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The role of Kampar watershed in achieving sufficient rice production and sustaining agriculture

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ABSTRACT

Agriculture is the largest global water consumer, crucial to understanding its impact on watersheds. This study was conducted in the Kampar watershed in Riau province, covering Kampar and Pelalawan regencies. It assesses the watershed's suitability for meeting agricultural water needs, particularly for rice cultivation. The study utilizes quantitative methods, applying the Penman–Monteith technique and benefit transfer analysis to measure the water footprint of agriculture. Key indicators include blue, green, and gray water footprints. The water footprint in the Kampar watershed is 173.84 m^3/t, with rice cultivation in the Kampar regency having 57.96 m^3/t blue, 32.19 m^3/t green, and 14.52 m^3/t gray water footprints. In the Pelalawan regency, the values were 41.09 m^3/t blue, 25.59 m^3/t green, and 2.49 m^3/t gray water footprints. The findings suggest a significant need for ample water usage from surface and groundwater in both Kampar and Pelalawan regencies for rice cultivation. Regarding the water availability in each district: Kampar regency has 1,063,281,652 m^3/year and Pelalawan regency has 987,542,991 m^3/year. This surplus in the Kampar watershed ensures sufficient water for rice cultivation in both districts, especially in the Kampar regency. These hold promising further agricultural development in the Riau province.

Key words: gray water, Riau province, rice farming, water footprint, water usage

HIGHLIGHTS

- In the Kampar watershed, blue water is primarily used for paddy farming.
- Kampar's paddy farming has a higher water footprint than Pelalawan's, but Pelalawan produces more paddy.
- Riau province, with ample water resources in the Kampar watershed, has untapped agricultural potential, especially in the Kampar district.

1. INTRODUCTION

Global challenges such as the climate crisis, population growth, urbanization, and agricultural resource limitations are contributing to the emergence of food scarcity on a global scale. World Food Programme (2022) provides an explanation that there was a notable rise in the global population experiencing hunger, with figures increasing from 650 to 768 million individuals in 2020. Furthermore, this upward trend persisted in 2021, with the number of individuals facing hunger further escalating to 828 million. According to projections, there is an anticipated decline of 20% in agricultural output and an average decrease of 15% in yields in developing nations by the year 2080 (Anggraeni 2020; Goncharova & Merzlyakova 2022). This decline is attributed to the impact of climate change, specifically the occurrence of water scarcity (Ali *et al.* 2021; Daszkiewicz 2022; Habib-ur-Rahman *et al.* 2022).

Indonesia encounters a significant difficulty in ensuring the provision of enough food supply to its population. To date, Indonesia has struggled to effectively meet the nutritional requirements of its population (Widada *et al.* 2017; Vadilaksono *et al.* 2023). The agricultural sector in Indonesia makes a significant contribution of 13.70% to the country's gross domestic product (GDP), positioning it as the second largest sector after the industry sector, which accounts for 19.88% of the GDP. Rice continues to dominate the modern landscape of agricultural production, serving as a primary means of ensuring food availability (Widada *et al.* 2017; Bashir & Yuliana 2019). Based on the statistics provided by the Central Statistics Agency of Riau Province (2022) in 2021, the total area of rice fields in Indonesia amounts to 10.4 million hectares, with an annual production of 54.4 million tons (Central Statistics Agency of Riau Province 2021). Rice exhibits the highest level of production in comparison to other food commodities. The cultivation of rice is heavily reliant on the availability of water resources due to the substantial amount of water required for the farming process, which exceeds the water demands of other agricultural commodities (Ikhwali *et al.* 2022), and both maximum and minimum temperature exhibit favorable effects on the output of rice (Dhamira & Irham 2020). This finding suggests that temperature exerts a significant influence on both the quality and quantity of rice yield.

According to the research conducted by Zuhdi (2021) utilizing a Klassen typology analysis, it has been determined that the agricultural sector has significant potential for development and is poised to make a substantial economic contribution to the region of Riau. Nevertheless, the prevailing circumstance entails that most of the rice consumed in the Riau province is sourced from external regions, notably West Sumatra, while only a minor fraction originates from local production. The annual reduction of rice production in Riau province persists. The districts in Riau have a prevailing trend of negative production patterns, characterized by a consistent reduction (Yulianda & Harini 2020). In the Riau province, there has been an annual decrease in rice production by 2.23% (Indonesian Ministry of Agriculture 2020). The rice production in Riau province had a decline from 389,188 tons in 2014 to 314,448 tons in 2022 (Central Statistics Agency of Riau Province 2023). A multitude of variables has been implicated in the decline of production, encompassing diminished planting area, subpar productivity, environmental influences, and pest infestation, including water availability that is highly dependent on rainfall (Fahri *et al.* 2014; Ramli & Bahri 2015; Isyandi 2016; Rustam 2019).

It is imperative to acknowledge the significance of water availability for rice plants, given that the agricultural sector accounts for most of the water consumption. The World Economic Forum (2013) stated that sustainable water management is seen as a significant concern in the twenty-first century, with supply shortfall being recognized as one of the most serious hazards confronting the society. According to the OECD (2012), over 1.6 billion individuals currently reside in areas characterized by significant water stress. Projections indicate that by the year 2050, this figure is expected to rise to 3.9 billion people. The distribution of this share exhibits regional disparities, with estimates of agricultural water usage ranging from 40% in countries with industrialized economies that rely on food imports to over 95% in nations where agriculture serves as the dominant economic sector (FAO 2014). Hence, it is crucial to acknowledge the significance of water regulation in the context of rice farming. In the study area, particularly in Kampar regency, according to the findings of Pratiwi & Yuwati (2022), water deficit still occurs during certain months, where the water content is lower than the water requirements for rice crops. In addition, during specific months such as July and August, there is a high level of drought in the Kampar watershed (Darfia & Rahmalina 2019). Insufficient water availability in rice crops can lead to the deterioration and reduction of rice yield, hence impacting food security (Dinar *et al.* 2019; Surendran *et al.* 2021; Mallareddy *et al.* 2023).

Numerous studies have addressed the adoption of sustainable agricultural practices in relation to the management of water resources. Isyandi (2016) did a study about potential food crop production and food security in the Kampar regency of Riau province. Their findings showed that agricultural land, the number of seeds, fertilizers, insecticides, and labor, both partially and simultaneously, affect the food security in the Kampar district. Pascual & Wang (2016) examined the effects of water management on rice varieties, yield, and water productivity within the context of the system of rice intensification (SRI). One noteworthy aspect of their findings is that not all characteristics of the SRI exert an influence on the development and production of rice plants. Nevertheless, a significant obstacle in the pursuit of sustaining and augmenting rice output lies in the fulfillment of water requirements. Dinar *et al.* (2019) conducted a review to assess the adequacy of the present freshwater supply in meeting the requirements of agricultural crops, given the persistent implications of water scarcity. Yusuf *et al.* (2020) conducted a study to ascertain the ecological conditions of rice farming and examine the index and ecological sustainability status of lowland rice farming in the Siak district, Riau. Kusumawardani & Permana (2021) conducted a study to assess the water requirements in the agricultural sector, with a specific focus on rice cultivation. Their findings indicate that the demand for water in this sector, particularly for rice plants, exceeds the allocated water resources on the island of Java. However, the available data on the management of rice farming in Riau are currently insufficient, specifically in the context of water use, which poses challenges in developing appropriate models for sustainable farming management. This research is essential for informed decision-making regarding the optimal utilization of water resources for sustainable rice farming, particularly in the Kampar watershed. This study not only examines the water footprint (WF) but also proposes the identification of regions appropriate for agricultural expansion by considering the WF and water balance.

