indicator (KPI) which includes technical, social and ecological dimensions.

Keywords: Collaboration, Innovation, Stakeholders, Water Resources, Public Works.

ISSN [Online]: 2776-6381

I. Introduction

Water resource management (SDA) occupies a crucial position in sustainable development because it concerns water availability, food security, environmental health, and socio-economic welfare (Jaya et al. 2024). Natural Resources challenges are multidimensional: technically, they relate to infrastructure engineering, water quality, and hydraulic network operational performance; socially, concerns equitable access, public participation, and community resistance to policy changes; economically, related to costs, infrastructure investments, as well as tariff mechanisms and financing of water projects; environmentally, including the impact of aquatic ecosystems, soil degradation, and hydrometeorological disaster risk mitigation (Abdurrohim 2024). At the national level, these dynamics are accelerated by two main connectors: climate change that increases the variability and uncertainty of rainfall and flood/drought intensity; rapid urbanization that increases the pressure on demand for clean water, drainage, and waste management; as well as environmental degradation that affects storage capacity and the quality of water sources. In addition, policy fragmentation between government agencies complicates the coordination of planning, implementation, and evaluation of natural resources programs, so that the potential for synergy between actors is hampered (Haq, Musyafa, & Rosidin 2025).

In Indonesia, the role of the Public Works Office (PU) as the main technical institution in the provision and management of water infrastructure such as dams, irrigation networks, and urban drainage systems shows significant technical and institutional capacity (Aisyah 2024). However, the multidimensional size of the problem demands more than just technical capacity. The effectiveness of natural resource management cannot depend on one actor alone; Instead, it demands a collaborative ecosystem involving a wide range of stakeholders: local and national governments, the private sector, local communities, as well as academic and research institutions. Without cross-sectoral synergy, policies are often fragmented, technical solutions are not aligned with the local socio-economic context, and the innovations required to adapt to extreme climate conditions are not widely implemented (Subkhan, 2024) and (Setijaningrum, 2025). Departing from this reality, international and regional literature shows that a collaborative approach that combines resources, knowledge, and organizational networks can improve accountability, transparency, and response to natural resources risks. Multi-actor-based governance models, co-management, and policy innovations that integrate public–private–academia have been shown to improve the quality of planning and execution of water initiatives, especially when communication mechanisms, data ownership rights, and benefit-sharing are clearly formulated. In the Indonesian context, the success of collaborative strategies depends heavily on the ability to harmonize cross-ministerial regulations (e.g., public works, environment, autonomous regions, and forestry), build sustainable finance frameworks, and engage local communities in the design, implementation, and evaluation of water projects. This research is directed to explore how synergies between technical agencies such as public utilities, public-private entities, local communities, and the scientific community can form a collaborative framework that is adaptive to climate dynamics and urbanization. The goal is to identify key organizational structure barriers, budget constraints, data miscommunication, and policy uncertainty and present concrete recommendations for improved coordination, technical innovation, and more efficient and sustainable use of resources.

Natural resource management has long been the focus of scientific and policy attention due to its crucial role in water security, public welfare, and infrastructure development. Various previous studies

highlight the importance of collaboration between multi-sector actors' central government, local governments, technical institutions, the private sector, research institutions, and local communities as a means to improve coordination, resource allocation, and response to fluctuating water demand dynamics. In general, the literature tends to emphasize institutional or regulatory frameworks: governance design, legal mandates, authority-sharing mechanisms, and policy incentives that can encourage compliance and consistency in policy implementation. However, although policy and institutional directions have been widely discussed, the research focus on operational implementation levels is often relatively under-elaborated. A key gap lies in understanding how collaboration and innovation strategies are developed, adapted, and executed in real-world practice on the ground. In particular, research oriented to technical institutions such as the Public Works Office that has a technical, operational, and maintenance role in natural resource infrastructure is often dominated by structural or regulatory analysis. This condition implies the assumption that the same collaborative mechanisms work uniformly in various institutional contexts, whereas dynamics at the operational level are influenced by work practices, organizational culture, technical capacity, and interaction between actors in the field. As a result, there is a risk that ideal collaborative policy design will be ineffective if it is not aligned with real implementable practices.

