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Determination of the Location of Kedungkandang Irrigation in Malang City Based on Soil Quality, Climate, and Availability Water Sources

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Abstract

This study aims to determine the location of Kedungkandang irrigation in Malang City by considering three main factors, namely soil quality, climate conditions, and availability of water sources. Kedungkandang irrigation, which has been operating since the Dutch colonial era, has an important role in supplying water to agricultural land in South Malang until now. This study uses direct observation methods, archival documentation, and interviews with experts to identify these factors. The results of the study indicate that good physical soil quality, supportive climate conditions, and stable water availability are the keys to the success of irrigation operations for more than a century. In addition, factors such as the type of crops irrigated and the direction of city development also have an impact on the sustainability of irrigation. This study provides important insights into the importance of proper planning in selecting irrigation locations to ensure the sustainability of infrastructure in the future.

Article Info

Keywords:
Kedungkandang Irrigation;
Soil Quality;
Water Availability;
Climate Conditions;
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1. Introduction

Irrigation is one of the key elements in supporting agricultural productivity, especially in areas with limited access to natural water sources. As global food demand increases, irrigation becomes a strategic solution to ensure adequate water supply for agriculture, especially in countries that depend on agriculture such as Indonesia. In Indonesia, well-managed irrigation systems have played an important role in supporting food security and local economies, as well as contributing to poverty alleviation, especially in areas that experience long dry seasons and rely on artificial irrigation to meet their water needs (Hussain et al., 2006). Water scarcity and competition from non-agricultural users pose significant challenges to irrigation practices (Pereira, 2005). However, innovations in irrigation technology such as optimized control systems can improve the efficiency of water use and crop management (Bradbury et al., 2009). Thus, effective irrigation systems not only support agricultural productivity but also play a significant role in rural development and poverty reduction in developing countries (Chaturvedi, 2000). One of the irrigation systems that is still operating well today is the Kedungkandang Irrigation located in Malang City, East Java. Built by the Dutch colonial government in the early 20th century, the Kedungkandang Irrigation has a main channel length of around 27.2 kilometers and was designed to support agricultural land in the South Malang area (Widira et al., 2023). This irrigation is part of the Dutch ethical political policy which aims to improve the welfare of the indigenous population through the development of agricultural infrastructure, including irrigation systems, in order to increase local food production (Maharani et al., 2023). This irrigation system not only plays a role in providing water for agricultural land, but is also part of the history of

good regional planning inherited from the colonial era.

Even though it has been operating for more than a century, the Kedungkandang Irrigation is still functioning optimally, especially in providing water supply for agriculture in the South Malang area. The success of this irrigation cannot be separated from careful planning, both in terms of location selection, construction materials, and periodic maintenance that continues to be carried out to this day. The selection of irrigation locations is a crucial factor in determining the future viability of this infrastructure, where locations are selected based on their proximity to natural water sources such as rivers, ensuring a reliable water supply (Nita et al., 2024). In addition, soil quality and topographic conditions that support effective water flow to agricultural lands are also major considerations (Nita et al., 2024). Carefully selected construction materials and designs adapted to local environmental conditions contribute to the longevity of this irrigation system (Paryanto et al., 2022). Regular maintenance carried out to date is essential to address wear and tear and ensure the infrastructure remains functional (Widira et al., 2023).

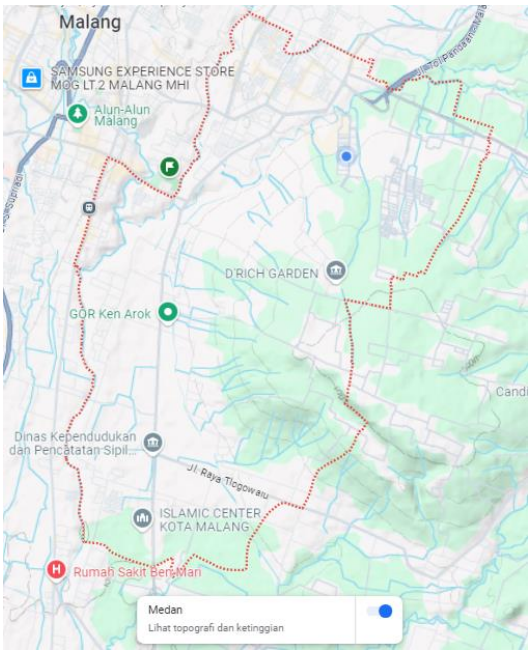

Figure 1. Topographic Map of Kedungkandang Area
Source: (Kota, 2019)

This study aims to identify and analyze the main factors that influence the selection of Kedungkandang irrigation locations. The main focus of this study is on three important factors, namely physical soil quality, climate conditions, and availability of water sources. Good soil quality, such as effective drainage, soil water retention capacity, and resistance to erosion, are key to the long-term success of irrigation infrastructure. Poor soil quality can cause structural failure of irrigation channels and reduce their effectiveness in providing water to agricultural land.

In addition to soil quality, climate factors also play an important role in determining the effectiveness of irrigation systems. A stable climate with adequate rainfall throughout the year ensures that the water supply channeled through the irrigation system remains constant, especially during the dry season. Research shows that the climate conditions in the South Malang area, which is included in the wet tropical climate zone, are very supportive of the sustainability of Kedungkandang irrigation. Consistent rainfall in this area, with an annual average of around 2000-3000 mm, reduces the need for additional irrigation during the dry season and allows for more efficient water management (Suleyman, 2024). In addition, adequate rainfall has a direct correlation with increased crop yields, especially for staple crops such as rice and corn that thrive in this climate (Syaranamual et al., 2024). However, although stable climate conditions are very beneficial, extreme weather events such as floods remain a challenge, so adaptive management strategies are needed in agriculture to overcome their negative impacts (Purnama et al., 2024).