2. MATERIALS AND METHODS

2.1. Study area

The study was carried out in 2023 within the Kampar watershed, encompassing four subdistricts in the Kampar regency: Kuok district, Kampar district, Kampar Kiri Hilir district, and Kampar Kiri Hulu district. In addition, it included four subdistricts in the Pelalawan regency: Langgam district, Pelalawan district, Teluk Meranti district, and Kuala Kampar district. The rationale behind the selection of these eight subdistricts was primarily driven by their significant reliance on the Kampar River, particularly for the purpose of irrigation in agricultural areas. The research site is depicted in Figure 1.

2.2. Data collection

The data used consist of primary and secondary data. Primary data include the types of agricultural commodities developed in the Kampar watershed covering Kampar and Pelalawan districts. Secondary data include crop production data, land area data, and fertilizers used in the agricultural system obtained from the Riau Province Agricultural Service. Data on watershed runoff in four districts originated from eight water estimation posts consisting of four water estimation posts belonging to the Sumatra III River Basin Office of Riau Province, which are in the villages of Gunung Bungsu, Gema/Kuntu, Gunung Sahilan, and Lipat Kain. Two water estimation posts in the Kampar regency are in District XIII Koto Kampar and Kampung Pinang, Panti Raja district, which were obtained from the PUPR Kampar regency. The two water estimation posts in the Pelalawan regency are in Lubuk Ogung Langgam and Pangkalan Kerinci districts, which were obtained by the PUPR Pelalawan regency. Rainfall data, climatology including average temperature, air humidity, wind speed, and duration of sunlight were obtained from Meteorological, Climatological, and Geophysical Agency Pekanbaru. Apart from that, there are other secondary data such as Kc values obtained from the FAO, which are available in the CROPWAT 8.0 software. The framework of this research is depicted in Figure 2.

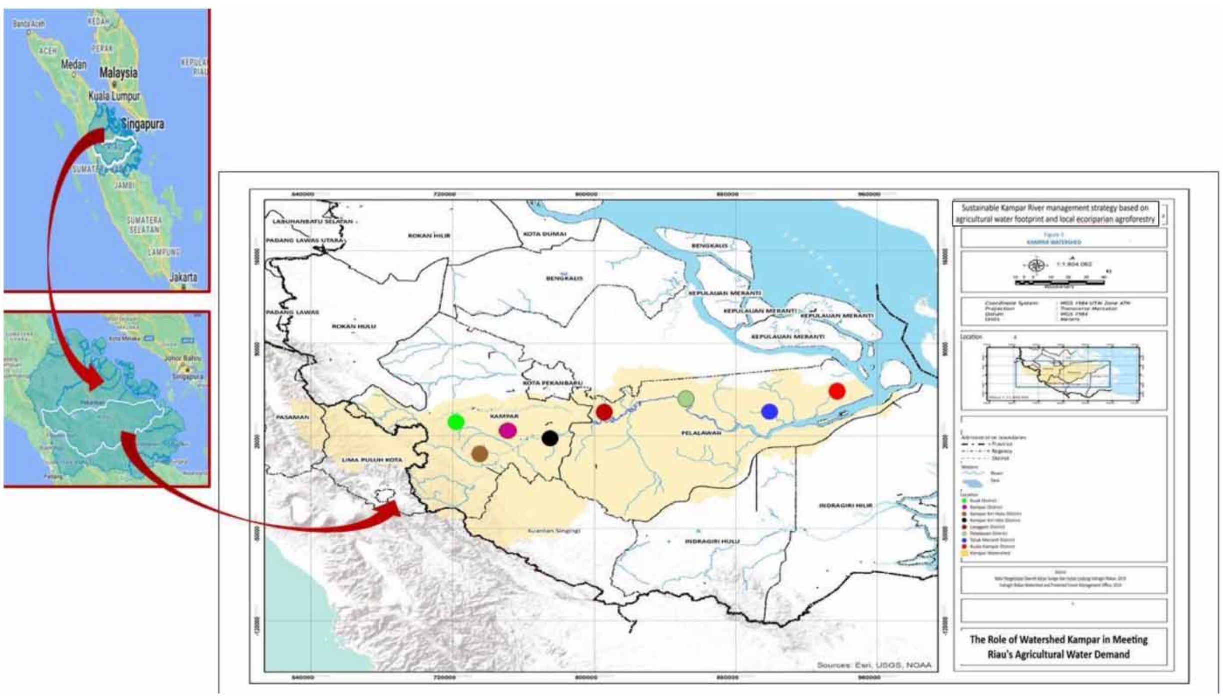


Figure 1 | Research location.

