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Network Governance of Rural Water Management to Cope with Adverse Impacts of Climate Change: Evidence from An Irrigated Dry Area in Central Java, Indonesia

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Abstract

Irrigation management in Indonesia has always involved challenges. There are at least three phases in irrigation management: the rain-fed phase, technical irrigation in irrigation buildings, and technical irrigation to mitigate climate change (CC). This study investigated irrigation management based on local wisdom as a form of CC adaptation. The research was conducted in Klambu Kanan Irrigation District (KKID), where 11,005 ha of rice fields are irrigated in three regencies. The subjects of this research were 40 irrigation Water User Associations (WUAs), and the research instrument was a model that provided incentives to manage WUAs, cropping patterns, and water fees in response to CC. The results showed that CC has had impacts on rice fields in the KKID, such as mud flooding due to changes in land cover. There are two models employed by the WUAs: a “self-governance model” (SGM) and an “auction model” (AM), the latter of which is a form of management based on “network governance” (NG). The SGM emphasizes the participation of members (community-based) through social capital, while the AM emphasizes the availability of capital in irrigation management (provider-based). More than 77% of WUAs employed the SGM, while the rest employed the AM. In addition, the SGM was utilized for 180 more days per year than the AM, which was used for 47 days per year. Finally, the productivity of the SGM was higher than that of AM. Further research is needed to compare SGM and AM to confirm that SGM is more widely applied than AM.

Keywords: climate change; community-based model; network governance; provider-based model

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INTRODUCTION

Climate change (CC) is a global phenomenon that has an impact on all sectors; this is especially true for agriculture, which depends on climatic conditions (Rojas-Downing et al., 2017; McCarl and Hertel, 2018; Rust, 2019; Habib-ur-Rahman et al., 2022). This has resulted in declines in crop production due to floods, droughts, and crop pests and diseases. The impacts of CC on farming depend on the location and the activities of communities. It has been found that upstream communities experienced different impacts of CC on water usage from downstream ones (Arifah et al., 2022); for example, downstream communities experienced water shortages and

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rising temperatures, while upstream communities were more likely to experience pest infestations.

On the other hand, the availability of irrigation infrastructure and irrigation management can reduce the impacts of CC (Turral et al., 2011; DuBois et al., 2012; FAO, 2014). Furthermore, good irrigation water management can reduce production losses due to CC (Rondhi et al., 2019; 2020). Good irrigation water management carried out by Water User Associations (WUAs) is the key to successful performance and can be achieved through institutional innovations that meet the needs of irrigation water users (Pahl-Wostl, 2015; 2019).

In Indonesia, agricultural irrigation management has evolved from a hierarchical model to a networking governance (NG) model (Rondhi et al., 2020). The hierarchical model emphasizes the role of the government in managing irrigation water, while the NG model focuses on irrigation water management based on agreements between water users and water managers. Thus far, research related to the use of the NG model in irrigation management has yielded varying results (Arifah et al., 2022; Mishra, 2023). Irrigation management in the form of contract management and collective action can reduce maintenance costs and shorten water distribution time (Zhou et al., 2017; Bruns, 2023; Tripathi et al., 2023), and the contract management model employed in Spain provides incentives for the management of irrigation water (Rica et al., 2012). This proves that using different methods in each region can improve the efficacy of irrigation water management. However, few studies have focused on limited water availability due to the impacts of CC. This study aims to determine the performance of farms based on irrigation water management models in areas that apply the NG model.

Theoretically, there are three models of irrigation management at the tertiary level based on who manages irrigation: hierarchical governance, community-based governance, and provider-based governance (Tenbensel, 2005; Pahl-Wostl, 2015; 2019). The former is a top-down model, while the others are participatory, where decision-making is based on interactions between water users and irrigation water providers (NG). The first model is suitable for areas with sufficient funds for operations and maintenance, which are usually provided by the government, while the second and third models were chosen due to the desire for member participation in reducing operational and maintenance costs. A previous study showed that participatory and community-based governance had positive impacts on farming efficiency (Suwanmaneepong et al., 2024), and it was determined that community-based governance should also be enhanced using social capital to enable sustainable irrigation management and reduce conflicts of interest (Mahaarcha and Sirisunhirun, 2023). Meanwhile, it was found that provider-based governance needs to be improved to achieve more equal irrigation water distribution (Suhaeti et al., 2018).

Irrigation management involves the distribution of water resources to agricultural areas. CC has an impact on water availability, which, in turn, impacts irrigation management. Klambu Kanan Irrigation District (KKID) is one of the three irrigation areas on the main Klambu Dam. The irrigated areas of the KKID cover roughly 11,005 ha and are rural. A study found that irrigation played an important role in rural areas, as it achieved higher technical efficiency compared with that in urban areas (Rondhi et al., 2024). However, the irrigated area decreased over time due to factors such as sedimentation, limestone mining, and a diminished water supply from the Kedung Ombo Reservoir. The decrease in the irrigated area was also exacerbated by recent CC. The KKID has played an important role in agricultural activities in surrounding administrative regencies, including Kudus, Pati, and Grobogan. The evolution of water management is a result of changing needs over time. Therefore, not all Dharma Tirta (irrigation management institution) models have transformed into auction models (AMs) (Rondhi, 2019).