The availability of stable water sources is also a key factor in maintaining the sustainability of Kedungkandang irrigation. The main water sources that support this irrigation system are the Amprong River and the Kalisari River, which have a large enough water flow to support irrigation operations throughout the year. The water discharge from these rivers is quite stable, even during the

dry season, thus ensuring sufficient water supply for agriculture in the South Malang area (Nita et al., 2024). This condition is very different from other areas in Indonesia that often experience water crises during the dry season, such as Amarasi which experiences critical water shortages and causes a decline in agricultural productivity (Lano et al., 2024). The stable water discharge from the Amprong and Kalisari Rivers also allows for several planting cycles, which ultimately increases food security and farmer incomes in this area (Sudianto et al., 2024).

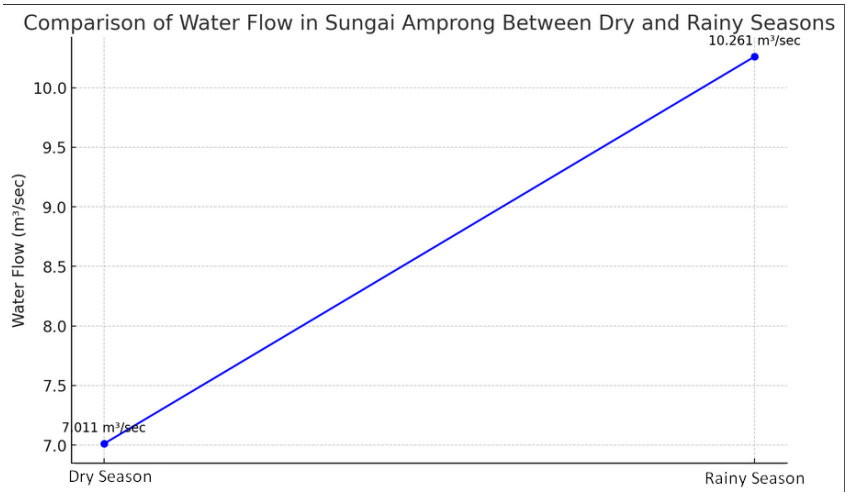

Figure 2. Grafik Debit Air Sungai Selama Musim Kemarau dan Musim Hujan
Source: (*Kecamatan Lowokwaru Kota Malang*, n.d.)

Furthermore, this study also highlights how urbanization and urban development around irrigation areas can impact the sustainability of irrigation infrastructure. Along with the increasing rate of urbanization in Malang City, agricultural lands that were previously irrigated by Kedungkandang irrigation have now been converted into residential and industrial areas. This land conversion has the potential to reduce irrigation capacity in providing water for agriculture, because there is less land that requires water supply (Amaya et al., 2024). In Malang City, existing spatial planning has not been fully effective in protecting agricultural land, and community participation in such planning is also still limited (Pujianti et al., 2024). Therefore, a mature and more comprehensive spatial planning policy is needed to protect the remaining agricultural lands and ensure that Kedungkandang irrigation continues to function optimally in the future (Afuw et al., 2024).

Uncontrolled urbanization can also affect the quality of water sources used by irrigation systems. Increased development around irrigation areas often causes water pollution, either through household or industrial waste. Research shows that almost 90% of large cities face the risk of declining water quality due to population density and urban runoff carrying pollutants (Liu et al., 2024). The accumulation of pollutants in urban areas worsens runoff which ultimately degrades water quality in nearby irrigation sources (Felli et al., 2024). Therefore, it is important to include environmental considerations in spatial planning so that water sources used by irrigation remain clean and suitable for long-term use. This study also highlights the importance of sustainable urban drainage systems that can better manage rainwater and mimic pre-urban hydrological conditions to protect water resources (Felli et al., 2024).

In addition, urban development also affects people's access to water. When agricultural areas are converted into housing and industry, the need for water for household and commercial needs increases, which in turn can reduce water flow to agricultural lands. Intensive urbanization increases competition between the agricultural and non-agricultural sectors in terms of water resource use, where studies show that urban growth often threatens water availability for the agricultural sector, especially in areas experiencing water stress (Pandya & Sharma, 2023). Socio-economic factors also affect water independence in the agricultural sector, resulting in decreased productivity in the region (Huang et al., 2023). Therefore, sustainable and integrative planning is needed, such as the water-energy-food nexus approach, to ensure that water needs for agriculture are met amidst increasing water needs in other sectors (Kitessa et al., 2022).

In a broader context, this study makes an important contribution to understanding how environmental, social, and economic factors interact to determine the sustainability of irrigation

infrastructure. This research is expected to be a basis for policy makers to formulate better water resources management strategies, especially in areas undergoing rapid urbanization. This research also provides practical insights for regional planners and water resources managers about the importance of considering the long-term impacts of land use changes on irrigation systems.

