Sustainability of irrigated agricultural area in the context of climate change: a case study in Rentang Irrigation Area, West Java Province, Indonesia

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Abstract. Rentang irrigation area is the second largest irrigated agriculture in West Java Province, with an annual paddy production that exceeds one (1) million tons. Administratively, the Rentang irrigation area is located in three regencies: Majalengka, Cirebon, and Indramayu. Appropriate irrigation infrastructure supports this irrigated farming area. However, many challenges threaten the sustainability of irrigation areas, among them changes in land use and environmental degradation caused by the growth of villages into urban areas, including climate change. Therefore, these issues challenge the sustainability of the irrigated agricultural area, which has the potential to disrupt the achievement of food security and increased nutrition, including the promotion of sustainable agriculture that is mandated in Sustainable Development Goal (SDG) No. 2. This study diverges from previous studies in two main points. First, it adopts a holistic approach to assessing sustainability, whereas prior studies tend to focus primarily on technical and economic aspects. Second, it integrates the socio-economic, environmental, and institutional dimensions within the context of climate change. The analysis is conducted using secondary data from 2015 to 2023. The data are synthesized into sustainability indicators using the DPSIR framework, offering a comprehensive assessment tool. The integration of this approach represents a key contribution to the development of sustainability evaluation in irrigated agricultural areas.

1 Introduction

Population growth and lower mortality rates have caused an imbalance between people and available agricultural land [1]. Irrigated agriculture has become a key solution, maximizing the use of limited natural resources to meet food demand. According to a World Bank survey, irrigated land accounts for only 20% of agricultural areas but produces approximately 40% of the world's food [2]. However, expanding irrigated farming also presents sustainability challenges.

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The aforementioned considerations prompted the author to conduct a study on the sustainability themes in the Rentang irrigation area. The selection of the Rentang irrigation area as the location for this study is because of its status as a primary contributor to the national paddy producers in the West Java province of Indonesia. The Minister of Public Work Regulation No. 14/PRT/M/2015 states that the DI Rentang area covers 87,803 hectares of agricultural land and harvests well over one million tons annually. The Rentang irrigation area is located in three administrative regions, primarily the Indramayu and Cirebon districts, with a small portion in the Majalengka district, where the Rentang Barrage services this area.

2 Literature review

The Rentang Irrigation Area (RIA) derives its name from the Rentang Barrage, which is located in Winong Village within the Jatitujuh Subdistrict of Majalengka Regency. It is the second-largest agricultural irrigation area in West Java after Jatiluhur. Approximately 95% of the irrigation system in RIA is of a technical nature, while the remaining areas have undergone modernization. The Rentang Barrage functions as the primary source of irrigation water, obtained from the Cimanuk River and the Jatigede Dam. The services' coverage area subsequently facilitates the distribution of the irrigation water.

RIA is characterized by a tropical climate, with temperatures ranging from 18.00°C to 39.40°C. The average recorded temperature was 28.37°C. Rainfall variability is attributable to the topography characteristic; the upstream area is hilly terrain, while the downstream area is more level and in closer proximity to the coast. Rainfall decreases from June to September, marking the dry season: during this period no rainfall is recorded. The rainy season, marked by light drizzle, typically begins in October. According to the data from the Kertajati meteorological station, the rainfall levels ranged from 0 millimeters up to 25.96 millimeters, while the humidity levels fluctuated from 79.30 to 92 percent. The velocity of the wind is moderate, ranging from 2.2 to 6 meters per second.

Research Development: RIA represents one of the main paddy granaries in West Java province, playing an important role in food security at both local and national levels. That has prompted numerous parties to direct increased attention toward it, including through comprehensive study and research. The summary and findings from previous research in three regencies: Majalengka, Cirebon, and Indramayu were grouped under four themes. This reference illustrates the conditions of RIA, shown in Table 1.

Table 1. Summary and findings of the research development

Theme	Objective
Water resources	- Forecasting Cimanuk & Jatigede water discharge using discharge and rainfall modelling [3].
Agricultural System (paddy cultivation)	- Verifying and ensuring the suitability of agricultural land in Indramayu [4].
Mitigation; risk mapping	- Minimizing losses in the agricultural sector through insurance with drought risk mapping for insurance [5].
	- Assessing the level of danger, vulnerability, and risk of climate change impacts on paddy production [6].
Adaptation	- Promoting ecological agricultural practices to reduce vulnerability to climate change [7].