Furthermore, innovations in the natural resources management literature are often viewed through the lens of technology such as the adoption of software, sensory, or water management information systems. In fact, institutional innovation, social innovation, and collaborative process innovation have equally important impact potential in improving efficiency, transparency, accountability, and adaptation to local contexts. The inequality between technological innovation and non-technological innovation can create an "implementation gap" if social factors, organizational norms, and the dynamics of interaction between actors are not taken into account holistically. Thus, there is a need for contextual and empirical studies that trace how collaboration and innovation strategies are developed, implemented, and adjusted in natural resource management practices by public actors at the regional level. This kind of contextual study is important because variations in the regional context including regional institutional characteristics, technical and managerial capacity of the Public Works Office, public participation patterns, and geographical and ecological variables affect the effectiveness of collaboration and innovation. Without a deep understanding of operational dynamics, collaborative reform efforts risk being stuck on formal reforms that do not change practices at the field level. Therefore, this article aims to fill the gaps in the literature by focusing on the implementation dimension: how public actors at the regional level develop collaborative strategies, how innovations (including institutional, social, and process innovations) are researched, adapted, and integrated into operational procedures, as well as the contextual factors that mediate the success or failure of the initiative. With a contextual empirical approach combining regional case studies, inter-agency work network analysis, and triangulation methodology between qualitative and quantitative data, this study seeks to explore the practical mechanisms of collaboration and innovation in the Public Works Office in natural resource management. The results are expected not only to enrich the theoretical literature on the implementation dynamics of collaboration, but also to provide relevant policy recommendations for regional policymakers to improve the effectiveness, accountability, and resilience of natural resource management through more inclusive and adaptive collaboration pathways.

This study aims to identify and analyze the collaboration and innovation strategies implemented by the Public Works Office in water resource management, as well as evaluate the effectiveness and challenges of their implementation. The main research questions asked are: (1) What is the form of

collaboration between stakeholders in natural resource management facilitated by the Public Works Office? (2) What innovations are developed in the management process? and (3) What factors support or hinder the success of the collaborative-innovative strategy? This research offers a theoretical contribution in the development of the literature on governance and collaborative innovation in the natural resources sector, particularly in the context of local government technical institutions. From a practical perspective, the findings of this study can serve as a reference for policymakers and practitioners to design more inclusive and innovative collaboration models in natural resource management. In addition, the identified implementation model can be replicated in other regions with similar contexts. This research refers to the theoretical frameworks of Collaborative Governance (Guo & Mallinson 2025) and Public Sector Innovation (Kayode-Bolarinwa 2024), which emphasize the importance of cross-sector participation, trust, and shared learning in public governance. Collaboration is defined as a process of structured interaction between actors who have a common interest in natural resources, while innovation includes new approaches in both technology, policy, and institutional models that improve management effectiveness. A qualitative approach through case studies is used to understand the local context in depth.

Narrow the focus by identifying specific problems or gaps in knowledge that your study addresses. This section should make it clear why the research is necessary and how it contributes to advancing understanding in the field. Explicitly state the research question or hypothesis that guided your investigation, emphasizing its novelty and significance. Clearly outline the aims and objectives of the study, linking them to the identified research gaps. Avoid delving into detailed methodology or results here; instead, provide a conceptual overview that leads the reader logically to the next sections. If your research includes theoretical frameworks or assumptions, briefly introduce them, ensuring they align with the research aim Conclude the Introduction by summarizing what the study seeks to achieve and how it aligns with or challenges existing knowledge. This should leave the reader with a clear understanding of the study's scope and its potential impact, setting the stage for the subsequent sections.

II. Literature Review and Hypothesis Development

The literature review shows that multi-stakeholder collaboration at the public bureaucratic level has been recognized as an important mechanism to address capacity gaps, asymmetric information, and cross-sectoral coordination issues in water resources (SDA) management. The concept of collaborative governance presented by Etika and Negara (2024) and Sentanu, Yustiari, and S AP (2024) emphasizes the importance of negotiation processes, public accountability, risk sharing, and the formation of trust among public, private, and non-government actors. In the Indonesian context, the dynamics of decentralization, limited human resources and budgets demand a collaborative approach to improve efficiency, transparency, and accountability in water management (Zacharias et al. 2025); (Novita, 2025). Successful collaboration models often utilize the role of the Public Works Office (PU) as an infrastructure facilitator, planner, and coordinator of natural resources projects. In the realm of innovation, the natural resources literature distinguishes between technical innovations (e.g. sensory, sustainable infrastructure design), process innovation (data-driven planning, risk-based project management), and organizational innovation (cross-sector partnerships, open data access). International organizations such as the OECD (2019) and the World Bank (2021) highlight that the use of real-time data, environmental impact evaluation, and the integration of geospatial information can