Background

Agriculture is the main sector that supports economic and social life in Indonesia. As an agricultural country, most of Indonesia's population depends on the agricultural sector for their livelihood. However, one of the biggest challenges faced by farmers is the availability of sufficient water to support agricultural activities, especially during the dry season. This is where the role of the irrigation system becomes very important, because irrigation provides the water supply needed to ensure that crops can grow well throughout the year. The irrigation system reduces farmers' dependence on rainfall which is often unpredictable, so that agricultural productivity is more guaranteed and food security can be better maintained (Aldyan, 2023). Thus, irrigation is key to supporting the livelihoods of most of Indonesia's population who depend on the agricultural sector for their livelihood (Feni et al., 2024). The increasing demand for water due to population growth and changes in land use are increasingly burdening existing water resources, so water management is a challenge that needs to be overcome through innovative irrigation solutions (Aldyan, 2023).

One of the oldest and most important irrigation systems in East Java is the Kedungkandang Irrigation, which was built in 1904 and completed in 1915 by the Dutch colonial government. This irrigation was designed to irrigate agricultural lands in South Malang. The construction of irrigation infrastructure at that time was part of the Dutch ethical policy, which aimed to improve the living conditions of the indigenous population through infrastructure development, including irrigation (Tan, 2024). The Kedungkandang Irrigation is one example of the success of this program, where to this day, the irrigation still functions well in supplying water to agricultural lands in the region, contributing to sustainable agricultural productivity for decades (Nawiyanto et al., 2024). In addition, this system plays an important role in improving food security and economic stability in the South Malang area (‘Izza et al., 2023).

The importance of the Kedungkandang Irrigation to the local community cannot be overstated. In addition to playing a role in increasing agricultural productivity, this irrigation has also contributed to the economic stability of the region. With reliable irrigation, farmers can manage their land more effectively, even during the dry season, reducing the impact of seasonal droughts that often hit the South Malang area (Sudianto et al., 2024). Consistent irrigation allows farmers to grow crops throughout the year, reducing dependence on erratic rainfall and ensuring stable yields (Malahayati et al., 2024). Local economic stability also increases, as farmers are able to produce more crops and reduce operational costs, including by adopting more efficient irrigation technologies such as the use of solar energy (Sudianto et al., 2024). However, challenges in terms of maintenance and community participation in irrigation management still need to be considered to maintain the sustainability of this irrigation system in the future (“Community Participation in the Maintenance of Agricultural Irrigation Network in the Ciburo Nagari Suayan Area, Fifty Kota Regency,” 2023).

Although this irrigation system has been functioning well for more than a century, new challenges continue to emerge, particularly related to environmental changes and urbanization. Rapid population growth and urbanization in Malang City have resulted in the conversion of agricultural land into residential and industrial areas, resulting in a substantial decrease in agricultural land (Darmawan et al., 2024). This conversion not only reduces the area of land irrigated but also increases pressure on water resources. The transport coefficient, which indicates the efficiency of water runoff, has increased significantly, reflecting the adverse effects of land-use change on water management (Darmawan et al., 2024). In addition, urbanization often causes increased water pollution, both from household and industrial waste, which has the potential to reduce the quality of water used for irrigation (Heryanda, 2022). These challenges require special attention to maintain water quality and irrigation functions in the long term.

The physical conditions of the environment around the irrigation canals have also changed significantly over time. Climate change that has occurred in recent decades has caused changes in rainfall and temperature patterns, which have a direct impact on the availability of water in the rivers that supply the Kedungkandang Irrigation. Decreased rainfall and longer dry seasons have significantly reduced the water supply available for irrigation, thus affecting agricultural yields in the area (Arboleda et al., 2024). To maintain optimal irrigation performance, adaptation strategies are

needed such as rehabilitation of irrigation canals, which can improve functionality and ensure that the canals are able to meet increasing water needs (Garin et al., 2024). In addition, the application of a dynamic irrigation scheduling model can help optimize water use and reduce losses, so that it can adjust to the variability of water availability due to climate change (Kloss-Weber, 2022).

In addition, the quality of the soil in the area irrigated by the Kedungkandang Irrigation also plays an important role in determining the success of this irrigation system. The South Malang area is known to have fertile soil, but changes in land use and unsustainable agricultural practices can damage soil structure, reducing the soil's ability to absorb and store water. Soil degradation due to unsustainable agricultural practices, such as compaction and erosion, can significantly reduce the water retention capacity of the soil (Thompson-Morrison et al., 2023). Damaged soil increases the risk of erosion, which in turn can reduce the effectiveness of irrigation systems in supplying water (Rafki et al., 2024). Therefore, the implementation of sustainable land management practices is essential to maintain soil quality and ensure that irrigation systems remain effective in the long term (Maharani et al., 2023). Involving local communities in irrigation management is also an important step to prevent soil degradation and improve system maintenance (Rafki et al., 2024).

Overall, the background of this study emphasizes the importance of Kedungkandang Irrigation in supporting agricultural sustainability in the South Malang area. This study also underlines new challenges arising from environmental and social changes, including urbanization, climate change, and soil degradation. In facing these challenges, appropriate policies and sustainable water resource management strategies are needed to ensure that this irrigation can continue to function well and provide benefits to local communities.

2. Methods

Research Methods

This study uses a qualitative approach with observation, interview, and documentation methods. Data collection was carried out through direct observation along the Kedungkandang irrigation channel, which covers the areas of Kedungkandang, Tajinan, Bululawang, Gondanglegi, and Pagelaran Districts. Interviews were conducted with experts in the fields of regional planning, irrigation engineering, and representatives from related agencies to understand the factors that influence the selection of irrigation locations. Data analysis was carried out using qualitative descriptive methods to explain how each factor contributes to the sustainability of the irrigation system.