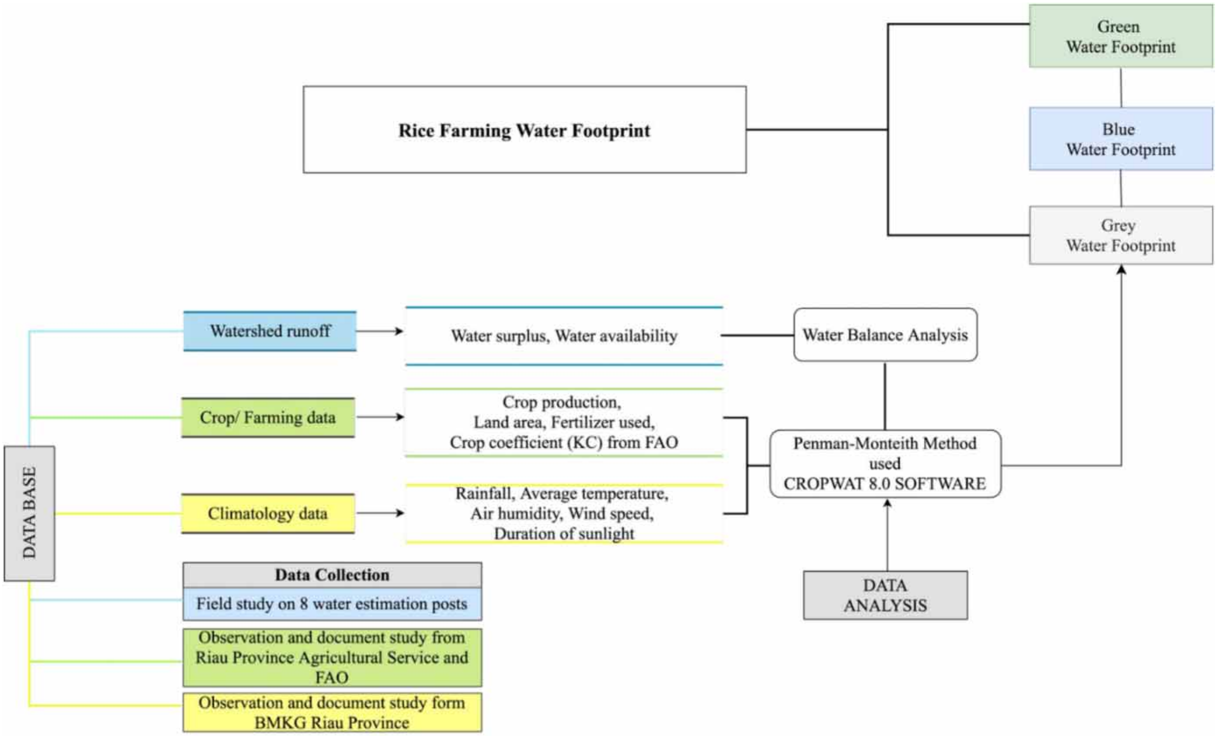


Figure 2 | Framework of the study.

2.3. Analysis

The Penman–Monteith method encompasses three categories of metrics employed for quantifying the overall WF, specifically blue WF, green WF, and gray WF (GWF). The elements that contribute to the formation of green and GWF include evapotranspiration (ET), cultivated plant characteristics, and production. The variables involved in the determination of the GWF indicator in relation to solvent water and production. The WF calculation model employed is outlined as follows:

$$\mathrm{WFtotal} = \mathrm{WFblue} + \mathrm{WFgreen} + \mathrm{WFgray}.$$

The method for determining the numerical value of each WF (blue, green, and gray) is described in the following sections.

2.3.1. Calculation of the blue WF of crops (WFblue)

The component of the blue WF (WFblue) of the crops within a geographical area was determined using the following equation:

$$\mathrm{WF}_{\mathrm{proc,blue}} = \frac{\mathrm{CWUblue}}{Y}\,(\mathrm{m}^3/\mathrm{ton})$$

Crop blue water use (CWUblue) is calculated as follows:

$$\mathrm{CWU}_{\mathrm{blue}} = 10 \times \sum_{d=1}^{\mathrm{lgp}} \mathrm{ETblue}$$

Plant ET (ETblue) is calculated based on the water requirements of plants. The present study utilized the CROPWAT 8.0 program to determine the plant water requirements (CWR). Assuming optimal growing conditions, it is postulated that the water requirements of plants are adequately fulfilled, resulting in the equivalence of real plant ET (ETc) and the water demands of the plants, denoted as ETc = CWR. ETc calculations are conducted based on the irrigation requirements

(IRs). The underlying premise of this methodology is predicated on the assumption that losses incurred through irrigation practices continue to exist and ultimately flow back into the basin. The estimated value of ET is derived from

$$\mathrm{ETblue} = \mathrm{IR}$$

$$\mathrm{IR} = \mathrm{ETc} - \mathrm{Peff}$$

The calculation of effective rainfall (Peff) is performed using the USDA S.C. method within the CROPWAT 8.0 software. In cases where the effective rainfall exceeds the total plant ET, the value of ETblue is set to zero. The estimation of ETc is conducted using a time step of 10 days over the entire growth season, employing the subsequent equation

$$\mathrm{ETc} = \mathrm{Kc} \times \mathrm{ETo}$$

The crop coefficient, denoted as Kc, is a parameter that integrates plant attributes and the overall impact of soil evaporation. The reference ET, represented as ETo (measured in millimeters per month), was determined using the Penman–Monteith method within the CROPWAT 8.0 software. This calculation incorporated climate data sourced from multiple agencies.

2.3.2. Calculation of the green WF of crops (WFgreen)

$$\mathrm{WF}_{\mathrm{proc,green}} = \frac{\mathrm{CWUgreen}}{Y} (\mathrm{m}^3/\mathrm{ton})$$

The quantification of green water consumption, referred to as CWU green, necessitates the assessment of crop ET (ETc) and effective rainfall (Peff) at a minimum. The measurements for both of these variables are denoted in cubic meters per hectare (m^3/ha) and are calculated using CROPWAT 8.0 software. The data utilized in ETc modeling encompass various factors, including monthly average, maximum and minimum temperatures, relative humidity, wind speed, and duration of sunlight. The term 'effective rainfall' (Peff) refers to a small portion of rainfall retained by the soil and potentially utilized by plants to fulfill their water requirements. The strategy employed in the CROPWAT model to calculate Peff is the USDA Soil Conservation Service method. Meanwhile, the variable Y represents the yield of the agricultural crop.

2.3.3. Calculation of the GWF of crops (WFgray)

The concept of the GWF refers to the quantification of the amount of freshwater necessary to absorb pollution loads, considering natural background concentrations and established environmental water quality requirements (Khan *et al.* 2021; Hoekstra *et al.* 2011):

$$\mathrm{WF}_{\mathrm{proc,gray}} = \frac{L}{\mathrm{Cmax} \times \mathrm{Cnat}} (\mathrm{m}^3/\mathrm{ton})$$

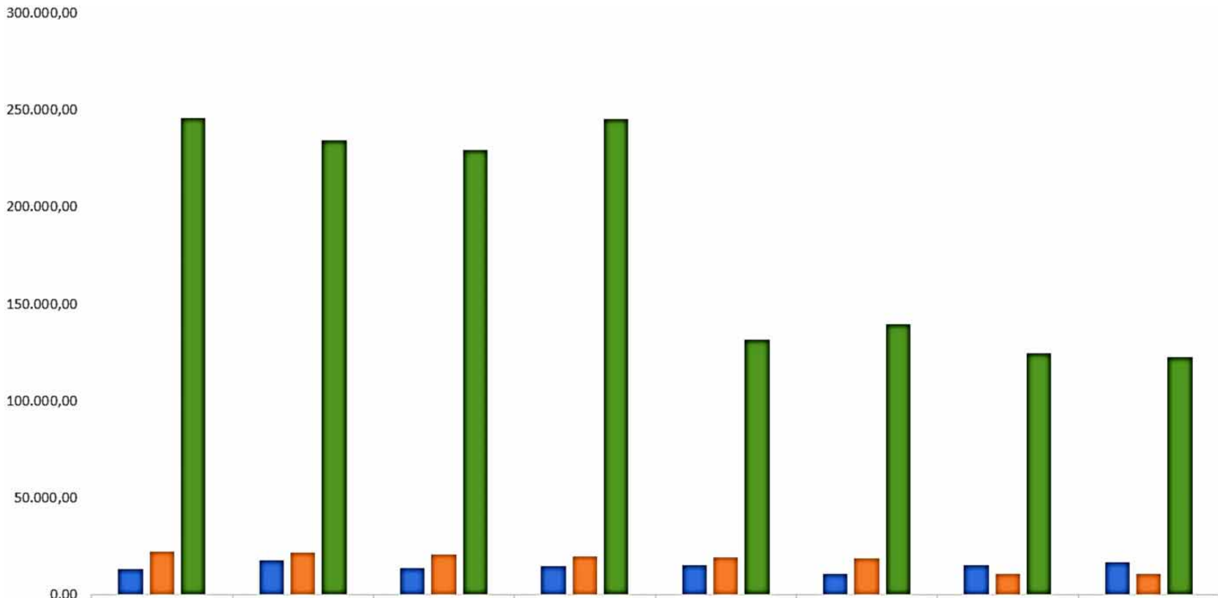
where WF is the water footprint, CWU is the crop water use, Y is the yield, L is the quantity of pollutant/fertilizer that is introduced into the water system (kg/year), Cmax is the maximum permissible pollutant concentration, and Cnat is the concentration of pollutants that naturally exist in water bodies.