Irrigation management in the KKID has evolved along with changes in policies related to Indonesian irrigation. The construction of irrigation canals up to tertiary canals began during the Dutch forced-cultivation era. In the 19th century, the Dutch implemented the Algemeene Water Reglement (AWR), which formally regulated irrigation in tertiary canals (Muryati and Triasih, 2021), and irrigation management was delegated (decentralized) to individual regions during the post-independence era. This form of irrigation management decentralization can be seen in Dharma Tirta and Subak as a means of water management organization at the tertiary canal level (Tirtalistyani et al., 2022). The Indonesian Reformation era also had an impact on irrigation regulation. Irrigation management has changed from Dharma Tirta model into a management contract system (auction system), where funds are paid at the beginning of the term of a new board member (Rondhi, 2015). Despite the auction system providing a new mechanism for irrigation management, not all Dharma Tirta management models have changed into an auction system.

A study has found that problems related to the distribution of water to rice plots and a lack of participation in decision-making, management, and maintenance were the causes of low irrigation efficiency (Cindy, 2022). The study reported that evolving irrigation management impacted agricultural production, and water availability played a key role in increasing agricultural production. In addition to these technical factors, most irrigation efficiency problems are related to the choice of model or factors related to irrigation management. Therefore, adaptations or adjustments need to be made to irrigation models, especially to cope with the adverse impacts of CC.

The main objective of this study is to investigate irrigation management based on local wisdom (self-governance model/SGM or AM) as a form of CC adaptation. Previous studies have focused on irrigation management models as well as effectiveness, welfare, equity, and efficiency in the irrigation process (Khanal et al., 2018; Takayama et al., 2018; Rondhi et al., 2020; Hoogesteger et al., 2023; Mallareddy et al., 2023). However, there is limited research linking agricultural production and CC, and this study aims to fill this gap.

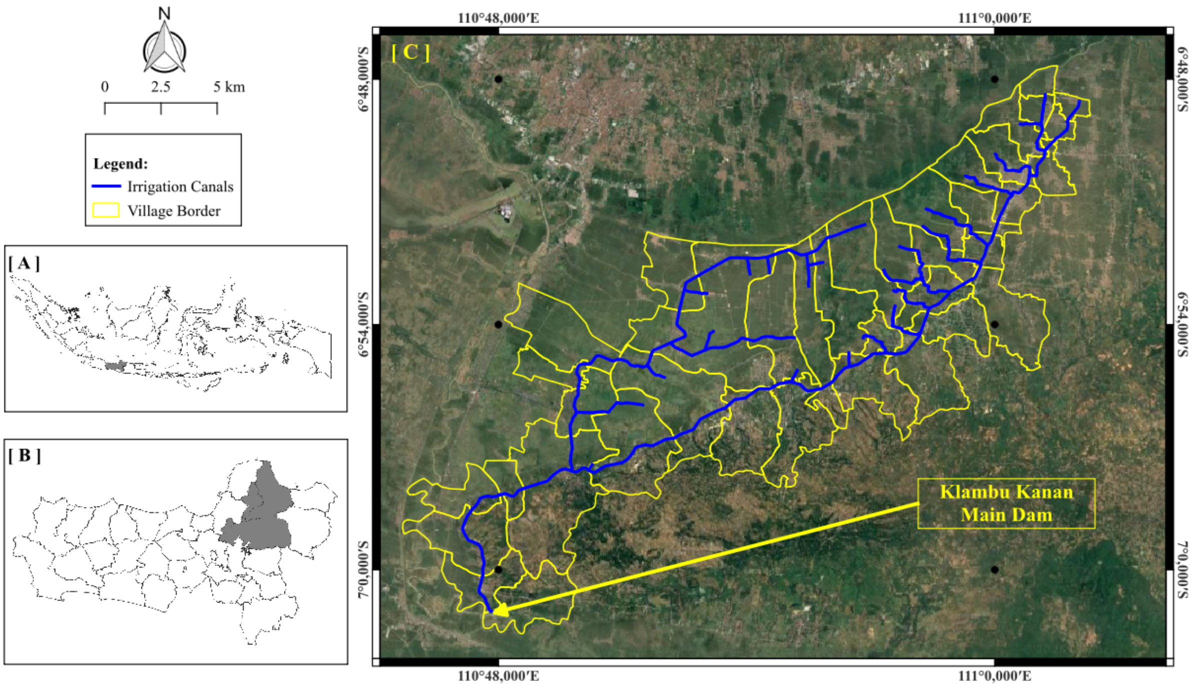
MATERIALS AND METHOD

Research location and respondents

The location of this study was the KKID (Figure 1), one of the irrigation areas in the Kedung Ombo Reservoir in Central Java, which irrigates areas across Sragen, Grobogan, Demak, Kudus, and Pati Regencies and covers 64,365 ha of paddy fields. The KKID was selected because the irrigation area is affected by CC due to the limited availability of irrigation water. The subject of this research was the 40 WUAs in the KKID. Information related to the WUAs was obtained from a KKID officer involved in maintaining the irrigation area. According to the officer's report, there is at least one WUA in every village across the KKID. A preliminary survey revealed that 40 active WUAs use water from the KKID.