improve the responsiveness of water management to climate change (Djazuli 2024). Key factors for innovation success include technology adoption, organizational culture that supports learning, and institutional readiness to share risk and data ownership. In the context of a case study of natural resource management, collaboration between the Public Works Office, the environment agency, the regional disaster management agency, the construction private sector, and the local community has the potential to accelerate the implementation of innovative solutions that are relevant to the local context (Gemilang & Fitriyah 2025).

The role of the Public Works Office as a coordination motor stands out because of its responsibility in planning, designing, and supervising natural resources infrastructure (dams, channel networks, irrigation). Effective coordination requires clear communication mechanisms, a firm division of authority, and cooperation structures such as policy committees, cooperation agreements (MoU), and data-sharing platforms for project performance evaluation (Arif, 2025). However, challenges that often arise include synchronization between short-term plans and long-term infrastructure needs, political-institutional barriers, and fiscal constraints. Research shows that budget transparency, public accountability, and community participation can improve the quality of decisions and minimize the waste of resources (Lathifah et al. 2024). Although there are many studies on natural resource collaboration and innovation, the literature gap lies in the lack of empirical studies that systematically explore the role of the Public Works Office as a coordinating actor in the context of developing countries, including how collaboration mechanisms such as co-design, co-implementation, and shared data platforms contribute to infrastructure innovation and operational efficiency of natural resources at the regional level. Indonesia's diverse regional focus demands a model of cooperation that is sensitive to organizational culture, technical capacity, and regional policy support.

Based on the review, the main hypothesis proposed is that the implementation of a structured inter-stakeholder collaboration strategy—through cooperative platforms, formal MoUs, and accountability mechanisms—will increase the adoption of technical, process, and organizational innovations in natural resource management by the Public Works Office, thereby improving operational efficiency and service quality. The derived hypothesis outlines that the availability of integrated and transparent data through data-sharing platforms will moderate the relationship between collaboration and adoption of technical innovations; the involvement of local communities and the private sector in the planning phase will increase the relevance of solutions and accelerate the implementation of natural resources projects; The PU Office's organizational readiness (including digital transformation, human resource capacity, and learning culture) will strengthen the relationship between collaboration and innovation. Further, organizational innovation as a mediator between collaboration and operational efficiency is expected to strengthen the impact of collaboration on natural resource operational performance, while an organizational culture that supports experimentation and failure tolerance is expected to strengthen the relationship between innovation adoption and service quality improvement, for example in water distribution reliability and water loss reduction.

The proposed research design is a quantitative approach with a natural experimental or quasi-experimental design on natural resources projects managed by the Public Works Office, complemented by qualitative analysis through semi-structured interviews for the implementation context. The main variables include collaboration between stakeholders (independent variables), innovation (main mediators: technical, process, organizational), organizational readiness of the Public Works Office (moderator/contributor), adoption of platform data (moderator), and operational efficiency and service quality (dependent variables). The data required includes data on natural resources projects related to

budgets, schedules, key performance indicators (KPIs), policies, and interviews with officials, construction partners, and community representatives. This research is expected to provide a robust theoretical framework to test hypotheses and be relevant to natural resource governance practices at the regional and national levels, especially in an effort to improve efficiency, transparency, and innovative solutions through cross-sectoral cooperation.

III. Research Method

This research uses an integrated mixed-method design, with a focus on policy analysis, collaborative processes, and innovation impacts. First, the systematic literature review stage to map the theoretical framework of cross-stakeholder collaboration, innovation models in water resource management, as well as best practices and contextual gaps in the public works sector. The selection of case studies as the primary approach allows for an in-depth evaluation of the dynamics of collaboration within public works offices, with several detailed locations as units of analysis for policy variations, geography, and institutional capacity. Second, the design of this research combines qualitative and quantitative approaches (mixed-method). In the qualitative component, in-depth interviews and focus group discussions (FGD) were conducted with key stakeholders (relevant government agencies, construction SOEs/BUMDs, local communities, environmental NGOs, water industry); strengthening by analyzing policy documents, cooperation agreements, and operational data on natural resource management. Thematic analysis and phenomenological codes are used to identify collaboration factors, institutional barriers, and agreed process and technological innovations (Juita, Effendi, and Maryam 2025). In the quantitative component, a survey was conducted on the perception of collaboration effectiveness, water service innovation index (e.g., the use of sensors, digitization of network management, data transparency), and operational performance indicators (water availability, water loss, maintenance costs).