The data processing in this investigation was conducted utilizing Excel and CROPWAT software, as described in previous studies by Altobelli *et al.* (2015, 2019). Calculation of the WF entails evaluating the carrying capacity of water resources through an analysis of water availability in the Kampar watershed. This analysis employs a water balance model, specifically the Mock method, which incorporates various data points such as rainfall, ET, ground surface water balance, soil storage and groundwater storage, soil moisture capacity, water surplus, and river flow (runoff).

3. RESULTS AND DISCUSSION

3.1. Rice production in Riau

The rice output and rice field area within the Kampar watershed, encompassing Kampar and Pelalawan regencies, exhibited significant oscillations between 2014 and 2022 (Figure 3). These fluctuations were mostly attributed to variations in rice



	2015	2016	2017	2018	2019	2020	2021	2022
Kampar	13.504,00	18.094	14.092	14.823	15.462	10.873	15.591	16.694
Pelalawan	22.332	21.679	20.773	19.988	19.647	18.697	10.905	10.871
Riau	245.625	234.356	229.468	245.397	131.817	139.852	124.801	122.561

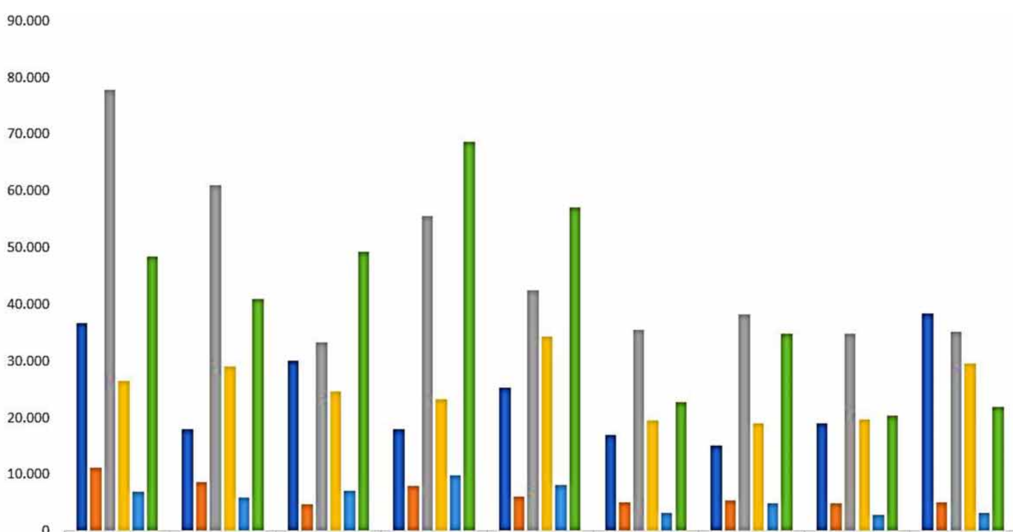
Figure 3 | Rice production equivalent to rice (tons) in Pelalawan and Kampar regencies in the Kampar watershed.

production levels and the diminishing extent of rice fields in both regencies. Rice production in the Pelalawan regency experienced significant fluctuations between 2014 and 2021. These fluctuations were accompanied by a substantial decrease in the rice field area, which declined by almost 67% from 11,126 to 4,979 hectares. In addition, there was a notable reduction in rice production, which decreased from 36,765 to 19,000 m^3/ton. However, it is worth noting that in 2021, there is projection of a slight increase in the rice field area, reaching 5,023 hectares. According to the Department of Food Crops and Horticulture of Riau Province (2022), the variability observed in rice production and rice field area within the Pelalawan regency can be attributed to several factors, including the conversion of rice fields to oil palm plantations, crop failure (known as puso), and forest fires. This phenomenon has been particularly prominent over the period spanning from 2015 to 2021. A similar issue was observed in the Kampar regency, where there was significant volatility in rice production between 2014 and 2021. This was accompanied by a substantial decline in rice fields, amounting to nearly 53%, from 6,928 to 2,905 hectares. In addition, there was a corresponding decrease in rice production, with yields dropping from 26,570 to 19,741 m^3/ton. However, it is noteworthy that there is a projected increase in rice field area to 3,123 hectares in 2021. According to the statistics provided by the Department of Food Crops and Horticulture of Riau Province (2022), the variations observed in rice production and rice field area in the Pelalawan regency can be attributed to two primary factors: the conversion of rice fields into oil palm plantations and instances of crop failure (puso), particularly during the period spanning from 2015 to 2021.

According to a study conducted by Yasar & Siwar (2016), similar trends were observed in Malaysia, where the amount of rice fields in Peninsular Malaysia, whether categorized by state or granary area, experienced a decline. Based on official records, there has been a significant decline in the extent of rice fields over the course of the past 15 years. Specifically, the area of rice fields has diminished by 88,321 hectares, which accounts for a reduction of 22.17%. This translates to an average annual decrease of 1.49%. In contrast, based on data from the granary regions, there has been a decrease in the size of the rice field by 10,790 hectares, which accounts for a reduction of 5.10% or an annual decline of 0.34%. There exists a notable association between the reduction in the size of rice fields and the overall national rice yield. Meanwhile, it is anticipated that the population will continue to grow, while productivity experiences a gradual expansion. According to the research conducted by Firmansyah *et al.* (2021), it was observed that the rate of land conversion in the Sidoarjo regency has exhibited a declining trend throughout the years. The study further predicts that the most significant conversion is anticipated to take place between the periods of 2020–2025 and 2025–2030. In the interim, it is projected that the Gresik regency will experience a gradual escalation in the rate of rice field conversion, with the most substantial conversion anticipated to transpire between the years 2035 and 2040. Meanwhile, the city of Surabaya is predicted to experience a loss of rice fields of 40.2 hectares per year due to the development of residential and industrial land. According to the findings of Barchia *et al.* (2022), there has been a significant decline in the extent of rice fields over the past decade in the Bengkulu province. Specifically, the study reveals a substantial loss of 6,819 hectares, which accounts for almost 74% of the total area. This decline is evident when comparing the rice field extent in 2008, which stood at 9,187 hectares, to the reduced area of 2,308 hectares observed in 2019. The potential decline in rice growing area at the Air Manjuto irrigation region poses a significant risk to agricultural production in Bengkulu.