Research design

This research used a mixed-method approach, combining quantitative and qualitative research with a case study (Creswell, 2013). There are four



[A]. Central Java Province relative to Indonesia
[B]. Grobogan, Kudus, and Pati Regencies relative to Central Java
[C]. Map of villages across Klambu Kanan Irrigation Area located on the intersection among Grobogan, Kudus, and Pati Regencies.

Figure 1. Location of KKID

Table 1. Description of independent variables

Variables	Notation	Description
WUA's management system	Y	Assigned 1 for SGM and 0 for AM
Rice production	X_1	Quantity of rice produced (kg)
Distance from main weir	X_2	Relative distance between WUA's location and Klambu Kanan main dam (km)
Water fees	X_3	Water fees that have to be paid by farmers (IDR)
Number of board members	X_4	Number of board members in WUA (people)
Managerial term duration	X_5	Duration of single managerial term of board members (years)

$$\log\left(\frac{\pi}{1-\pi}\right) = \beta_0+\beta_1X_1+\beta_2X_2+\beta_3X_3+\beta_4X_4+\beta_5X_5 \quad (1)$$

Where, π indicates the probability of an event occurring (e.g., SGM) and β_i represents the regression coefficients associated with the reference group and X_i explanatory variables.

possible conditions when conducting qualitative and quantitative analysis; the qualitative analysis can be standalone or occur before, concurrently with, or after the quantitative analysis (Ayre and McCaffery, 2022). In this study, quantitative analysis was performed before conducting qualitative analysis. The quantitative analysis involved binary logistic regression, while the qualitative analysis involved focus group discussions (FGDs) and in-depth interviews. These qualitative methods were employed to determine the perceived impact of climate change by WUAs to determine the efficacy of their irrigation management models. In-depth interviews were conducted with WUA leaders using interview guides and structured questionnaires about irrigation management in their tertiary coverage areas.

Data analysis

The research stage began with physical identification of the condition of the irrigation area from upstream to downstream, which was carried out by digitizing the location of each WUA and its irrigation area coverage. The first step was to conduct a descriptive statistical analysis of WUA operations, which provided a basic overview of each WUA's management system. This overview was used as a comparative measure to determine the appropriateness of each management system used in the KKID. The second step was to determine each WUA's preferred management system through quantitative analysis using a binary logistic regression model to examine and quantify the predictive association between independent variables and binary outcomes (Beacom, 2023), where 1 is for the SGM and 0 for the AM. The binary logistic regression model employed in this study can be expressed as follows Equation 1.

Table 1 describes the explanatory variables in more detail. The binary logistic regression model was selected in this study because it represents each WUA's preferred management system. In addition, logistic regression was better than the Linear Probability Model (LPM) in terms of linearity, as it was linear not only in X but also in terms of the parameters. The logistic regression model also offered advantages in interpreting the regressand (Y), with an increase in the positive coefficient of X (regressor) increasing the odds that the regressand equals 1 (meaning some event interest happens) (Gujarati and Porter, 2003). The analytical computation was performed using R-Studio. The last step was the qualitative analysis, which involved FGDs and in-depth interviews to support the binary logistic regression results.

RESULTS AND DISCUSSION

WUA governance is affected by the environment and tends to improve. CC affects the condition of irrigation canals and, in turn, irrigation management. An example of this is irrigation management in the KKID, which has experienced a shift from before the formation of the irrigation districts to the present. This progression can be described across three periods: before 1990, from 1990 to 2000, and after 2000.

The KKID is one of three important irrigation districts of Klambu Dam, the main source of which is Kedung Ombo Dam, established in 1991. The irrigation area is located along Kendeng mountain range (Figure 1) at an altitude of 300 m above sea level. It features 60 km of irrigation canals for agricultural land and domestic needs across 40 villages, from Penganten Village in Grobogan Regency (upstream area) to Kosekan Village in Pati Regency (downstream area) (Figure 2). The irrigation canals consist of primary and secondary canals managed by the government, and tertiary canals are built and managed by WUA managers. Before 2015, the number of tapping gates was 138, but due to changes in land conditions (long-term impacts of climate change), the number of buildings increased to 164. The addition of these 26 new buildings was intended to reduce the time required to reach farmers' fields.