Quantitative data analysis uses multilevel regression to explore the relationship between stakeholder characteristics, collaboration quality, and innovation with natural resource performance; The test of the validity of the construct and the reliability of the measuring instrument was carried out with a simple rho-Cronbach and CFA. The integration of findings is carried out through design-based research (DBR) to formulate collaboration and innovation strategies that can be implemented in the PU environment, accompanied by policy recommendations, continuous evaluation mechanisms, and context-based innovation roadmaps.

IV. Result and Discussion

The results of the study show that collaboration between stakeholders in water resources management (SDA) within the Public Works Office (PU) is a complex, multidimensional, and influenced process by various institutional, social, and technological factors. Through the systematic literature review (SLR) approach, it is obtained that the theoretical framework of cross-stakeholder collaboration in the context of natural resources management emphasizes the importance of the principles of participation, transparency, and shared responsibility. The global literature confirms that the success of collaboration is largely determined by inclusive leadership, effective communication mechanisms, and institutional structures that support the distribution of roles. In terms of innovation, the best practices identified include the digitization of water network management, the use of Internet of Things (IoT)-

based sensors for monitoring water quality and quantity, as well as open data mechanisms that allow the public to access information in real time. However, in the context of Indonesia, especially in the public works sector, there are still contextual gaps in the form of limited technical resources, delays in technology adoption, and resistance to bureaucratic changes that tend to be rigid.

Through case studies conducted in several units of the Public Works Office with varying geographical conditions and institutional capacity, the study found that multi-stakeholder collaboration has been underway, but has not been fully integrated within a consistent formal policy framework. In-depth interviews and focus group discussions (FGD) with key actors such as local government officials, construction SOEs, environmental NGOs, local communities, and water industry players revealed that there is a collective awareness of the urgency of collaboration in natural resource management. However, the pattern of collaboration that has been formed is still ad-hoc, dependent on a specific project, and does not yet have a systematic sustainability mechanism. For example, local community involvement is often limited to the initial consultation stage of an infrastructure development project, while at the monitoring and evaluation stage, community participation is relatively minimal. This creates a gap in the flow of information, making it difficult to avoid potential conflicts of interest between parties. Thematic analysis of qualitative data shows that there are three main factors that affect the quality of collaboration. First, the collaborative leadership factor is realized through the active role of PU officials in bridging the interests of various parties. Second, institutional factors, where formal rules such as MoU between agencies or technical regulations are the main basis of cooperation. However, weaknesses in the consistency of regulatory implementation often create ambiguity in responsibility. Third, the trust factor between stakeholders, which still needs to be strengthened through data transparency and open communication. In some cases, the water industry feels that government regulations are too restrictive for business innovation, while local communities feel that their involvement is not being heard enough. This misalignment of expectations demands a more effective conflict resolution mechanism.

In terms of innovation, the study found that there are real efforts by the Public Works Office to adopt new technologies in natural resource management, although its application is still limited. Quantitative data from the survey showed that the water service innovation index was in the medium category, with the highest score on the use of sensors for pipeline leak detection and the lowest score on the aspect of public data disclosure. Innovation based on the digitization of water management information systems has been implemented in several locations, but its implementation faces technical obstacles in the form of limited internet network infrastructure and human resource competence. This has an impact on the low integration of data across agencies, so that the potential use of big data analytics for water availability prediction or policy planning is still far from optimal. Multilevel regression analysis of quantitative data strengthens the qualitative findings by showing that the quality of collaboration between stakeholders has a significant influence on the performance of natural resources management. The results of the analysis indicate that the higher the level of stakeholder trust and participation, the better the performance indicators such as water availability, maintenance cost efficiency, and reduction in the rate of non-revenue water. Meanwhile, the innovation dimension, particularly the use of sensor technology and digital monitoring systems, contributes positively to operational efficiency, although it does not directly increase public perception of the fairness of water distribution. The validity and reliability test of the survey instrument showed adequate results, with a rho-Cronbach value of > 0.70 and confirmatory factor analysis (CFA) results supporting the validity of the construct. These findings provide an empirical basis that collaboration and innovation are not