Research Design

This study uses a qualitative descriptive research design, with a case study approach to understand the factors that influence the determination of the location of Kedungkandang Irrigation in Malang City. This design was chosen because it allows researchers to dig up in-depth information related to the phenomenon being studied, especially related to aspects of soil quality, climate, and water availability. The main focus of this study is to analyze how these factors affect the sustainability of irrigation in supporting agricultural productivity in South Malang. This research design consists of several stages, namely:

1. Collection of primary and secondary data through direct observation in the field, interviews with experts, and document analysis.
2. Qualitative descriptive data analysis, where the data obtained will be processed and analyzed in depth to understand the relationship between these factors and irrigation operations.
3. Preparation of a research report, which includes an explanation of field findings, interviews, and data analysis conducted.

Population and Sample

This study was conducted with a population covering the entire area traversed by the Kedungkandang Irrigation, which stretches from Kedungkandang District to Pagelaran in Malang City. Given the importance of obtaining relevant data from various perspectives, purposive sampling technique was used to select respondents who have direct knowledge and experience related to the irrigation system. The selection of respondents was carried out by considering their involvement in the management, utilization, and technical understanding of irrigation. With this approach, the study is expected to provide in-depth insights into various aspects that affect the sustainability of irrigation, both from a technical, social, and environmental perspective.

The research sample consisted of ten people selected based on their different but complementary backgrounds. Farmers who own land along the irrigation channel were selected as part of the

respondents. They have direct experience in using water from the Kedungkandang Irrigation to support their daily farming. Their views are important to understand the challenges in the field, such as uneven water availability or the potential for decreased water discharge due to the long dry season. With their insights, this study can reveal how irrigation plays an important role in maintaining local agricultural productivity.

In addition to farmers, the study also involved officials from the irrigation department who are responsible for managing and maintaining the irrigation system. They have a deep understanding of the physical condition of the irrigation channels and the policies implemented to ensure fair and efficient water distribution. Interviews with these officials will provide information on challenges in irrigation maintenance, such as channel damage or needed repairs, and how environmental changes, such as urbanization, impact irrigation performance. By involving them, the study is able to dig deeper into the government's efforts to keep irrigation infrastructure functioning optimally.

Academic perspectives are also invaluable in this research. Academics with expertise in irrigation engineering and regional planning were selected to provide technical analysis on factors affecting the sustainability of Kedungkandang Irrigation. They can provide scientific perspectives on the role of soil quality, climate conditions, and water resources in determining irrigation effectiveness. In addition, they can also help identify potential innovative solutions to address emerging issues, such as the use of technology to improve the efficiency of water distribution. Thus, academic input will enrich the analysis and provide a strong theoretical basis for this research.

This study also involved community leaders involved in irrigation management organizations. As community representatives, they have social and cultural views on irrigation use in the area. Their involvement is important to understand the social dynamics related to water distribution and possible conflicts between users. In addition, their views can help reveal how local communities adapt to environmental changes and increasing urbanization pressures. These perspectives provide a rich social dimension to the study, thus reflecting the role of irrigation in people's daily lives.

Finally, dam managers who are responsible for distributing water from rivers to irrigation channels were also selected as key respondents. They have deep insight into how irrigation systems are technically operated, including the challenges of maintaining stable water flows throughout the year. These managers can provide valuable information on how water availability is monitored, as well as the steps taken to ensure that water needs for agricultural land are met. With their involvement, this study will gain a clearer picture of the technical aspects of water management in the region.

The respondents selected in this study reflect the diversity of roles and responsibilities related to the operation of Kedungkandang Irrigation. Each group of respondents provides a unique and important perspective, both in terms of technical, social, and environmental. By involving farmers, irrigation officials, academics, community leaders, and dam managers, this study can produce a comprehensive and multidimensional analysis of the irrigation system that has been functioning for more than a century.

Data Collection Techniques

Data were collected through three main methods, namely observation, interviews, and documentation. Observations were made by observing the physical condition of the irrigation channels and the surrounding areas through which the Kedungkandang irrigation passes, in order to understand the influence of topography, soil quality, and climate on irrigation. Interviews were conducted in depth with experts who have experience in irrigation management and regional spatial planning. Documentation was used to collect secondary data from various sources such as technical reports, topographic maps, and historical documents related to the construction of the Kedungkandang Irrigation.

Data obtained from observations, interviews, and documentation were analyzed using qualitative descriptive analysis methods. This analysis includes systematic interpretation of data to understand how physical soil quality factors, climate conditions, and water availability affect irrigation sustainability. Data from interviews were processed using triangulation techniques to validate information obtained from various sources. In this analysis, researchers also considered external variables, such as the impact of urbanization and climate change, which can affect the sustainability of irrigation systems.

3. Results and Discussion

Results

This study revealed that the physical quality of the soil is one of the main factors influencing the selection of the Kedungkandang Irrigation location. The South Malang area is dominated by Andosol and Latosol soil types, which have good drainage characteristics. These characteristics allow water to flow smoothly to agricultural land, minimizing the risk of erosion and structural damage to irrigation channels. In addition, soil with good water retention capacity is essential to maintain soil moisture longer, especially during the dry season. The results of interviews with local farmers support this finding, with farmers acknowledging that the irrigation system is very helpful in maintaining agricultural productivity, especially during the dry season. However, they also identified challenges related to the uneven distribution of water in some areas, especially during the dry season.

