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Impact Evaluation of National Strategic Irrigation Infrastructure on Agricultural Intensification and Land Productivity: Evidence from Indonesia's Outer Islands

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ABSTRACT

The development of national strategic irrigation infrastructure is a key policy for strengthening food security, improving agricultural productivity, and reducing regional disparities, particularly outside Java and Bali. In this study, "outer islands" refers operationally to agricultural regions outside Java and Bali, including Sumatra, Kalimantan, Sulawesi, Nusa Tenggara, Maluku, and Papua, which face challenges in irrigation development, water management, and agricultural productivity. Despite substantial government investment, empirical evidence on the impacts of irrigation infrastructure on agricultural intensification and land productivity remains limited. This study evaluates the effectiveness of national strategic irrigation infrastructure in supporting agricultural development across Indonesia's outer islands. A qualitative systematic literature review was conducted by synthesizing recent national and international studies on irrigation management, water productivity, agricultural intensification, and land productivity. The analysis examines the relationships among irrigation infrastructure, water resource management, farming intensity, crop productivity, and sustainable agricultural practices. The findings indicate that improved irrigation infrastructure enhances cropping intensity, land productivity, water-use efficiency, and farmers' resilience to climate variability. However, its effectiveness depends on institutional governance, operation and maintenance quality, technological innovation, and stakeholder participation. Regions with integrated irrigation management demonstrate greater agricultural productivity than those relying solely on infrastructure expansion. This study contributes by integrating infrastructure, irrigation governance, technological innovation, and farmer participation within a single analytical framework for Indonesia's outer-island agricultural systems. It concludes that irrigation development should combine physical investment with institutional

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strengthening, smart irrigation technology, and sustainable water governance.

Keywords: irrigation infrastructure; agricultural intensification; land productivity; water management; Indonesia; outer islands; sustainable agriculture; irrigation governance

1. Introduction

Agriculture remains one of the most important sectors supporting economic development, food security, and rural livelihoods in Indonesia. As an archipelagic country with diverse geographical characteristics, Indonesia faces significant challenges in ensuring equitable agricultural productivity across regions, particularly in the outer islands. In this study, "outer islands" refers operationally to agricultural regions located outside Java and Bali, including Sumatra, Kalimantan, Sulawesi, Nusa Tenggara, Maluku, and Papua. These regions generally face greater challenges related to irrigation infrastructure, water resource management, and agricultural productivity. To address these challenges, the Indonesian government has prioritized the development of national strategic irrigation infrastructure to improve agricultural productivity and strengthen national food security [1].

Reliable irrigation infrastructure plays a crucial role in maintaining agricultural production by ensuring adequate water availability throughout the growing season. A well-functioning irrigation system enables farmers to increase cropping intensity, improve land utilization, and reduce the risk of crop failure caused by water shortages [3].

Recent technological developments have further enhanced irrigation performance through the implementation of smart irrigation systems based on artificial intelligence. These technologies improve water distribution efficiency, optimize irrigation scheduling, and support more effective operational management, thereby increasing agricultural productivity [2].

Agricultural intensification has become increasingly important as productive agricultural land continues to decline due to urbanization and land-use conversion. Rather than expanding cultivated areas, intensification emphasizes increasing production through efficient water management, improved farming practices, and sustainable irrigation systems [14].

Several studies have shown that optimizing irrigation networks can significantly improve water-use efficiency and support higher agricultural productivity. Infrastructure improvements combined with proper irrigation management contribute to more stable crop production under varying environmental conditions [12].

Sustainable irrigation management also requires complementary approaches, including evapotranspiration analysis, water footprint assessment, reservoir development, and irrigation network optimization to ensure efficient allocation of water resources while maintaining environmental sustainability [10].

Furthermore, improvements in irrigation infrastructure have been shown to increase land productivity and strengthen the resilience of rice farming systems against climate variability. More reliable irrigation services allow farmers to maintain production even during periods of limited rainfall [11].

The implementation of subsurface drainage systems and other modern irrigation technologies has also demonstrated positive impacts on both land productivity and water productivity in irrigated paddy fields. These innovations support more sustainable agricultural production while reducing water losses [13].

Despite numerous studies discussing irrigation performance and agricultural productivity, previous research generally focuses on technical aspects or individual irrigation schemes. Comprehensive evaluations that examine the impact of national strategic irrigation infrastructure on agricultural intensification and land productivity in Indonesia's outer islands remain limited [1].

Therefore, this study aims to evaluate the impact of national strategic irrigation infrastructure on agricultural intensification and land productivity in Indonesia's outer islands through a systematic review of previous empirical studies. The findings are expected to provide recommendations for improving irrigation policy, strengthening water governance, and supporting sustainable agricultural development in Indonesia.