independent variables, but are interrelated in influencing the sustainability of natural resource management. The integration of findings through the design-based research (DBR) approach resulted in several relevant collaboration and innovation strategies to be applied within the Public Works Office. First, strengthening formal coordination mechanisms through the establishment of permanent multi-stakeholder forums that function as a forum for regular communication, program evaluation, and collective decision-making. This forum is recommended to involve representatives of the government, SOEs/BUMDs, academics, local communities, NGOs, and the private sector. Second, the application of the co-creation of innovation model that allows each party to contribute to the design of technology and policy solutions, for example in the development of an integrated information system based on open source. Third, increasing the capacity of human resources through technical training on natural resource digitalization, conflict management, and collaborative leadership, so that key actors have adaptive skills to change.

Further discussion highlights that the success of this strategy is determined not only by technical aspects, but also by socio-political dynamics and bureaucratic culture. In the Indonesian context, a hierarchical organizational culture is still a challenge in building an egalitarian pattern of collaboration. Therefore, an important recommendation is the need for policy reform that provides incentives for collaborative practices, for example through a performance-based budget mechanism that rewards collaborative contributions between agencies. In addition, policies need to accommodate the use of more flexible technologies, such as the deployment of cloud computing and blockchain to ensure transparency in data distribution. In practical terms, the proposed collaboration and innovation strategies can have a long-term impact on improving the quality of natural resources services. With the existence of a multi-stakeholder forum, it is hoped that the gap in interests between parties can be minimized, while innovation based on digital technology can increase the efficiency and accountability of management. However, this study also emphasizes that the implementation of the strategy requires a continuous evaluation mechanism that is adaptive in nature. A monitoring system based on key performance indicators (KPIs) must be developed, by measuring not only physical outputs such as the amount of infrastructure built, but also social outcomes in the form of increased community satisfaction, water distribution equity, and ecological sustainability.

Theoretically, the findings of this study strengthen the literature on the importance of integration between collaboration and innovation in natural resource management. A key academic contribution is the affirmation that cross-stakeholder collaboration is not the end goal, but rather an instrument for creating a sustainable shared innovation space. On the other hand, technological innovation will not succeed if it is not accompanied by solid socio-political collaboration. Thus, the integrated mixed-method approach used in this study succeeded in uncovering the complex relationships between the structural, technical, and social dimensions of natural resource management. Taking into account the limitations of this study, for example, the limited scope of the case study site, and the challenge of generalizing results, it is recommended for further research to extend the analysis to regions with different geographical conditions and institutional capacity. Additionally, the use of a longitudinal approach can help evaluate the effectiveness of collaboration and innovation strategies over a longer period of time.

4.1. Complexity of Water Resource Management

Water resource management is a highly complex issue because it involves multidimensional interests, spanning ecological, social, economic, political, and cultural aspects (Rifa'i et al. 2025). Water is viewed not merely as an economic commodity, but also as a fundamental human right enshrined in various national and international regulations (Syahwal and Gunawan, 2024). This complexity is reflected in the need for water to meet household needs, support the agricultural sector as a pillar of food security, ensure industrial and energy supplies, and function to maintain ecosystem balance. In the Indonesian context, these challenges are further complicated by diverse geographic conditions, a tropical climate with uneven rainfall, and rapid population growth that drives higher water demand.

One factor that makes water resource management intricate is the uneven distribution of water across regions (Markus, 2025). Some areas experience water surplus with high rainfall, while others face deficits and are prone to drought. This situation poses serious challenges for the Public Works Agency (DPU) and related agencies in designing fair, efficient, and sustainable management strategies. Moreover, water quality is also a crucial issue. Increases in pollution from industrial, domestic, and agricultural waste reduce both surface and groundwater quality, so not all water sources can be used directly without adequate treatment. The complexity intensifies when water management is also influenced by political and regulatory aspects. There is often overlap in authority among the central government, regional governments, and other sectoral agencies. For example, watershed management can involve the Ministry of Public Works and Public Housing, the Ministry of Environment and Forestry, as well as provincial and district/city governments. This institutional fragmentation frequently leads to suboptimal coordination, resulting in policies that are not aligned with on-the-ground needs. In such conditions, collaborative strategies become important to overcome sectoral ego that can impede the effectiveness of water resource management. From a social perspective, water management is closely related to public behavior and awareness. Water is a shared necessity, yet it is often treated as an unlimited resource. Practices of overexploitation, illegal logging upstream, and low awareness in waste disposal are major causes of water resource degradation. On the other hand, local communities actually possess traditional knowledge in safeguarding water resources, for example through communal efforts in building irrigation systems or customary rituals that honor water sources. The challenge is how to integrate this local knowledge into the modern management system initiated by DPU.