To mitigate the loss, it is imperative to implement measures that bolster infrastructure facilities and provide incentives, agrochemical subsidies, and agricultural insurances. In addition, it is crucial to refrain from further conversion of rice fields.

Figure 3 depicts the fluctuating trend of paddy-to-rice conversion in the Kampar regency. Notably, there was a significant decline in 2020, followed by a subsequent increase in 2021–2022. This pattern can be attributed to the diminishing area of rice fields dedicated to rice cultivation in both 2019 and 2020, as observed in Figure 4. The Pelalawan regency has experienced a significant decline of approximately 46.7% in the conversion of paddy to rice since 2020. This decline can be attributed to various factors, including crop failures, forest fires, and the utilization of new rice seeds that are unsuitable for cultivation in peatland areas. These unfavorable conditions have primarily affected a rice field area spanning nearly 1,000 hectares. A comparison with Figure 4 further supports this observation. In comparison to the paddy-to-rice conversion data in the Riau province, it can be observed that these two districts collectively account for around 14.2–16.5% of the overall rice production in the province of Riau. According to the findings of Zainul *et al.* (2021), their research indicates that the projected rice productivity for the years 2019–2045 follows a certain trend. Specifically, the projected rice productivity for the year 2025 is estimated to be 64,465 quintals per hectare. Furthermore, the research suggests that this figure is expected to increase to 68,797 quintals per hectare by the year 2035. Finally, the projected rice productivity for the year 2045 is anticipated to reach 77,462 quintals per hectare. According to projections, the estimated land area for the year 2045 is expected to be approximately 27.64 million hectares. In the year 2045, it is expected that Indonesia will have a surplus of 37.80 million tons of rice. However, based on the estimated levels of rice production and domestic rice consumption, there is a possibility that the country may need to import approximately 15 million tons of rice.



	2014	2015	2016	2017	2018	2019	2020	2021	2022
Paddy Production (m3/ton) Pelalawan	36.765	18.036	30.113	17.955	25.277	16.896	15.154	19.000	38.447
Paddy field area (ha) Pelalawan	11.126	8.716	4.764	7.932	6.064	5.064	5.450	4.979	5.023
Water Footprint (m3/ton) Pelalawan	77.882	61.012	33.348	55.524	42.448	35.448	38.150	34.853	35.161
Paddy Production (m3/ton) Kampar	26.570	29.035	24.672	23.277	34.283	19.567	18.947	19.741	29.581
Paddy field area (ha) Kampar	6.928	5.849	7.038	9.797	8.147	3.252	4.976	2.905	3.123
Water Footprint (m3/ton) Kampar	48.496	40.943	49.266	68.579	57.029	22.765	34.828	20.334	21.861

Figure 4 | Field area, production, and WF of rice in Pelalawan and Kampar regencies in the Kampar watershed.

According to the WF analysis depicted in Figure 4 for the Pelalawan regency, the rice crop exhibited a maximum WF value of 77,882 m^3/ton in 2014, while the minimum WF value occurred in 2016 at 33,348 m^3/ton. The decline in WF observed in 2016 can be attributed to a significant decrease in the cultivated area of rice fields compared to the previous year. Specifically, the area of planted rice fields decreased from 8,716 hectares in 2015 to 4,764 hectares in 2016. The occurrence of this problem can be attributed to an extended dry season lasting approximately 8 months, coupled with extensive peatland fires. This is particularly significant as most of the rice fields in the Pelalawan regency are situated on vast expanses of peat. In addition, the conversion of rice fields into oil palm plantations has further exacerbated the issue. It is worth noting that this trend is projected to persist until 2022. In contrast to the occurrences in Kampar regency, rice's greatest WF value in 2017 was recorded at 68,579 m^3/ton, while the lowest value was observed in 2022 at 21,681 m^3/ton. The decline in water availability in 2022 can be attributed to the prolonged dry season, particularly during the early planting phase. This has resulted in insufficient water supply for rice fields, with approximately 68% of rice fields in Kampar regency relying solely on rainfall. Irrigation is only possible through tertiary canals, which are limited in their water reservoir capacity. Furthermore, there is no provision for water pumping from the Kampar River to support irrigation in several areas, including Kampar, North Kampar, and East Kampar districts. Since 2019, there has been a significant decline in the extent of cultivated rice fields compared to the preceding year. Specifically, the area decreased from 8,147 hectares in 2018 to 3,252 hectares in 2019. This downward trend persisted until 2022, with a further reduction to a mere 31,232 hectares. It is worth noting that there was a temporary increase of 4,976 hectares in 2020, but this was followed by another decline from 2021 to 2022 (Department of Food Crops and Horticulture of Riau Province 2022; Central Statistics Agency of Riau Province 2023). In addition to being attributed to diminished production, the determination of cultivation methods, particularly the selection of seeds, irrigation techniques, and fertilization practices, is the primary factor that impacts the quantification of WF. According to data from the Central Statistics Agency of Riau Province (2023), the annual rice production in Indonesia for the year 2021 amounted to 54.5 million tons. A modest decrease in productivity is observed when comparing the production levels of 2019 and 2020. The potential long-term implications of this situation are a cause for concern, particularly considering the projected deficiency of 90 million tons of rice husk by the year 2050 (Ikhwali *et al.* 2022). The potential decrease in rice production poses a significant threat to the food security situation in Indonesia. This concern is further exacerbated by the potential risks associated with global climate change, particularly in irrigated regions that heavily rely on the use of agrochemicals (Kusumawardani & Permana 2021).

3.2. Green, blue, and gray WF of rice plants in the Kampar watershed

This study integrates the all-encompassing concept of WF, including blue, green, and gray water indicators, to evaluate the water needs of rice plants. The average WF is often calculated by dividing the total water use, encompassing blue, green, and gray water, by the land's productivity. The WF of crops in a particular region is determined by the ET rate. ET, which refers to the water needs of plants, can fluctuate based on the climate, soil properties, and plant features (Allen *et al.* 1998). The WF is the cumulative total volume of water consumed by CWU for each unit of crop yield (kg ton^{-1}), including both direct and indirect WFs. The result of this division provides the measurement of the WF linked to each separate water category. The research findings indicate that the overall WF linked to rice farming in the Kampar watershed area is 173.84 m^3/ton (Figure 5).