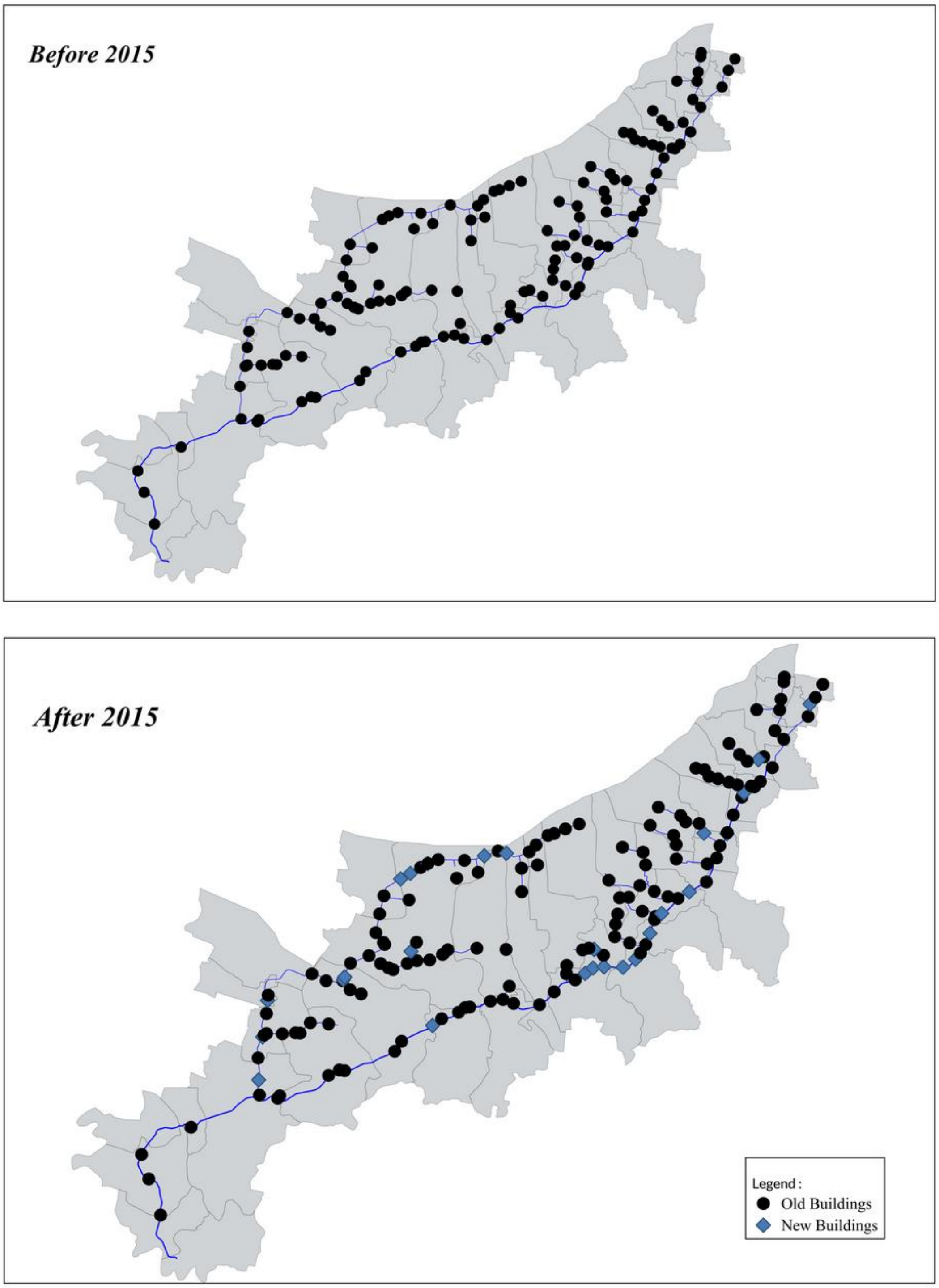


Figure 2. Locations of irrigation structures before 2015 (2000 to 2015) and from 2015 to present

Over more than 30 years (1991 to 2023), land cover in the mountain area has shifted from annual crops to seasonal food crops. Before the 1990s, the dominant plants in the mountains were teak trees, mahogany, acacia, and other plants that stored water during the rainy season. However, the conditions in this area have changed. When it rains, the roots of food crops are not able to store water, so water flows directly downstream, which can cause landslides. This change in land cover has also led to higher rates of soil erosion during rainfall, resulting in shallower irrigation canals and slowing the flow of water to rice plots.

Before 1990, the availability of irrigation water was limited, with sources relying on rainfall and Jeratun Seluna River. WUAs used water pumps to transfer water from the river to the rice plots. The irrigation water regulation was managed by a group of farmers who were members of Dharma Tirta. Because obtaining irrigation water required the use of a water pump, irrigation water fees were high, amounting to 1/8 and 1/12 of the harvest yield. Due to the effort required to provide and distribute water, the WUA conducted operations and maintenance activities throughout the season. Therefore, management by WUAs was known as “self-governance,” which meant that the rights to irrigation water management were determined by consensus.