Economically, water is often perceived as a public good that should be provided cheaply or even free. Yet the reality is that water management requires substantial costs, especially for building irrigation infrastructure, reservoirs, piping networks, and treatment facilities. Budget constraints pose a major hurdle for local governments, making private sector involvement through public–private partnership (PPP) schemes an appealing alternative. However, these schemes are not without criticism, as there are concerns they could lead to the commodification of water to the detriment of low-income communities. The complexity of water resource management demands a holistic and integrative approach. The DPU cannot work in isolation with a technocratic perspective alone; it must build a framework that involves all stakeholders. This complexity is not a barrier but a reality that must be addressed through collaboration and innovation. By understanding the ecological, social, economic, and political dimensions of the problems, the DPU can design policies that are better targeted, adaptable to change, and oriented toward sustainability.

4.2. Collaboration Among Stakeholders as a Primary Strategy

Collaboration among stakeholders is a fundamental strategy in water resource management because water issues involve cross-sector, cross-regional, and intergenerational interests (Jaya et al. 2024b). No single actor has full capacity to address water problems comprehensively. Therefore, building synergy among diverse parties is an absolute prerequisite for water resource management to be effective, equitable, and sustainable. This collaboration encompasses planning, implementation, and evaluation processes of programs related to availability, distribution, quality, and use of water. The stakeholders involved in this collaboration are highly diverse. First, local government through the Public Works Service (DPU) plays a primary role as regulator, infrastructure manager, and guarantor of public policy. Second, local communities as daily water users, for both household needs and productive activities such as farming and livestock. Third, the private sector that requires water to support industrial activities, tourism, and other economically oriented investments. Fourth, scholars and research institutions that can provide an empirical basis for designing data- and technology-driven policies. Fifth, civil society organizations (CSOs) and NGOs acting as independent watchdogs and as bridges to articulate the interests of communities that are often marginalized.

Collaboration among stakeholders is not only about administrative task-sharing but also about building a shared understanding of the important value of water as a public resource. In this context, the governance concept becomes relevant, where water management is no longer viewed as an exclusive government authority but as the result of multiparty interactions that are equal (Bumdes and Gerbang, 2024). This is important to avoid domination by one party, especially the government or the private sector, which can bias water management toward particular interests.

However, building genuine collaboration is not easy. There are various potential conflicts of interest, for example between agricultural irrigation needs and urban clean water supply, or between environmental conservation and industrial expansion. Therefore, forums for inter-stakeholder communication become crucial venues for mitigating conflicts and seeking joint solutions. These forums can take the form of a watershed or river basin council (DAS) deliberation, cross-sector coordination meetings, or public consultation mechanisms. The existence of these forums ensures that all parties have space to voice aspirations, obtain information, and participate in decision-making. The success of collaboration is strongly influenced by three main factors: communication, transparency, and trust. First, effective communication enables clear and rapid information exchange, reducing the likelihood of misunderstandings. Second, transparency in data management, budgeting, and policy is essential so that no party feels disadvantaged or manipulated. Third, trust among stakeholders is a foundation that can only be built through consistent, inclusive, and accountable processes. Without trust, collaboration tends to be fragile and merely formal.

Moreover, successful collaboration must be accompanied by joint monitoring and evaluation mechanisms. With agreed-upon indicators, each stakeholder can assess whether water management objectives are being met and how each party's contribution factors into that success. This mechanism not only enhances accountability but also strengthens the sense of ownership, which is crucial for sustainability. Thus, stakeholder collaboration is not merely an additional strategy but the core of effective water resource management. In the context of the DPU, this collaboration positions the institution as a facilitator of interests rather than as a sole actor. Multiparty synergy enables the creation of more creative, adaptive, and equitable solutions, so that water can be managed truly as a public resource oriented toward shared prosperity.