According to Figure 5, the quantity of blue WF is recorded as 99,050 m^3/ton, surpassing the quantities of green WF (57,780 m^3/ton) and GWF (17,010 m^3/ton). The predominant sources of water utilized for rice production in the Kampar district are groundwater and surface water, as opposed to precipitation. The rice growing system in Kampar and Pelalawan areas necessitates a higher volume of blue water (173,840 m^3/ton) compared to green and gray water. Therefore, it is imperative to implement a rice farming approach that utilizes a prevailing irrigation system at the designated research site. According to Kusumawardani & Permana (2021), the agricultural sector in Indonesia predominantly depends on water resources derived from groundwater, surface water, or irrigation systems. Indonesia exhibits a notable feature whereby 75% of its overall surface runoff is accessible during a 6-month period known as the rainy season, while the remaining 25% is available during a corresponding 6-month period referred to as the dry season.

The Kampar district exhibits a greater value of WFblue, measuring 57,960 m^3/ton, in comparison to the Pelalawan district, where the value stands at 41,090 m^3/ton. The phenomenon can be attributed to the considerable volume of rice production and the substantial WF associated with each kilogram of rice cultivated in the Kampar district. Based on the research conducted by Bulsink *et al.* (2010), it has been shown that the WF of rice plants is larger than that of other crops. This is mostly

Figure 5 | Comparison of green, blue, and gray WF values of rice plants in Kampar and Pelalawan regencies in the Kampar watershed.

attributed to the substantial volume of rice production in Indonesia. According to the research conducted by Ewaid *et al.* (2021), the utilization of water in the cultivation of rice, particularly in terms of the blue WF, is significantly greater in Iraq, amounting to 3,082.2 m^3 per ton, in comparison to the green WF, which stands at 8.8 m^3 per ton. The necessity for increased water irrigation arises from the hot and arid climatic conditions that prevail during rice cultivation in Iraq. According to the findings of Lathuillière *et al.* (2018), the research indicated that agriculture emerged as the primary contributor to the overall blue WF within the basin.

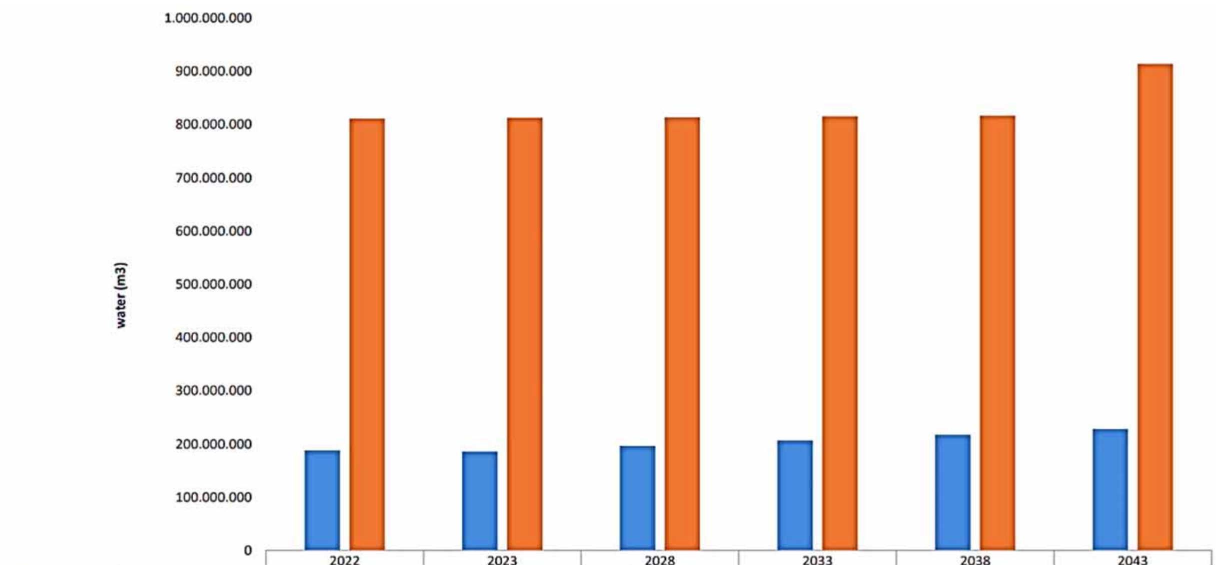
The WF value associated with rice growing in the Kampar regency is 32,190 m^3/year, which exceeds the corresponding value of 2,490 m^3/year observed in the Pelalawan regency. The green WF in agricultural goods refers to the cumulative amount of rainfall that undergoes evaporation from the soil over the growing season, encompassing plant transpiration and other forms of evaporation (Hoekstra & Chapagain 2008). The findings of Chapagain & Hoekstra (2011) indicate that the fluctuation of the green to blue water ratio exhibits significant temporal and spatial variability. In India, Indonesia, Vietnam, Thailand, Myanmar, and the Philippines, the proportion of green water is significantly more than that of blue water. Conversely, in the United States and Pakistan, the blue WF is four times bigger than the green water component. The observed phenomenon may be attributed to a rise in precipitation intensity, as noted by Krishnamurthy *et al.* (2009) and Li *et al.* (2018); this is consistent with the findings that Kampar district has a greater level of rainfall compared to Pelalawan district. To alleviate the strain on the limited global blue water resources, it is imperative to enhance water productivity in both irrigated and rain-fed food production. This can be achieved through the augmentation of yields and the mitigation of non-beneficial evaporation (Hogeboom *et al.* 2020; Mekonnen & Hoekstra 2020).

In contrast, the GWF has the smallest proportion among the various components of the WF, amounting to 17,010 m^3/ton. The results of Bulsink *et al.* (2010) indicate a decreased GWF in rice growing in Indonesia compared to the blue and green WFs. The GWF value of rice plants in the Kampar district is recorded at 14,520 m^3/ton, which surpasses the GWF value seen in the Pelalawan district, measuring at 25,590 m^3/ton. The elevated GWF in rice cultivation within the Kampar regency can be attributed to the substantial utilization of pollutants and fertilizers. This phenomenon is closely associated with the comparatively wider expanse of rice agricultural land in the Kampar district as opposed to the Pelalawan district. According to Aryani *et al.* (2021) and Wu *et al.* (2021), the surface and ground water resources have been negatively impacted by the excessive application of fertilizers and manure, mostly due to the elevated levels of nitrogen (N) deposition. The mitigation of the nitrogen-associated GWF is of utmost importance, as failure to do so could result in significant water pollution connected to food production and a decline in the capacity of freshwater absorption. Furthermore, the implementation of modifications to irrigation and drainage techniques has the potential to effectively regulate and reduce groundwater withdrawal rates. The risk of pollutant leaching is positively correlated with increasing precipitation levels, a phenomenon that can be alleviated by the implementation of strategies aimed at minimizing drainage during the initial phases of plant development.