The 1990 to 2005 period was characterized by the existence of irrigation infrastructure, including dams and irrigation canals built by the government. Access to irrigation water became easier, eliminating the need for water pumps and reducing farmers’ workloads. Irrigation fees during this period were also lower than in the previous period, varying between 1/12 and 1/20 of the amount obtained from a harvest, with yields of 60 to 100 kg ha^{-1}. The availability of irrigation water increased farmers’ expectations of services for irrigation water management, such as eradicating pests and plant diseases. In this period, the term “auction system” was introduced for irrigation water management, where the rights to irrigation water management were auctioned to obtain the highest bid.

The period of 2005 to present is marked by wider access to forest resources, which has led to deforestation. The impact of deforestation is twofold: mud flowing into the rice fields and limited water reserves in the upstream area because water flows directly downstream when it rains. This situation has an impact on the shallowness of irrigation canals and farmers’ rice plots, as well as increases the time required to drain irrigation water from upstream to downstream. As a result, the workload for maintaining primary, secondary, and tertiary canals has also increased. The irrigation water fees in this period vary between 1/10 and 1/18 of the harvest yields, and the irrigation water management model varies between the SGM and the AM.

In the KKID, of 40 WUAs, 31 applied the SGM, while the rest applied the AM (Table 2). The SGM was chosen as irrigation water management requires a considerable amount of money for operational and maintenance costs. On the other hand, the AM was chosen due to the need for infrastructure development funds in tertiary plots.

The SGM was more dominant than the AM, employed by 31 WUAs (77.5%), whereas the AM was only employed by 22.5% or 9 WUAs. There were two harvest seasons in one year, with the productivity of the first season relatively similar between the SGM and AM (both systems yielded 4.11 tons ha^{-1}). In the second harvest season, the productivity of the SGM was higher than that of the AM. Both models yielded 5.3 and 4.6 tons ha^{-1}, respectively. In addition, the SGM was geographically dominant in the entire downstream area except for two villages, while the AM dominated in the upstream area (Figure 3).

In the SGM, the election of the WUA chairperson or board was determined through a member meeting, and the operational and maintenance costs incurred in the SGM were higher than in the AM, whereas in the AM, the WUA chairperson was determined by an investment at the beginning of their new term. This investment was used for the development of agricultural infrastructure in the WUA area. Table 2 shows that the cost of maintenance or WUA activities for the SGM was 84,216,000 IDR $year^{-1}$, equivalent to 460,200 IDR ha^{-1}. The irrigation maintenance cost incurred by the SGM was 84,216,000 IDR, greater than that incurred by the AM (75,350,000 IDR). Although the AM appeared to cost less in terms of maintenance, the potential fee per year was greater, at 740,337,599 IDR, compared to that of the SGM, which was only 85,547,849 IDR. The SGM conducted more operational and maintenance activities (8 to 21 times) than the SGM (5 to 18 times). The annual management salary in the WUA AM was 22,000,000 IDR per person, which was significantly higher than the SGM's annual wage of 3,000,000 IDR per person.

In terms of water fees, there are two kinds of payment: cash or in kind. In-kind contributions, typically in the form of harvest yields, are predominantly used in the AM, while cash payments are more common in the SGM. Table 2 shows that 90% of WUAs employing the AM used in-kind payment, while 90% of WUAs utilizing the SGM used cash payment. In-kind payments are considered easier to collect as they align with harvest periods. Conversely, cash payments require less effort to manage, particularly when farmers are already aware of their payment obligations. Table 2 indicates that the average cash fee for the AM was 750,000 IDR ha^{-1} $year^{-1}$, higher than that for the SGM, which was 415,966 IDR ha^{-1} $year^{-1}$. Water fees

Table 2. Irrigation water management based on SGM and AM

Aspects	AM		SGM		Description
Number of WUAs	9	(23)	31	(77)	Number of WUAs (percentage)
Irrigated area (ha)	1,255	(139)	3,680	(199)	Total (average)
Governing period (years)	3		4		Average per WUA
Board members (persons)	106	(12)	257	(8)	Total (average)
Farmer members (persons)	1,900	(238)	6,251	(202)	Total (average)
1st season rice yield (ton ha^{-1})	6.1	-	6.1	-	-
2nd season rice yield (ton ha^{-1})	4.6	-	5.3	-	-
Water fee (IDR ha^{-1})	750,000	-	415,966	-	-
Average board member fee (IDR $year^{-1}$)	22,000,000	-	3,000,000	-	-
Infrastructure fund availability	Yes, initial time	-	Depends on management performance	-	-
Operational and maintenance activity (day $year^{-1}$)	47	-	180	-	-
Maintenance cost (IDR $year^{-1}$)	75,350,000	(188,375)	84,216,000	(460,196.7)	Total (average)
Cash payment	3	(10)	26	(90)	Total (percentage)
Average cash value (IDR ha^{-1} $year^{-1}$)	750,000	-	415,966		-
Payment in kind	6	(55)	5	(45)	Total (percentage)
Average in-kind value (kg ha^{-1} $year^{-1}$)	1,194.7	-	357.4	-	-
Perception of climate change effect	9	(100)	27	(85)	Total (percentage)
Rice productivity and magnitude of CC effect	-	-	-	-	-
< 25%	3.89		3.93		In ton ha^{-1}
26–50%	4.34		4.11		In ton ha^{-1}
51–75%	5.00		2.40		In ton ha^{-1}
76–100%	4.00		4.36		In ton ha^{-1}