Table 1. Interview Results with Farmers

No.	Question	Respondent 1	Respondent 2	Respondent 3
1	How does the Kedungkandang irrigation system help your agricultural productivity?	"Very helpful, especially during the dry season"	"Main source of water during dry season"	"Important to maintain yields throughout the year"
2	Are there any challenges related to water distribution?	"Sometimes the distribution is uneven"	"Often lack of water during dry season"	"There is competition for water with other farmers"
3	How does urbanization impact irrigation?	"Land conversion reduces water availability"	"Increased water pollution from residential areas"	"Lack of water due to new housing developments"
4	What are the suggestions for irrigation improvement?	"Repair irrigation channels upstream"	"Increased maintenance of channels"	"Need better management in the dry season"

Source: Processed Data by Researchers

In addition to soil quality, climate conditions in the South Malang area also play a key role in maintaining the sustainability of the irrigation system. The average annual rainfall reaches 2000-3000 mm, making this area very suitable for year-round agriculture. Stable rainfall patterns ensure sufficient water supply during the rainy season to support irrigation operations. However, when the dry season arrives, the sustainability of water supply is highly dependent on the availability of water from the Amprong River and Kalisari River, which are the main sources of water for irrigation. From interviews with irrigation department officials, it was found that although the water discharge from these rivers is quite stable, there are challenges in maintaining even water distribution, especially when the water discharge decreases.

Table 2. Interview Results with Irrigation Service Officials

No.	Question	Respondent 1	Respondent 2
1	What is the current physical condition of the Kedungkandang irrigation channel?	"Good condition, but needs regular maintenance"	"Some channels have started to deteriorate, especially downstream"
2	How is water distribution managed?	"Water is distributed according to schedule"	"Water distribution is limited during the dry season"
3	What are the challenges in managing irrigation?	"Urbanization narrows irrigation land"	"Lack of resources for channel repair"
4	What steps are taken to maintain the sustainability of irrigation?	"Gradual improvement of channel infrastructure"	"Increased cooperation with local communities"

Source: Processed Data by Researchers

This study also found that rapid urbanization in the Malang City area poses a major challenge to the sustainability of irrigation. The conversion of land from agriculture to housing and industry has caused a decrease in the area of land irrigated by the Kedungkandang irrigation system. Agricultural

land that previously received irrigation water is now decreasing, resulting in competition in terms of water use between the agricultural and non-agricultural sectors. This challenge is reinforced by the results of interviews with academics who stated that urbanization has the potential to pollute irrigation water sources, especially due to household and industrial waste.

Table 3. Interview Results with Academics

No.	Question	Respondent 1	Respondent 2
1	What factors influence the selection of irrigation locations?	"Soil quality, topography and climate"	"Water availability and soil conditions"
2	How does urbanization affect Kedungkandang irrigation?	"Urbanization reduces water flow and worsens pollution"	"Land conversion narrows irrigation space"
3	How to overcome the challenges of irrigation sustainability?	"Spatial planning must be stricter"	"Better water management is needed in the dry season"

Source: Processed Data by Researchers

In addition, interviews with community leaders showed that local communities have an important role in managing irrigation water. They participate in village meetings and are involved in water management organizations to address potential conflicts in water distribution. However, conflicts related to water distribution still arise, especially during the dry season when water supplies are limited.

Table 4. Results of Interviews with Community Leaders

No.	Question	Respondent 1	Respondent 2
1	How are local communities involved in irrigation management?	"Through village deliberations"	"There is a water management organization"
2	Are there conflicts related to water distribution?	"Sometimes there are conflicts during the dry season"	"Conflicts often arise over water distribution"
3	Suggestions for increasing community participation	"Involving more residents in management"	"Education about the importance of maintaining irrigation"

Source: Processed Data by Researchers

Finally, interviews with dam managers revealed that the water discharge from the Amprong and Kalisari Rivers is quite stable, but there are challenges in maintaining even water distribution along the irrigation channels. Dam managers conduct regular monitoring to ensure that the water supply remains sufficient, especially during the dry season.

Table 5. Results of Interview with Dam Manager

No.	Question	Respondent 1
1	How is the condition of water flow from the river to the irrigation channel?	"Water discharge is quite stable, but decreases during the dry season"
2	What are the challenges in distributing water to agricultural land?	"Difficulties during the dry season, especially in ensuring even distribution"
3	Steps taken to maintain smooth water distribution	"Regular inspection and arrangement of water distribution schedules"

Source: Processed Data by Researchers

This study emphasizes the importance of mature spatial planning and sustainable water resource management to maintain the sustainability of irrigation. In addition, water quality monitoring and proper irrigation channel maintenance need to be carried out periodically to ensure that the Kedungkandang irrigation system continues to function optimally amidst the growing environmental and social challenges.

Discussion

The results of this study indicate that soil physical quality is one of the key factors influencing the selection of the Kedungkandang Irrigation location in Malang City. Andosol and Latosol soil types in this area play a vital role in supporting irrigation infrastructure due to their good drainage properties.

Andosol, with its high water retention and drainage capabilities, helps reduce the risk of erosion that can damage irrigation channels (Fuadi et al., 2024). Effective drainage also ensures even distribution of water throughout the agricultural land, increasing crop productivity and the sustainability of the irrigation system (Rafki et al., 2024). In addition, maintaining soil quality is not only important for plant growth but also for the sustainability of the irrigation system itself, as well-managed soil helps reduce erosion and maintain irrigation efficiency (Suleyman, 2024).

Soil texture that allows water to flow smoothly is very beneficial, especially during the dry season when water is a very limited resource. Farmers in this area depend on consistent water availability from the irrigation system to maintain their crop productivity. Soils with good water retention, such as clay soils that have superior moisture retention capacity compared to sandy soils, allow crops to survive longer during periods of no rainfall (Mhimdi et al., 2024). This explains why farmers experience direct positive impacts from efficient irrigation systems, especially during the dry season. Effective irrigation scheduling can also improve water productivity and crop resilience under drought conditions (Maurya et al., 2024). Therefore, maintaining soil and irrigation canal conditions is a top priority in water resource management.