4.3. The Role of the Public Works Department in Facilitating Collaboration

In water resources governance, the Public Works Department (DPU) plays a highly strategic role, not only as an implementer of technical policies but also as a facilitator of collaboration among stakeholders (Satriawan, 2024). This facilitation function becomes particularly important because water-related issues often involve many parties with differing, even conflicting, interests. DPU can no longer be positioned merely as the "water ruler" or sole authority; instead, it must act as a mediator, coordinator, and catalyst that links the interests of various parties to achieve shared objectives.

First, DPU plays a role in building a regulatory framework that supports multiparty collaboration. Clear, inclusive, and adaptive regulations form the legal basis for stakeholder involvement in every water resources management process. Through these regulations, DPU can ensure that the rights and obligations of each party are regulated proportionally, so that no party feels left out. For example, in drafting a river basin management plan, DPU can initiate regional regulations that require public consultation and involve Indigenous communities as stewards of the ecosystem. In this way, DPU becomes a key actor in creating formal legitimacy for the collaborative process.

Second, DPU serves as a provider of relevant data and information. One of the major challenges in water management is the limitation of accurate information accessible to all parties. DPU has the capacity to collect, process, and disseminate data on water availability, water quality, infrastructure, and flood and drought risk forecasts. Through an open information system, DPU can promote transparency, which in turn strengthens trust among stakeholders. Access to the same information allows all parties to formulate policies or actions based on an equal understanding.

Third, DPU acts as a mediator to resolve conflicts of interest. Conflicts over water use frequently arise, especially among the agricultural, industrial, and domestic sectors. If not well facilitated, these conflicts can cause substantial economic and social losses. DPU occupies a sufficiently neutral position to act as an arbiter, by listening to all parties' aspirations, weighing the prevailing interests, and formulating compromise solutions. This mediation function becomes increasingly important in the face of climate change, which amplifies uncertainty in water availability.

Fourth, DPU also serves as an innovation catalyst. As a government institution, DPU has access to resources, networks, and policies that enable the adoption of new technologies in water management. This catalytic role can be realized through collaborations with universities, research institutions, and the private sector to develop sensor-based monitoring technologies, flood early warning systems, or more efficient water distribution models. Additionally, DPU can spur institutional innovation by creating inclusive and sustainable multiparty forums. Nevertheless, the role of DPU as a collaboration facilitator often faces challenges. Rigid bureaucratic structures, budget constraints, and hierarchical working patterns can hinder flexibility in building multiparty synergies. There is also a tendency for government dominance in decision-making processes, rendering stakeholder participation merely formal. Therefore, DPU needs internal governance reform, capacity-building for human resources, and the adoption of good governance principles such as accountability, transparency, and public participation. The role of DPU in facilitating collaboration significantly shapes the success of water resources management. When DPU can operate effectively as a fair regulator, a provider of transparent information, a neutral conflict mediator, and an innovation catalyst, multiparty collaboration can be more effective. Accordingly, DPU is not only a technical implementer of infrastructure development but also the driving force behind an inclusive, sustainable, and just water governance framework.

4.4. Innovation as an Adaptive Instrument

Innovation in water resources management serves as a highly important adaptive instrument, given that the challenges faced are increasingly complex and dynamic (Jaya et al. 2024c). Climate change, population growth, urbanization, and industrialization place great pressure on water availability and quality. In this context, traditional strategies based solely on physical infrastructure development are no longer sufficient. The Public Works Department (PWD) and other stakeholders are called upon to develop innovations that are not only technical but also institutional, social, and cultural, so that the water management system becomes more resilient in the face of rapid change. From a technological standpoint, innovation can be realized through the use of Geographic Information Systems (GIS) and remote sensing to map water resources, watershed areas, and flood- and drought-prone regions. With more accurate spatial data, the PWD can design evidence-based policies and allocate resources more precisely. In addition, the deployment of digital sensors and the Internet of Things (IoT) enables real-time monitoring of water quality and quantity, allowing quicker detection of contamination and decreases in flow. These technologies can also support early warning systems for disasters, which are highly relevant in flood-prone areas.