were closely related to plot productivity. The AM system yielded a higher productivity of 1,194.72 kg^{-1} ha^{-1} year^{-1} compared to the SGM, which produced 357.44 kg^{-1} ha^{-1} year^{-1}.

The SGM had a lower average daily work duration compared to the AM. Table 2 shows that the average daily work duration for the AM was 5 hours per day, while for the SGM, it was 4.3 hours per day. However, the frequency of working days for the AM was lower compared with the SGM.

The magnitude of CC upstream and downstream of the KKID irrigation area can also be found. Most WUAs in the KKID experienced a magnitude of CC in the range of less than 25%, 26 to 50%, and 51 to 75% in certain areas. High CC magnitudes (76 to 100%) were especially found in the downstream areas, while only one village in the upstream areas experienced a high CC magnitude.

The determinants of an irrigation water management system are given in Table 3. These results show that three variables are statistically significant: rice production, distance relative to the KKID main dam, and water fee. The latter two variables are significant at the 5% real level, while the rice production variable is significant at the 10% level. Other variables, such as the number of board members and managerial term duration, have no significant effect on the decision to use the AM or SGM. In terms of the goodness-of-fit of the estimated model, it can be concluded that the model is quite good. The Akaike information criterion (AIC) value of 29 is lower than the null AIC of 30, and the Pseudo-R^2 values are generally at or above 50%.

Irrigation water management

The FGDs and in-depth interviews revealed two types of irrigation management in the KKID: SGM and AM. Figure 3 illustrates that AM is predominantly implemented in the upstream areas of the irrigation system, where water discharge is higher and silt levels are lower compared to downstream areas. These conditions provide greater advantages for AM management in tertiary canals. This subsection generally focuses on how WUA management responds to CC, which causes flooding, sedimentation, and drought. WUAs employing the SGM and those employing the AM have distinct payment procedures and costs. The CC strategy, which involves production, distance to the main dam, water fees, number of board members, and managerial term duration, is discussed in detail in the next subsection.