In addition to soil quality, climate conditions are also a determining factor in the sustainability of the irrigation system. The climate conditions in South Malang are very supportive of the Kedungkandang irrigation system due to the high annual rainfall. The stable average rainfall of between 2000-3000 mm per year ensures sufficient water supply for the irrigation system (Nita et al., 2024). This stability is important to maintain the sustainability of water supply during the rainy season and replenish natural water sources used during the dry season (Suleyman, 2024). However, challenges arise during the dry season, when water availability is significantly reduced. Therefore, irrigation system management must be adaptive to these seasonal changes to maintain effective water distribution and reduce the impact of water scarcity on agriculture (Azmanajaya et al., 2024).

The effects of climate change are becoming increasingly pronounced, affecting rainfall patterns and increasing the frequency of extreme weather phenomena such as droughts and floods. These changes require dynamic adaptation strategies in water resource management. Changing rainfall patterns and rising temperatures are projected to increase water demand across sectors, putting pressure on already limited resources (Parvaze et al., 2023). Effective management requires a deep understanding of long-term weather patterns and the use of technology to monitor and respond to fluctuations in water resources. Advanced monitoring systems are essential for forecasting water needs and assessing drought risk, allowing for more equitable distribution of water for irrigation (Ciampittiello et al., 2024). With such systems, it is hoped that water distribution for irrigation will be more effective, even during extreme weather conditions, reducing the risk of future water shortages (Arboleda et al., 2024).

Table 6. Rainfall Forecast for the 2023-2024 Rainy Season in East Java Province

Rainfall	City/District	Sub-District
1501-2000 mm 7 ZOM (9,5%)	Malang City	Blimbing, Kedungkandang, Klojen, Lowokwaru, and Sukun

Source: (Ii, 2023)

One of the interesting findings of this study is the impact of increasingly rapid urbanization in the Malang area, which poses a major challenge to the sustainability of irrigation. Agricultural land that was previously irrigated by irrigation systems is now widely converted into residential and industrial areas. The results of interviews with academics stated that urbanization not only reduces the area of land that requires water from irrigation, but also worsens water pollution in rivers that are the main source of irrigation. Urbanization causes waste from settlements and industry to pollute water flows, which in turn reduces the quality of water used by farmers.

Urbanization also affects people's access to water. The need for water for domestic and industrial purposes increases along with population growth and housing development. This creates competition for water use between the agricultural and non-agricultural sectors. Community leaders interviewed stated that conflicts often arise over water distribution, especially during the dry season, when water availability is reduced. They also suggested increasing community participation in irrigation management to address these conflicts and ensure that farmers' interests are prioritized.

On the technical side, dam managers also face challenges in maintaining even water distribution.

Although the water discharge from the Amprong River and Kalisari River is quite stable throughout the year, they admit that during the dry season, water distribution becomes more difficult. In interviews, managers mentioned that they regularly monitor the irrigation channels to ensure that water is distributed properly, but they also need support in terms of infrastructure maintenance to keep it optimal.

Facing the challenges posed by changing soil and climate conditions, adaptation strategies are essential. Proactive and innovative policies need to be implemented to sustainably manage and utilize soil and water resources. This includes the use of modern, more efficient irrigation technologies, such as drip irrigation systems or sensor-based irrigation that can optimize water use. In addition, it is important to integrate weather and climate data into irrigation planning systems to more accurately predict water needs. The application of these techniques will increase the adaptive capacity of irrigation systems to changing climate and soil conditions.

Education and training for irrigation managers and farmers on sustainable water resource management practices is vital. Workshops and seminars can be used as a platform to disseminate knowledge on efficient irrigation techniques and sustainable land management. This increased awareness and skills will help local communities better manage their resources, which in turn will increase resilience to climate fluctuations and sustainable resource use. Inter-sectoral collaboration between government, the private sector, academic institutions and civil society needs to be strengthened to support these initiatives. Through this collaborative and integrated approach, the Kedungkandang irrigation system can continue to support agriculture in the region despite increasingly complex environmental challenges.

4. Research Implications

Practical Implications

In practical terms, the results of this study provide important insights for local governments and related agencies regarding the importance of maintaining agricultural areas irrigated by the Kedungkandang Irrigation. The government needs to strengthen spatial planning policies that protect agricultural land from conversion to non-agricultural areas. In addition, routine maintenance and improvement of irrigation infrastructure need to be carried out to ensure that irrigation channels continue to function optimally amidst environmental changes and urbanization. This study also encourages irrigation agencies to continue to monitor water quality and the physical condition of channels to prevent a decrease in irrigation capacity. For farmers, the results of this study emphasize the importance of adaptation in choosing types of crops that are appropriate to the availability of water in irrigation areas.

Theoretical Implications

From a theoretical perspective, this study enriches the literature on irrigation management and sustainable infrastructure planning, especially in tropical areas with relatively stable climate conditions. This study also highlights the importance of considering environmental factors, such as soil quality and water sources, in long-term irrigation infrastructure planning. The irrigation planning model used in this study can be a reference for similar studies in other areas that have similar challenges. In addition, this study contributes to the understanding of the relationship between regional planning, irrigation sustainability, and urbanization, which is increasingly relevant with the increasing pressure on water resources in developing cities.