Rice holds significant agricultural and dietary importance in the Riau province, serving as a fundamental staple crop. One of the key aspects in endeavors to enhance food production is the adequacy of water supply to cater to the IRs of both irrigated and rain-fed rice fields. Hence, ensuring the provision of adequate water for the irrigation of rice crops is crucial, as it is vital to meet the plants' optimal water requirements. The establishment of a precise water requirement is crucial to facilitate the effective and efficient utilization of water resources. The analysis of water demands encompasses various deciding elements, such as rainfall patterns, cropping patterns, and the timing of plowing and planting activities. The water requirements can be determined by considering the duration of irrigation during the planting phase, the growth time of the plants till harvest, and their impact on achieving optimal production. Through WF analysis, it can serve as an indicator of the impact of water use on agricultural production. Wijayanti *et al.* (2023) found that areas with a high rate of WF will experience inefficiencies in agricultural practices, leading to a decrease in production yields.

3.3. Kampar watershed as a source of agricultural water

The cultivation of rice demonstrates variations in irrigation needs, crop yields, cropping systems, and environmental impacts, depending on the geographic location. The water balance graph (Figure 6) presents an analysis of the Kampar watershed discharge in the Kampar regency. It reveals a significant surplus of water originating from the Kampar River, which serves as the primary water source in the Kampar watershed. Projections for the upcoming two decades, specifically from 2023 to 2043, suggest that only 25–27% of the necessary water discharge will be met by the available water discharge. In the Pelalawan regency, a similar pattern was observed (Figure 7), wherein the water discharge utilized for rice production accounted for only 22–24% of the predicted water availability. Water availability in this district is not a concern due to the abundant water resources found in the Kampar River, which serves as the primary water source within the Kampar watershed. If fluctuations in rice production occur, the underlying causes are not primarily attributed to water availability. Rather, they can be attributed to various factors such as suboptimal functioning of irrigation infrastructures, limited duration of irrigation, inadequate coverage of irrigated rice fields, insufficient maintenance of irrigation systems, and deficiencies in rice cultivation technology. Yang *et al.* (2021) identified several key aspects that significantly impact the efficient utilization of irrigation water. These elements include irrigation technology, organizational integrity, crop types, water price management, local economic level, and channel seepage prevention. Therefore, Sawadogo *et al.* (2023) assert that biophysical elements exert a significant influence on crop irrigation, hence affecting the viability and sustainability of agricultural practices across diverse climatic contexts.



	2022	2023	2028	2033	2038	2043
Water used (m3/year)	187.968.664	185.380.135	196.292.860	206.685.696	217.209.652	227.938.004
Estimated presence of water (m3/year)	811.512.836	812.777.414	813.864.685	815.471.855	816.697.882	914.001.669

Figure 6 | Water balance (m^3/year) in the Kampar regency in the Kampar watershed.

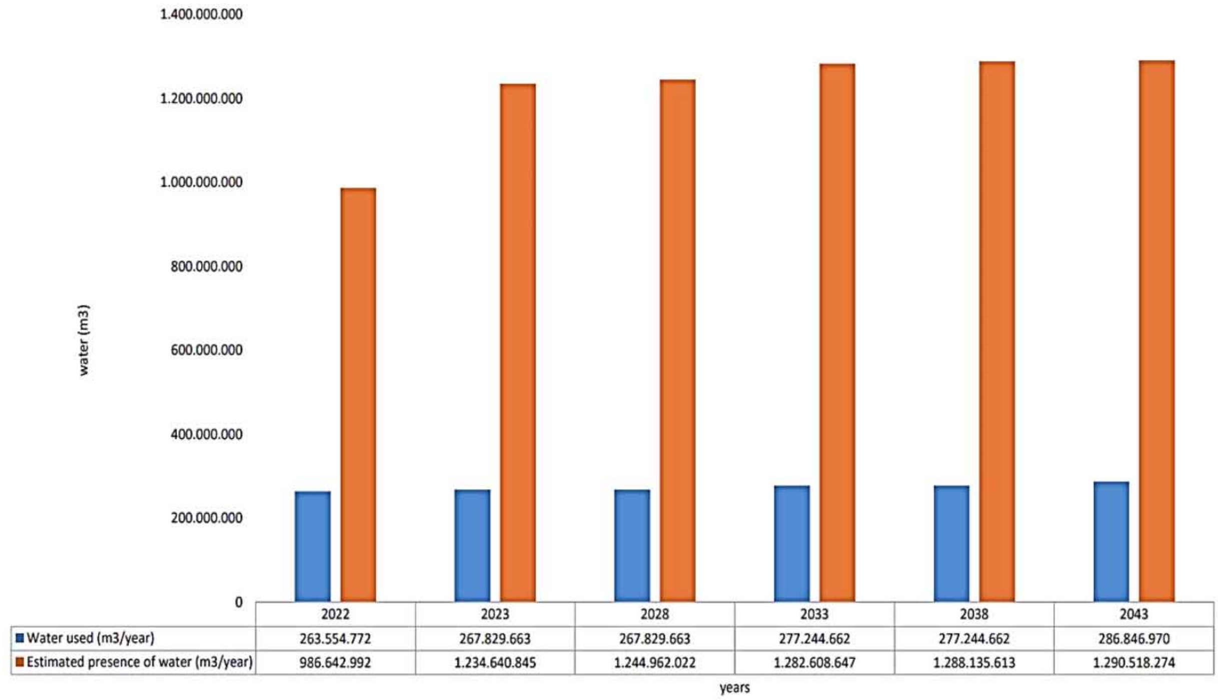


Figure 7 | Water balance (m^3/year) in the Pelalawan regency in the Kampar watershed.

According to the projections and recommendations derived from the water balance analysis of the Kampar watershed in the Kampar district (Figure 8), it is suggested that nine districts, namely, Kampar, North Kampar, East Kampar, Kuok, Bangkinang, Rumbio Jaya, Kampar Kiri, Kampar Kiri Hilir, and Mount Sahilan, should be designated as rice centers. These districts collectively cover an area of 3,144.07 km^2, which accounts for approximately 27.85% of the total land area of the