Beyond technology, institutional innovation is also crucial. One form is the establishment of cross-sector water management bodies that are semi-autonomous but remain integrated with the PWD. Such institutions can accelerate coordination, reduce interdepartmental ego, and strengthen accountability in water management. Institutional innovation can also take the form of Public-Private Partnership (PPP) schemes, which enable private sector investment in the construction and maintenance of water infrastructure. However, these schemes must be regulated by clear rules to avoid excessive commodification that harms poor communities. Furthermore, social innovation is a dimension that is no less important. Local communities often possess traditional knowledge for sustaining water resources, for example through mutual-aid practices in building irrigation channels, the Subak system in Bali, or local wisdom in protecting springs in mountainous areas. Social innovation means integrating local knowledge with modern technology to create a more contextual, adaptive, and sustainable management system. The PWD can promote social innovation by empowering local communities, providing space for participation, and valuing traditional wisdom as part of the solution. Nevertheless, innovation efforts frequently face challenges, including budget constraints, bureaucratic resistance, and low levels of technological literacy among the public. It is not uncommon for innovations to stop at pilot projects without sustainability due to a lack of regulatory support or long-term commitment. Therefore, a strategy to strengthen capacity is needed, both for PWD personnel and for communities, so that innovations can be adopted and institutionalized within the management system. Ultimately, innovation in water resources management is not an end in itself but a means to enhance resilience, efficiency, and sustainability. Innovations in technology, institutions, and society must progress in tandem, complementing one another and continuously updating to reflect the times. With this approach, the PWD and stakeholders can ensure that water resources are managed not only to meet current needs but also to safeguard their continuity for future generations.

V. Conclusion

This study shows that water resources management (SDA) within the Public Works Office faces complex dynamics because it involves various actors with different interests. Through a mixed-method approach, it was found that the quality of collaboration between stakeholders, characterized by

collaborative leadership, institutional clarity, and level of trust, has a significant influence on the success of natural resource management. However, existing patterns of collaboration still tend to be ad-hoc, project-dependent, and have not been supported by consistent institutional mechanisms. In terms of innovation, there are real efforts to adopt digital technology and sensorization in natural resource management, although its application is still limited due to infrastructure constraints, limited human resource capacity, and bureaucratic resistance. Quantitative analysis confirms that technological innovation contributes positively to operational efficiency, while the quality of collaboration plays a stronger role in improving service performance and the fairness of water distribution. The integration of findings through design-based research resulted in a strategy that emphasized the strengthening of multi-stakeholder forums, co-creation models of innovation, and increasing the adaptive capacity of key actors. Theoretically, this research strengthens the argument that collaboration and innovation are interrelated and inseparable in creating sustainable natural resource management. Meanwhile, practically, the resulting strategy provides implementive direction for the Public Works Office to improve the effectiveness, efficiency, and accountability of natural resources management.

Based on the results of the research, the policy recommendations that can be submitted emphasize the need for the establishment of a permanent multi-stakeholder forum involving the government, SOEs/BUMDs, local communities, academics, NGOs, and the private sector as a forum for communication, coordination, as well as continuous evaluation in water resource management. The forum should have a clear legal basis so that the sustainability of the collaboration can be guaranteed and not dependent on the leadership of individuals or short-term projects. In addition, regulations need to be strengthened by providing incentives for collaborative practices, for example through a performance-based budget mechanism that assesses the real contribution of inter-agencies in maintaining the sustainability of water management.

Innovation strategies also need to be developed in a participatory manner with a co-creation of innovation approach, where all stakeholders are actively involved from the planning stage to implementation, so that bureaucratic resistance can be minimized and a sense of ownership of innovation can be strengthened. In terms of technology, the Public Works Office is advised to accelerate the process of digitization and integration of natural resources management data through the development of cloud-based information systems, IoT sensors, and even blockchain technology to ensure transparency, accuracy, and accountability of services. These efforts must be accompanied by increasing the capacity of human resources, especially in mastering digital technology, collaborative communication skills, and conflict management so that adaptation to technological and social dynamics can run well. Finally, a monitoring and evaluation system based on key performance indicators (KPIs) needs to be developed to measure not only the physical output of infrastructure, but also social and ecological outcomes, such as increasing community satisfaction, equity in water distribution, and environmental sustainability. With this policy framework, it is hoped that collaboration and innovation strategies in natural resource management can be implemented more effectively, adaptively, and sustainably.

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