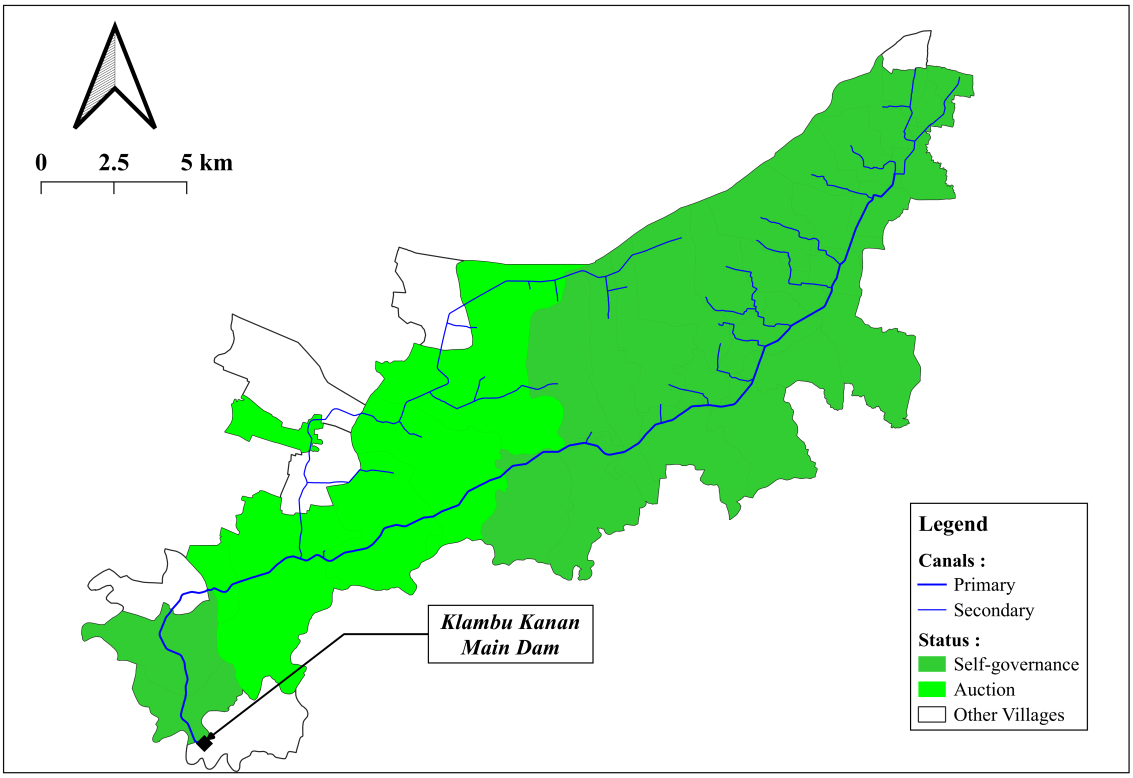


Figure 3. Distribution models used by WUAs in KKID

The geographical advantages in the upstream area encouraged farmers to adopt the AM system because it had a relatively smaller risk factor compared to the downstream area. One significant risk faced by farmers was water shortages in irrigation areas, which influenced their preference for management systems that maximized profits (Wibowo et al., 2017; Rudnick et al., 2019; Gonçalves et al., 2020). Water shortages in an irrigation area will encourage WUA administrators to obtain greater profits.

Villages in the downstream areas often experienced flooding during the rainy season. This caused WUA management to look for alternatives to reduce or eliminate the risk of flooding. However, each alternative led to increased costs, which subsequently reduced wages for WUA management. As a result, the AM system—characterized by payment at the beginning of the management period—was less suitable for downstream areas. Under the AM system, management was required to bear costs upfront, meaning that higher risks for member farmers translated into lower benefits for management. It is important to note that the AM system had specific implications, particularly its high dependence on harvest quantity.

The SGM was a form of community-based water management that used social capital as the main decision-making consideration in WUAs. In this system, social capital is manifested through cooperation among members in irrigation operations and maintenance. In contrast, the AM was profit-oriented. Consequently, the effectiveness of SGM irrigation canal management depended heavily on active member participation. This finding is also in line with Ogunleye et al. (2021), who stated that a social capital network in the form of member participation significantly influences either CC adaptation or adoption strategies. However, there is still scope for further investigation into how social capital works and the best alternative to cope with the impacts of CC in WUAs.

WUA governance and strategy to cope with the impacts of CC

This section discusses the proposed strategy to address the impacts of CC. The strategy, formulated based on logistic regression analysis, can be seen in Table 3. CC has had a significant effect on water resource systems around the world (Ougougdal et al., 2020), and water scarcity has been predicted to worsen in the next 25 to 100 years (Hamududu and Ngoma, 2020; Nikolaou et al., 2020). Another study also showed that CC could lead to a 140% increase in irrigation water demand while reducing production by up to 12% in the future (Durodola and Mourad, 2020). Additionally, rice productivity decreased by 3.5% for every 1 °C increase in global temperature (Malhi et al., 2021).

Irrigation governance by WUAs in the KKID area has followed the local governance scheme, which can be improved by involving related local stakeholders and water users in the decision-making process (Ricart et al., 2021). Although the new management and approaches have been adopted, failures are still widely encountered in irrigation water management, especially in mitigating or adapting to the impact of CC (Prosser et al., 2021).

The negative coefficient of production variable indicates that farmers had more tendency to increasingly prefer AM as paddy production increased. Table 2 shows that the paddy productivity of the AM was lower than that of SGM in the second harvest season. Although the rice productivity of the AM was lower, the productivity of the AM was relatively higher than that of the SGM in terms of CC magnitude.

The water fee coefficient was $-5.41\text{x}10^{-7}$ with an odds ratio of 1. The negative coefficient value indicates that as water fees increased, the WUA was more likely to choose the AM over the SGM. Regarding water fees, the total potential value of water fees for the AM was 740,337,599 IDR, which is greater than the total potential value of the SGM, which was only 85,547,849 IDR.

In addition, the results of the survey showed that 29 WUAs used cash payments for water fees. While cash payments were characteristic of the SGM, they were also found in both AM and SGM WUAs. Specifically, 26 WUAs using the SGM and 3 using the AM relied on cash payments. Similarly, while payment in goods or crops was typical of the AM, some SGM WUAs also accepted this form of payment. In total, 6 WUAs employing the AM and 11 employing the SGM used in-kind payments.

The variable of relative distance to the KKID main dam had a coefficient of 0.2 and was statistically significant at the 5% level. This coefficient value indicates that as the distance from the KKID main dam increases, WUAs are more likely to adopt the SGM. The odds ratio value for the relative distance variable was 1.221, suggesting that WUAs are 1.221 times more likely to choose the SGM over the AM as their distance increases. The relative distance variable not only

Table 3. Logistic regression estimation results of models employed by WUAs

Variables	β	exp(β)	*p*-value
Constant	-3.473	0.03	0.33
Rice production (X_1)	-0.199	0.82	0.09*
Distance from main weir (X_2)	0.153	1.17	0.03**
Water fees (X_3)	-5.41×10^{-7}	1	0.04**
Board members (X_4)	0.001	1	0.89
Managerial term duration (X_5)	1.251	3.49	0.22
McFadden	0.58	-	-
McFadden (adj)	0.30	-	-

Note: * = 10%; ** = 5% significance level

represents the WUAs' relative position to the KKID main dam but also reflects the location of the agricultural land they manage. It can be concluded that WUAs are more likely to prefer SGM as their distance from the KKID main dam increases.