Sustainability Concept: In simple terms, the concept of sustainability is understood as having four dimensions, namely social, economic, environmental, and institutional. This concept is further expected to provide a solution to the threat of vulnerability in various sectors. One such sector is agriculture, which is increasingly being affected by the degradation of environmental conditions and natural resources [8].

Climate Change: Based on observations of temperatures in Indonesia from 1940 to 2024, there has been a deviation or increase in the average monthly surface temperature. Over a period of 83 years, the temperature has shifted by 0.5°C to 1.0°C [9]. Projections for the period 2011 to 2040 indicate that a study using the RCP 8.5 emissions scenario shows an increase in extreme rainfall in various regions of West Java province, including Cirebon and Indramayu [10].

DPSIR Frameworks: DPSIR is a framework for analyzing how humans interact with the environment. It consists of five key factors—Driving force, Pressures, State, Impact, and Response—that form a chain of cause and effect. This approach assists in explaining complex human-environment relationships and supports developing policies for sustainable systems. is an analytical framework used to understand the dynamics of interactions between humans and the environment [11]. Accordingly, the complex conditions in RIA can be illustrated broadly, comprehensively, and in a linked manner. This approach allows for clear identification of the sustainability dimension indicator, as shown in Figure 1.

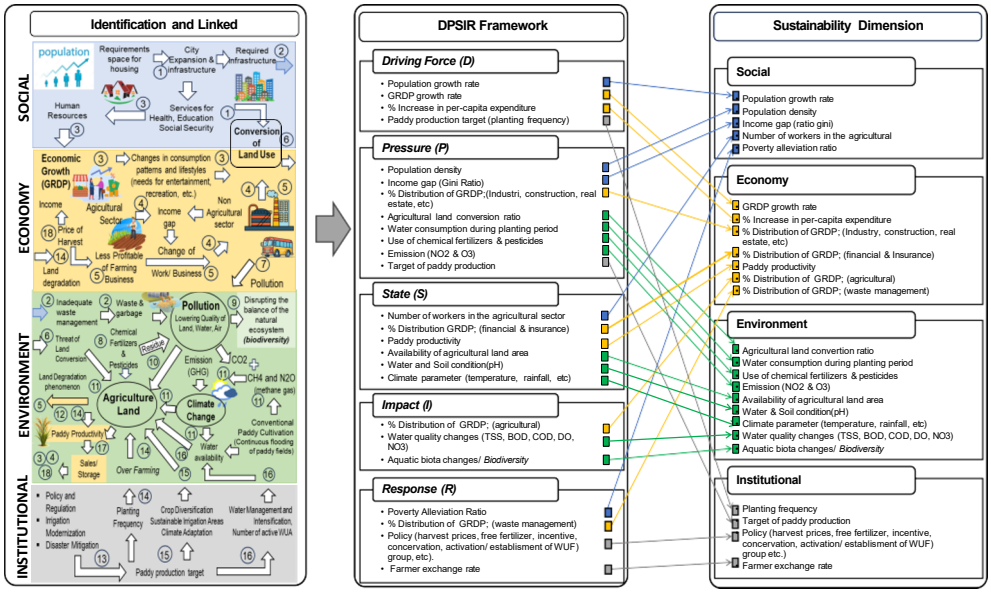

Fig. 1. Through linking and identifying conditions, the DPSIR framework interprets the indicators based on sustainability dimensions.

According to Bradley and Yee (2015), social and economic factors give rise to the motivation for human activities to obtain the basic needs, such as food, raw materials, water, housing, health, culture, infrastructure, and security [12]. These needs increase with population growth. These factors serve as potential drivers of human progress within the DPSIR framework, such as economic and social development [13].

The above factors will then become pressures that will directly affect environmental change. There are three general forms of pressure: i) excessive use of resources, ii) changes in land use, and iii) greenhouse gas emissions, including pollution from chemicals, waste, and radiation released into the air, water, and soil [13], [14].

The level of pressure will impact the state of natural resources, which is reflected in physical, geochemical, chemical, and biological conditions. This includes the current state of waste and garbage management, housing conditions, energy availability, and clean water [12], [13], [14]. This includes the massive conversion of agricultural land. The current state of condition addresses the impact of past human activities that have contributed to climate

change. An example is the industrialization era, which increased carbon dioxide (CO_2) emissions. In addition, the conventional paddy cultivation system, which is still widely practiced, contributes significantly to methane (CH_4) and nitrous oxide (N_2O) emissions.

An impact is any change to nature and the environment, whether physical, chemical, or biological. This includes non-direct changes that often go unnoticed. However, the accumulation of these changes can become problematic in the future. These alterations can affect the overall condition and status of natural ecosystems in a region [15].