2. Materials and Method

Research Design

This study employed a qualitative research approach using the Systematic Literature Review (SLR) method to evaluate the impact of national strategic irrigation infrastructure on agricultural intensification and land productivity in Indonesia's outer islands. The SLR approach was adopted because it enables a systematic, transparent, and comprehensive synthesis of existing scientific evidence regarding irrigation development and its contribution to agricultural performance. Unlike conventional literature reviews, SLR follows a structured protocol to minimize bias during article identification, selection, evaluation, and synthesis, thereby producing more reliable research findings.

Data Sources and Literature Search Strategy

Secondary data were collected from peer-reviewed national and international journal articles indexed in Scopus, ScienceDirect, SpringerLink, MDPI, Taylor & Francis, Google Scholar, and SINTA. Supporting information was also obtained from official publications issued by the Government of Indonesia and other institutions related to irrigation development and agricultural policy. The literature search was conducted using combinations of several

keywords, including *national strategic irrigation*, *irrigation infrastructure*, *agricultural intensification*, *land productivity*, *water productivity*, *irrigation management*, *food security*, and *Indonesia*. Boolean operators ("AND" and "OR") were applied to refine the search results and improve the relevance of the retrieved publications.

Study Selection

The article selection process consisted of four sequential stages: identification, screening, eligibility assessment, and final inclusion. During the identification stage, publications relevant to irrigation infrastructure and agricultural productivity were retrieved from the selected databases. Duplicate articles were subsequently removed before proceeding to the screening stage, where titles and abstracts were evaluated based on their relevance to the research objectives. The eligibility assessment involved a full-text review of the remaining articles. Publications were included if they (1) discussed irrigation infrastructure or irrigation management, (2) analyzed agricultural intensification, land productivity, or water productivity, (3) focused on Indonesia or presented findings applicable to Indonesian agriculture, (4) were published between 2018 and 2026, and (5) were available in full-text format. Articles that were duplicated, lacked sufficient methodological information, or were unrelated to the research topic were excluded from the review. Ultimately, 15 peer-reviewed journal articles that fulfilled all inclusion criteria were selected for qualitative synthesis.

Data Extraction

Relevant information from each selected article was extracted using a standardized data extraction form. The extracted information included the author(s), publication year, study location, research objectives, research design, analytical methods, variables examined, and key findings. This procedure ensured consistency during data collection and facilitated comparison among the reviewed studies.

Data Analysis

The selected studies were analyzed using thematic content analysis, which involved identifying recurring concepts, patterns, and relationships across the literature. The extracted findings were categorized into several analytical themes, namely irrigation infrastructure development, irrigation management, water productivity, agricultural intensification, land productivity, institutional governance, and technology adoption. Following thematic classification, a narrative synthesis was conducted to integrate empirical findings from previous studies. The synthesis focused on explaining how national strategic irrigation infrastructure

influences agricultural intensification and land productivity while identifying factors that either strengthen or limit the effectiveness of irrigation investments in Indonesia's outer islands.

Research Framework

This study assumes that national strategic irrigation infrastructure serves as the primary intervention for improving agricultural performance. Improved irrigation infrastructure is expected to enhance irrigation service reliability, increase water-use efficiency, and encourage the adoption of better farming practices. These improvements subsequently promote agricultural intensification through higher cropping intensity and more efficient land utilization, ultimately contributing to increased land productivity and sustainable agricultural development. The conceptual framework therefore links irrigation infrastructure development with irrigation management, agricultural intensification, water productivity, and land productivity as interconnected components influencing agricultural outcomes.

3. Result

Characteristics of the Selected Studies

The literature search identified a number of publications related to irrigation infrastructure, agricultural intensification, and land productivity. After applying the inclusion and exclusion criteria, 15 peer-reviewed journal articles published between 2018 and 2026 were included in the final analysis. The selected studies covered various research topics, including irrigation policy, irrigation modernization, water productivity, irrigation network management, smart irrigation systems, climate adaptation, and sustainable agricultural development in Indonesia. Most of the reviewed studies employed quantitative approaches, while several adopted qualitative methods or simulation-based analyses. The research locations represented diverse agricultural regions, including Java, Sumatra, Kalimantan, Sulawesi, Nusa Tenggara, and several outer-island irrigation areas. This diversity provides a comprehensive understanding of how irrigation infrastructure contributes to agricultural development under different environmental and institutional conditions.