The relative distance variable was unavoidable for WUAs in the KKID, as water volume and discharge decreased with increasing distance from the KKID main dam. Primary canals will provide a larger volume of water and greater discharge compared with secondary and tertiary ones (Li et al., 2018). Theoretically, agricultural areas closer to irrigation canals tend to have higher productivity and experience more structural transformations, such as population growth and economic shifts, compared to those farther away (Asher et al., 2022). However, in addition to the relative distance from the main dam, soil conditions and soil fertility also affect the productivity and structural–economic transformation of farms in an irrigated area. Soil salinity can affect farmers' distance to irrigation canals (Duan et al., 2022). Therefore, the distance variable, related to spatial uniformity and land fertility, affects the volume of irrigation water, irrigation efficiency, and economic conditions of irrigation areas (Howell, 2005).

The standard operating procedures in the SGM were different from those in the AM, particularly in terms of limited funding and water availability in the dry season. Therefore, limited resources were employed as the basis for the SGM in the downstream areas to determine perceptions of the impact of CC in the form of drought, which contrasted with the perceptions of other WUAs in the KKID. WUAs employing the SGM faced limited resource conditions with relatively more water problems compared with those employing the AM. CC mitigation and prevention measures were relatively low compared with the AM in terms of the number of working days in tertiary canals.

Irrigation water management has evolved from an "ulu-ulu" system—as was suggested by the government—to a system that is independently managed by farmer associations or groups. The establishment of WUAs is motivated by efforts to regulate water distribution effectively. However, despite these efforts, WUAs still face challenges in achieving full independence and sustainability (Rakhimov et al., 2020). The effects of limited resources and geographical conditions on the management and development of infrastructure are key points when considering WUAs' independence in the effort to distribute irrigation water to all farmers. The sustainability of WUAs or public-private institutional cooperation was influenced by the operation and condition of irrigation infrastructure and drainage (Gany et al., 2019). Training programs, especially those related to WUA management, play a crucial role in enhancing farmers' capacity to manage irrigation effectively, thereby contributing to the acceleration of agricultural sector progress (Mishra and Aithal, 2022).

The main objective of irrigation management in the KKID was to distribute water efficiently. However, besides the quantity of distributed water, its quality must also be considered, as CC affects irrigation water quality (Fahad et al., 2020). In response to ongoing CC around the world, WUAs, as irrigation water distribution institutions, must improve both irrigation water management and infrastructure. WUAs tend to respond to changes that occur around them, such as economic, institutional, and environmental changes, by conducting better management of water distribution organizations, adopting more efficient technology, renewing irrigation infrastructure, and maintaining water sources originating from highlands (Leroy et al., 2022). Improving irrigation management performance and crop productivity using irrigation water is crucial in addressing climate change, especially rising temperatures and humidity (El-Sanatawy et al., 2021). The improvement and enhancement of management performance and irrigation technology should be implemented through a far-reaching government policy, to develop irrigation technologies that can generate water reserves for rural needs (Wang et al., 2020).

The WUAs in the KKID have established a strategy in response to CC. The WUAs employing the SGM conducted more operational and maintenance activities, with a frequency of 180 days per year, whereas those employing the AM had an average frequency of 47 days. This shows that the SGM has a higher intensity of work completion compared with the AM. Maintenance work included the removal of silt and the clearing of trash from the tertiary canals. This suggests that the SGM was preferred over the AM in areas with a lot of silt due to CC.

Shifting planting time is one of the strategies that farmers can adopt in response to CC (Ding et al., 2020). In addition to shifting planting time, selecting appropriate cultivars can also help mitigate the effects of CC (Yan et al., 2020; Elnashar and Elyamany, 2023). CC can pose a risk to the users of water resources, especially for irrigation. There are three methods of overcoming CC risks: avoiding risks, such as through technological adaptation; transferring risks, such as through cooperation or collaboration with water source providers; and preventing risks, such as by reducing carbon gas emissions (Elnashar and Elyamany, 2023). Both the SGM and AM are methods that farmers can use to avoid the risks associated with CC.

CONCLUSIONS

There are two types of irrigation management models: the SGM, which is a community-based model, and the AM, which is a provider-based model. The AM was preferred from the perspective of higher production capacity, proximity to the main dam, and lower irrigation water fees. Furthermore, the SGM incurred greater expenses compared to the AM. This research suggests that community-based irrigation management is a form of local wisdom that can mitigate the effects of CC through providing operational and maintenance financing. In addition, community-based irrigation management serves as a social capital network that helps WUAs choose the most effective adaptation and adoption strategies for dealing with the impacts of CC. Social capital in the SGM is manifested in the cooperation among members for performing operational and maintenance activities.

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