Therefore, a response is needed from individuals, groups, the community, or the government as policy makers to take appropriate action at any point in the chain between the driving force and their impacts. These measures may include preventive actions, compensation, improvements, or adaptations in response to changes in welfare caused by environmental or health conditions [12].

3. Data and method

Based on the DPSIR framework, this study observed the conditions of RIA during the period 2015-2023. The analysis utilized secondary data from the Indonesian Central Statistics Bureau, covering the Majalengka, Cirebon, and Indramayu districts in West Java Province. The climate data was obtained from the Kertajati Meteorological Agency. The environmental reports are from the RIMP project under BBWS Cimanuk Cisanggarung of the Public Work Ministry.

4. Result

The DPSIR framework compiles the sustainability assessment results, presenting them across four main dimensions: social, economic, environmental, and institutional. The analysis used descriptive statistics and regression graph interpretation to observe the direction and trends of each indicator. The findings are presented below.

Social dimension: The population growth trend exhibited a downward trend until the end of 2018. However, 2019 indicated a marked increase, followed by a precipitous decline in 2021. This anomalous rise in population during 2019 may be associated with short migration patterns. The temporary increase in population contributed to growing social inequality because of uneven resource distribution and limited access to social services. Consequently, the population density in certain areas intensified, leading to heightened demand for basic necessities. In parallel, the agricultural sector's workforce participation rate declined from 2015 to 2018. However, since 2019, there has been a notable resurgence, largely attributable to socio-economic impact of the Covid-19 pandemic. The crisis led to widespread job losses in non-agricultural sectors, forcing a significant portion of the population to revert to agriculture as an alternative means of subsistence and economic security.

Economic dimension: For the first period, from 2015 to 2018, paddy productivity increased, but the percentage contribution of the agricultural sector to GRDP decreased significantly. Meanwhile, the GRDP of sub-sectors such as the manufacturing industry, construction, and real estate increased continually but decreased in 2023. In the second period, from 2019 to 2023, Covid-19 as a global pandemic caused an economic contraction, with GRDP growth reaching negative values. The increase in the Gini ratio indicates that this phenomenon represents a form of socio-economic pressure. As a result of these conditions, agriculture became the economic backbone of communities affected by the pandemic, with paddy production reaching its highest level in 2020 during the study period. Subsequently, paddy productivity increased by 7 tons per hectare, and the frequency of paddy cultivation now exceeds twice annually.

Environment dimension: The environment is showing alarming trends: water quality is deteriorating, especially with regard to Total Suspended Solids (TSS), Biochemical Oxygen Demand (BOD), and Chemical Oxygen Demand (COD). Environmental degradation can have long-lasting impacts on the sustainability of the agricultural sector and people's lives. The average annual temperature rises by 0.122°C, and the average annual rainfall decreases by -0.0612 mm. Despite irrigation supporting this area, the shifting planting season occurred for climate adaptations.

Institutional dimension: Since 2016, the frequency of paddy planting has increased significantly, primarily due to the increased supply of irrigation water from the Jatigede Dam. However, the unstable selling price of paddy remains a major challenge, as prices tend to fall during the harvest season. Another factor that must be considered is the increasing planted area during the study period, which corresponds with the rise in the number of Water User Associations (WUAs). This growth reflects the expanding participation of farmer groups. However, it may also lead to several challenges. For example, the heightening demand for irrigation water can strain irrigation systems, reduce efficiency, and heighten competition among WUAs, especially during dry periods. Environmental risks such as land degradation and excessive agrochemical use may also emerge, alongside potential disparities in access and decision-making among WUAs. These issues demonstrate the importance of coordinated water management and inclusive governance.

5. Conclusion

The Rentang Irrigation Area (RIA) faces sustainability challenges due to population fluctuations, economic pressures, environmental changes (including climate change), and institutional issues. These factors collectively influence land use, water availability, and labor dynamics. Although agricultural intensification supports economic resilience, environmental degradation and price instability continue to cause major difficulties. Addressing these issues requires a strategic balance between productivity, sustainability, and community welfare. Therefore, the integration of social, economic, environmental, and governance policies is imperative.

It is recommended that subsequent study focus on measurable indicators of sustainability. This approach aims to generate a sustainability value that can objectively evaluate performance across social, economic, environmental, and institutional dimensions. Hereinafter, evaluation results can be used as a basis for formulating adaptive, inclusive, and sustainable irrigation management policies.

Data that support the findings of this study are available from the author upon reasonable request. The authors declare no conflict of interest.

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