Social Implications

From a social perspective, this study shows that irrigation sustainability not only impacts the agricultural sector, but also the welfare of communities around the irrigation area. Kedungkandang irrigation has been a source of livelihood for thousands of farmers for more than a century, and the decline in irrigation capacity due to urbanization could threaten local food security. The results of this study provide encouragement for the government and community to work together to protect water resources and agricultural land. In addition, this study opens up discussions about the importance of community involvement in irrigation planning and management to ensure that the interests of agriculture and urbanization can be balanced sustainably.

Policy Implications

The policy implications of this study are significant, especially in the context of water resources planning and management in Malang City. The results show that effective irrigation location and

management require policies that are based on empirical research on soil quality and hydrological conditions. This suggests that existing policies need to be adjusted to improve the efficiency and sustainability of existing irrigation systems, as well as in planning new systems.

Furthermore, the findings on the impact of urbanization on water resources suggest the need for stricter spatial planning policies to protect agricultural land from urban expansion. Recommendations for developing new policies may include restrictions on the conversion of agricultural land to other uses and improving infrastructure to address pollution. This will help ensure that irrigation remains effective and can support local agricultural needs despite urban pressures.

Economic Implications

From an economic perspective, the efficiency of the Kedungkandang irrigation system has direct implications for agricultural productivity, which is the backbone of the local economy. This study shows that investment in good irrigation systems and efficient water resource management can significantly increase agricultural output. This highlights the importance of allocating adequate financial resources for the maintenance and improvement of irrigation infrastructure.

This study also provides a basis for cost-benefit analysis in the implementation of new irrigation technologies and more efficient water management methods. Increased efficiency can reduce long-term operational costs and improve the economic sustainability of agriculture in the region. Therefore, investment in advanced irrigation technologies should be seen as a strategic move that can reduce the economic risks faced by agricultural communities.

Environmental Implications

The findings of this study on the interactions between soil quality, water availability, and climate conditions provide important insights into the environmental implications of irrigation systems. By adapting more sustainable irrigation practices, negative impacts on the environment can be reduced, such as reduced soil erosion and increased groundwater retention. This highlights the importance of strengthening responsible natural resource management practices.

Furthermore, the results of the study emphasize the need to protect water sources from the impacts of urbanization and industrial contamination. This includes implementing mitigation strategies to manage and control pollution of water sources that can affect water quality for irrigation. These measures not only support environmental sustainability but also ensure safe water quality for agriculture and human consumption.

Technology Implications

The findings of this study on the Kedungkandang irrigation system open up huge opportunities for the application of more advanced irrigation and water management technologies. The application of technologies such as weather sensors, smart irrigation systems, and remote monitoring technologies can dramatically improve the efficiency of water use. These technologies not only ensure more accurate and timely water distribution but also help in early detection of infrastructure damage or leakage, which can be immediately addressed to avoid wastage of resources.

Furthermore, the integration of information and communication technologies in irrigation management systems allows for better data collection and stronger evidence-based decision-making. The data collected from these technologies can be used for predictive analytics that aid in long-term water resource planning and response to climate change. The use of AI and machine learning to optimize water allocation and use can revolutionize the way we manage agricultural water resources.

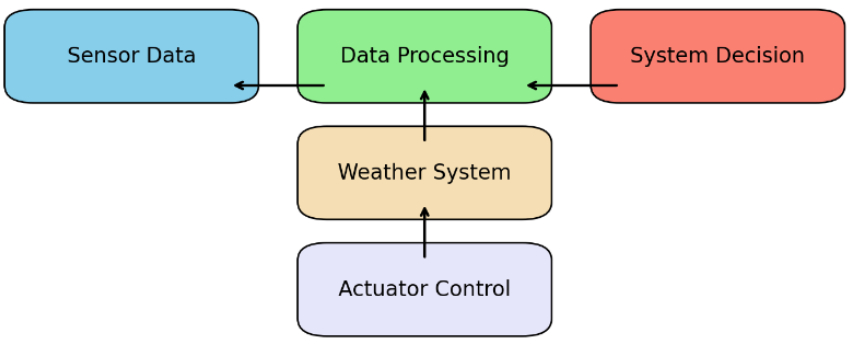

Figure 4. Flowchart of Smart Irrigation System Integration
Source: Researchers

Health Implications

The study also highlights the health implications of effective water resource management, especially in the context of providing clean and safe water for agricultural purposes and human consumption. Contaminated irrigation water can carry pathogens and pollutants to crops that are ultimately consumed by humans, causing a variety of health problems. Therefore, good irrigation systems are not only important for productivity but also to prevent public health risks.

Improving water quality through improved water management and treatment technologies can reduce the prevalence of water-related diseases. Initiatives such as filtration, disinfection, and irrigation systems that reduce direct contact of crops with surface water can strengthen public health. Public health education on safe water use and hygienic agricultural practices are essential components that should be included in agricultural development programs.