Table 1. Summary of the Selected Studies

Aspect	Description
Number of reviewed articles	15
Publication period	2018–2026
Research approach	Quantitative, qualitative, simulation, and policy analysis

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Main research topics	Irrigation infrastructure, irrigation management, water productivity, agricultural intensification, land productivity
Study areas	Java, Sumatra, Sulawesi, Kalimantan, Nusa Tenggara, and other regions of Indonesia

Impact of Irrigation Infrastructure on Agricultural Intensification

The reviewed studies consistently indicate that irrigation infrastructure has a positive influence on agricultural intensification. Improved irrigation systems provide a more reliable water supply, allowing farmers to increase planting frequency and optimize land utilization throughout the year. Consequently, areas with better irrigation services generally achieve higher cropping intensity than regions with inadequate irrigation facilities. Modern irrigation technologies further improve agricultural intensification by increasing operational efficiency and reducing water losses. The implementation of smart irrigation systems enables more precise irrigation scheduling, thereby improving water allocation and supporting sustainable agricultural production. In addition, rehabilitation of irrigation canals and modernization of irrigation networks contribute to greater irrigation reliability and reduced production risks. These findings suggest that agricultural intensification is not solely determined by the availability of irrigation infrastructure but also by the effectiveness of irrigation operation, maintenance, and institutional management.

Impact of Irrigation Infrastructure on Land Productivity

The reviewed literature demonstrates that improvements in irrigation infrastructure contribute significantly to increased land productivity. Reliable irrigation enables farmers to maintain adequate soil moisture during critical crop growth stages, resulting in higher crop yields and more stable agricultural production. Several studies also report that efficient irrigation management improves water productivity by maximizing crop output per unit of water used. Modern irrigation technologies, including subsurface irrigation systems and optimized irrigation networks, further enhance land productivity through improved water distribution and reduced irrigation losses. However, the magnitude of productivity improvement varies among regions due to differences in environmental conditions, water availability, institutional capacity, and infrastructure maintenance. Therefore, physical infrastructure alone cannot guarantee optimal agricultural productivity without effective governance and sustainable management practices.

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Factors Influencing Irrigation Performance

The synthesis identified several key factors influencing the effectiveness of irrigation infrastructure.

Table 2. Key Factors Affecting Irrigation Performance

Factor	Influence on Agricultural Productivity
Irrigation infrastructure quality	Improves water distribution reliability
Operation and maintenance	Maintains irrigation system performance
Institutional governance	Supports equitable water allocation
Technology adoption	Enhances irrigation efficiency
Farmer participation	Strengthens irrigation management
Climate variability	Influences irrigation water availability

The findings indicate that successful irrigation development requires an integrated approach combining physical infrastructure, institutional strengthening, technological innovation, and community participation.

Overall Findings

Overall, the reviewed studies demonstrate that national strategic irrigation infrastructure has substantial potential to improve agricultural intensification and land productivity in Indonesia. Infrastructure development increases irrigation reliability, promotes efficient water utilization, and supports sustainable agricultural production. Nevertheless, irrigation investment is most effective when accompanied by strong institutional governance, regular infrastructure maintenance, technological innovation, and active farmer participation. These complementary factors determine whether irrigation infrastructure can deliver long-term benefits for agricultural productivity and food security, particularly in Indonesia's outer islands.

4. Discussion

The findings of this study indicate that national strategic irrigation infrastructure plays a significant role in improving agricultural intensification and land productivity in Indonesia's outer islands. The availability of reliable irrigation systems enables farmers to optimize planting schedules, increase cropping intensity, and reduce the risks associated with water shortages, ultimately contributing to more stable agricultural production [1].

The results also demonstrate that irrigation infrastructure alone is insufficient to maximize agricultural productivity without effective irrigation management. Water distribution

efficiency, routine maintenance, and institutional coordination are essential components that determine whether irrigation systems can operate sustainably and provide long-term benefits for agricultural development [3].

Technological innovation has emerged as another important factor influencing irrigation performance. Smart irrigation systems supported by artificial intelligence improve irrigation scheduling and optimize water allocation, allowing farmers to utilize water resources more efficiently while reducing operational losses. These technologies are increasingly relevant as Indonesia faces growing pressure on water availability due to climate change and increasing agricultural demand [2].

Another important finding is that efficient irrigation management contributes directly to improvements in land productivity through more effective utilization of available water resources. Modern irrigation technologies, including subsurface irrigation systems, have been shown to increase both water productivity and crop productivity while supporting sustainable agricultural production systems [13].

The present findings are also consistent with previous studies reporting that irrigation development enhances agricultural resilience against climate variability. Reliable irrigation infrastructure enables farmers to maintain crop production during prolonged dry seasons and minimizes production losses caused by irregular rainfall patterns [11].

In addition, improvements in irrigation infrastructure encourage more intensive land utilization through increased planting frequency and higher cropping intensity. Areas with adequate irrigation services generally demonstrate better agricultural performance than regions with limited irrigation facilities because water availability remains relatively stable throughout the production cycle [12].

The literature further suggests that sustainable irrigation development should not focus exclusively on constructing new infrastructure. Supporting components such as irrigation network optimization, water-use efficiency, evapotranspiration analysis, reservoir development, and environmental sustainability should also be integrated into irrigation planning to maximize long-term agricultural productivity [10].

Despite the positive impacts identified in this review, several challenges remain. Differences in institutional capacity, financial resources, infrastructure maintenance, and farmer participation continue to influence irrigation performance across regions. Consequently, similar irrigation investments may produce different productivity outcomes depending on local governance capacity and management effectiveness [8].

From a policy perspective, these findings suggest that future irrigation investment should adopt a more integrated approach by combining physical infrastructure development with institutional strengthening, technological innovation, and participatory irrigation management.

Such an approach is expected to improve irrigation efficiency while promoting sustainable agricultural intensification and increasing land productivity, particularly in Indonesia's outer islands [1].

Overall, this study confirms that national strategic irrigation infrastructure serves as an important driver of agricultural development. However, the long-term success of irrigation investment depends not only on infrastructure expansion but also on effective governance, continuous maintenance, efficient water management, and the adoption of appropriate irrigation technologies that support sustainable agricultural systems [3].

This study evaluated the impact of national strategic irrigation infrastructure on agricultural intensification and land productivity in Indonesia's outer islands through a systematic literature review of previous empirical studies [1]. The findings indicate that irrigation infrastructure plays a fundamental role in increasing water availability, improving cropping intensity, and enhancing agricultural productivity in various regions of Indonesia [12]. The reviewed studies also demonstrate that reliable irrigation systems contribute to more efficient land utilization and support sustainable agricultural development through improved water resource management [13].

The results further reveal that the effectiveness of irrigation infrastructure depends not only on physical development but also on institutional governance, operation and maintenance, and stakeholder participation [3]. Regions with well-managed irrigation systems generally achieve higher agricultural productivity than areas where irrigation infrastructure is inadequately maintained [14]. Therefore, irrigation development should be accompanied by improvements in institutional capacity and long-term management strategies to ensure sustainable agricultural performance [8].

Technological innovation has become an increasingly important component of modern irrigation management [2]. Smart irrigation systems, efficient water allocation, and irrigation network optimization have demonstrated considerable potential for improving irrigation efficiency while reducing water losses [6]. These technological approaches are expected to strengthen agricultural resilience against increasing climate variability and water scarcity [11].

The review also indicates that sustainable irrigation development requires integrated planning that considers environmental sustainability, water productivity, and efficient utilization of available water resources [5]. Supporting infrastructure such as reservoirs, tertiary irrigation networks, and modern irrigation facilities contributes to improving irrigation reliability and long-term agricultural productivity [7]. Consequently, future irrigation policies should integrate infrastructure investment with sustainable water management and technological innovation [4].

This study has several limitations because the analysis relied exclusively on secondary data collected from previously published scientific literature [1]. Differences in research methods, study locations, and analytical approaches among the selected studies may influence the overall synthesis of findings [12]. Nevertheless, the consistency of evidence across the reviewed literature indicates that national strategic irrigation infrastructure remains an important driver of agricultural intensification and land productivity in Indonesia [13].

Future studies are recommended to employ quantitative impact evaluation methods using panel data, remote sensing, or spatial econometric approaches to estimate the causal effects of irrigation infrastructure on agricultural productivity [14]. Comparative research involving different irrigation systems and geographical regions is also encouraged to strengthen empirical evidence for future irrigation policy development in Indonesia [15]. Integrating economic, environmental, and institutional perspectives will further improve understanding of how national strategic irrigation infrastructure can support sustainable agricultural development and national food security [3].

5. Conclusions

This study demonstrates that national strategic irrigation infrastructure plays a fundamental role in promoting agricultural intensification and improving land productivity in Indonesia's outer islands by increasing water availability, enhancing cropping intensity, and strengthening agricultural resilience to climate variability. The findings also indicate that the success of irrigation development depends not only on physical infrastructure investment but also on effective institutional governance, efficient water management, regular maintenance, stakeholder participation, and the adoption of modern irrigation technologies. By synthesizing recent empirical evidence, this study advances current knowledge by providing a comprehensive understanding that sustainable agricultural development requires an integrated approach combining infrastructure development, technological innovation, and sound irrigation governance. Nevertheless, this study is limited because it relies exclusively on secondary data from published literature, and variations in research methods, study locations, and analytical approaches among the reviewed studies may influence the overall synthesis of findings. Therefore, future research is recommended to employ quantitative methods such as panel data analysis, remote sensing, spatial econometric models, or comparative regional studies to provide stronger empirical evidence regarding the long-term impacts of irrigation infrastructure. Furthermore, future policy and research should integrate physical infrastructure investment with institutional capacity building, digital irrigation technologies, participatory water management, and environmental sustainability to improve irrigation efficiency, support sustainable agricultural intensification, and strengthen national food security in Indonesia.

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