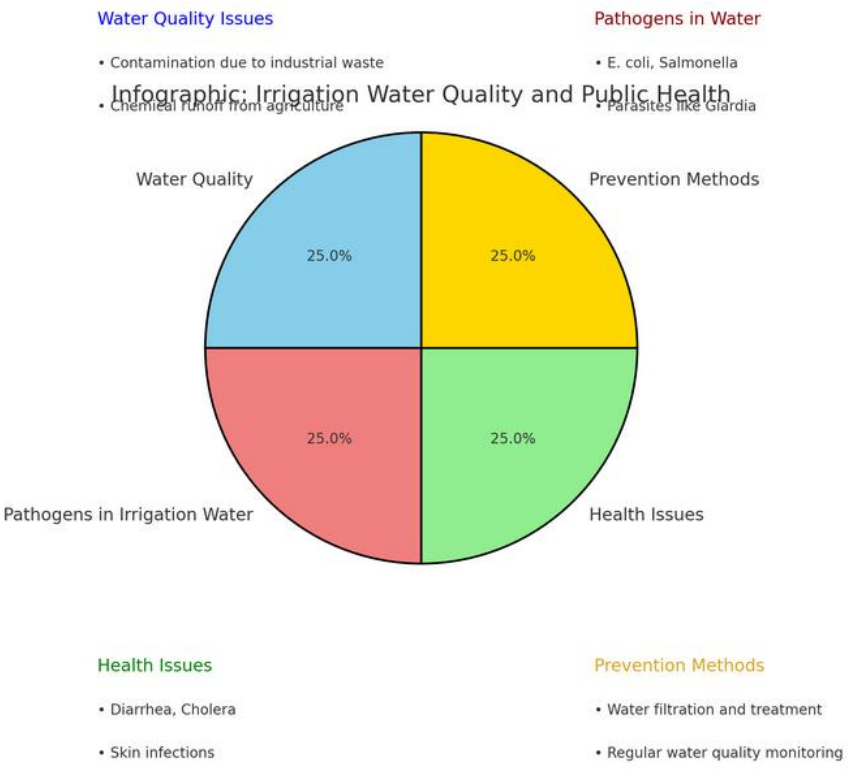

Figure 5. Picture Caption
Source: Researchers

Educational Implications

This study underscores the need for integration of education in irrigation and natural resource management, strengthening curricula in educational institutions that include studies on sustainable water management and efficient agricultural practices. Enhanced education and training for farmers, irrigation managers, and policy makers can strengthen the understanding and application of best practices in irrigation. These educational programs should emphasize emerging technologies, sustainability, and adaptation to climate change.

Focused educational programs can also promote further research and development in irrigation technologies, enabling future generations of engineers and technicians to continue innovating. Collaborations between universities, research institutions, and the agricultural sector can create a strong platform for knowledge and technology transfer. These educational initiatives can directly influence the way local communities manage natural resources and strengthen their resilience to environmental and socio-economic pressures.

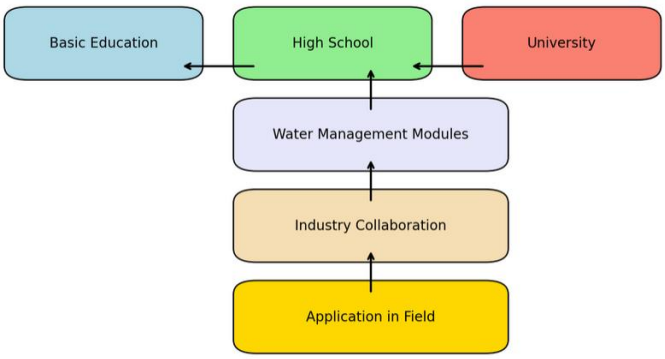

Figure 6. Flowchart of Education and Training in Water Resources Management
Source: Researchers

5. Conclusion

Conclusion

This study shows that the sustainability of the Kedungkandang irrigation system in Malang City is largely determined by three key factors: soil quality, climate, and water availability. The area's soil, consisting mainly of Andosol and Latosol, has good drainage and water retention capabilities, which are vital for preventing erosion and maintaining infrastructure. Additionally, the South Malang climate, with 2000-3000 mm of rainfall annually, helps sustain water availability throughout the year. Despite this, water distribution during the dry season poses a challenge, with limited water impacting agricultural productivity.

Urbanization in Malang City adds new pressures to the Kedungkandang irrigation system. Agricultural land once irrigated by this system is now being converted into residential and industrial areas, reducing the need for irrigation. Urbanization also leads to increased pollution from household and industrial waste, which lowers water quality and negatively impacts agricultural productivity. This shows that urbanization not only reduces farmland but also affects water availability and quality.

Community participation in irrigation management is crucial to ensuring the system's sustainability. Local involvement in decision-making and water management helps address conflicts over water distribution, particularly during the dry season. However, disputes still arise when water supplies are limited, highlighting the need for stronger community involvement and more robust spatial planning policies. With a more inclusive approach, the sustainability of the Kedungkandang irrigation system can be better maintained in the face of environmental and social changes.

This research provides valuable insights for policymakers and irrigation managers on the importance of maintaining soil quality, climate conditions, and water availability. Addressing the challenges posed by urbanization and environmental changes requires more adaptive spatial planning and water resource management. These findings are not only relevant for irrigation managers but also for the government in formulating policies that ensure the sustainability of irrigation systems in rapidly urbanizing areas like Malang City.

Recommendations for Further Research

Future research should focus on the impact of urbanization, especially land conversion, on irrigation sustainability. This can offer insights into controlling urban growth to maintain agricultural water availability. Additionally, the use of modern irrigation technologies, such as sensor-based smart systems, should be explored to improve water efficiency and distribution during the dry season. Research on water quality is also critical, especially considering increased pollution from urbanization. Effective monitoring and management methods are needed to maintain agricultural productivity and irrigation sustainability. Further studies should explore the socio-economic impacts of land-use changes on farmers, ensuring that spatial planning supports both development and local livelihoods. Collaboration between farmers, academics, government, and irrigation managers will be key in developing fair and sustainable policies for irrigation and water resource management in the future.

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