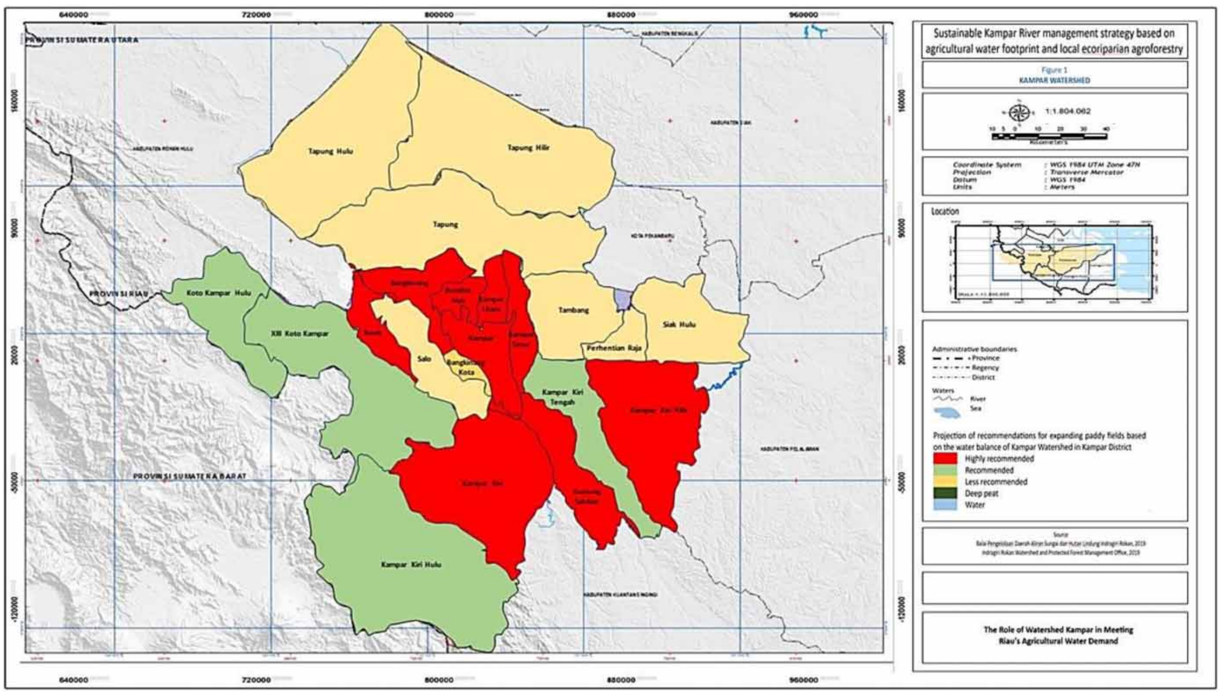


Figure 8 | Projection of recommendations for expanding rice fields based on the water balance of the Kampar watershed in the Kampar district.

Kampar regency, measuring 11,289.28 km^2 (Central Statistics Agency for Kampar Regency 2023). Among the subdistricts in the Kampar regency, four have consistently served as prominent rice production hubs. These subdistricts include Kampar, North Kampar, East Kampar, and Rumbio Jaya (Central Statistics Agency of Pelalawan Regency 2023). However, it is worth noting that between 2016 and 2022, there has been a reduction in the extent of rice fields due to their conversion for alternative purposes, particularly for oil palm cultivation. There are four districts, namely, Kampar Kiri Hulu, Kampar Kiri Tengah, Hulu Koto Kampar, and XIII Koto Kampar, which have been identified as suitable for development into rice centers. These districts possess a significant water surplus due to their geographical location in the upper reaches of the Kampar Kanan River and Kampar Kiri River, which are part of the Kampar watershed. Nevertheless, it is imperative to consider certain criteria pertaining to the function of these three districts as regions dedicated to protection and conservation. The subdistrict of Kampar Kiri Hulu exhibits a hilly topography owing to its location within the Bukit Barisan mountain range. Situated upstream of the Kampar Kiri River, it also falls within the boundaries of the Bukit Rimbang-Bukit Baling Wildlife Reserve, which has been elevated to the status of the Bukit Rimbang-Bukit Baling Nature Reserve since 2020. Consequently, the implementation of cultivation technology is imperative in this area. The primary objective is to establish this district as a prominent hub for rice production. Similarly, the Hulu Koto Kampar and XIII Koto Kampar subdistricts are situated in the upstream region of the Kampar Kanan River. These subdistricts are encompassed within the Bukit Barisan mountain range and are located inside the Suligi Nature Reserve area as well as the Bukit Bungkuk Nature Reserve (Central Statistics Agency of Pelalawan Regency 2023). The development of the Kampar Kiri Tengah district can be facilitated with the integration of irrigated rice production, leveraging the presence of six tributaries that discharge into the Kampar Kiri River, alongside upland rice agriculture. In addition, it is worth noting that there exist eight subdistricts that are not deemed suitable for rice cultivation due to their conversion into oil palm plantations, industrial plantation forests, and other purposes. Moreover, the limited water resources accessible from the Kampar watershed, particularly from the Kampar Kanan River, further restrict the feasibility of rice production in these subdistricts. The subdistricts in question are Bangkinang Kota, Salo, Tapung, Tapung Hulu, Tapung Hilir, Perhentian Raja, Mine, and Siak Hulu. The Tapung district, specifically Tapung Hulu, is intersected by two significant rivers, known as the Tapung Kiri and Tapung Kanan rivers. These rivers subsequently merge and run in a downward direction, ultimately joining the Siak River and forming the Siak watershed.

The Kampar watershed in the Pelalawan district (Figure 9) has been identified as highly suitable for expanding rice fields. These districts are Teluk Meranti, Kuala Kampar, Pelalawan, and Bunut. In the past, Teluk Meranti and Kuala Kampar in the Pelalawan regency served as rice centers. However, between 2016 and 2022, there has been a reduction in the extent of rice fields due to their conversion for alternative purposes, specifically the establishment of oil palm plantations. The overall area of Pelalawan regency, which measures 13,067.29 km^2, comprises four subdistricts that collectively account for 51.35% or 6,710.45 km^2 of the region's total land area. Particularly in the case of Teluk Meranti, a significant proportion of its land, amounting to 63%, consists of deep peat. Consequently, the conversion of this region into an extension of rice fields is not feasible due to its inclusion inside a designated protection area, namely, the Tasik Serkap Wildlife Reserve and the Tasik Besar Serkap Wildlife Reserve. Three districts, namely, Bandar Petalangan, Pangkalan Kuras, and Langgam, have been identified as suitable areas for expansion and development as rice centers. Moreover, it is worth noting that there exist five subdistricts that are not deemed suitable for rice cultivation. This is primarily since these areas have been converted into oil palm plantations, industrial plantation forests, and other land uses. In addition, the limited water resources available from the Kampar watershed further restrict the feasibility of rice production in these subdistricts. The subdistricts include Bandar Sekijang, Pangkalan Kerinci, Pangkalan Dimples, Ukui, and Kerumutan. Among the five subdistricts, it is noteworthy that two of them have been designated as conservation forest areas. Specifically, these places are the Kerumutan Wildlife Reserve Area located in Kerumutan and the Tesso Nilo National Park situated in Ukui (Regional Development Planning Agency of Kampar Regency 2021). Protected areas play a crucial role in the conservation of freshwater biodiversity and the promotion of human water security, which is essential for the well-being and prosperity of individuals. While these areas often prioritize terrestrial ecosystems and less frequently encompass freshwater resources, their significance in safeguarding such resources should not be underestimated (Harrison *et al.* 2016; Hermoso *et al.* 2016; Altobelli *et al.* 2019; Acreman *et al.* 2020).

3.4. WF and water crisis

The concept of WFs is important for evaluating appropriate water resource management. Gaining an understanding of the importance of WFs can help us make wise and efficient use of freshwater resources. Due to the link between population

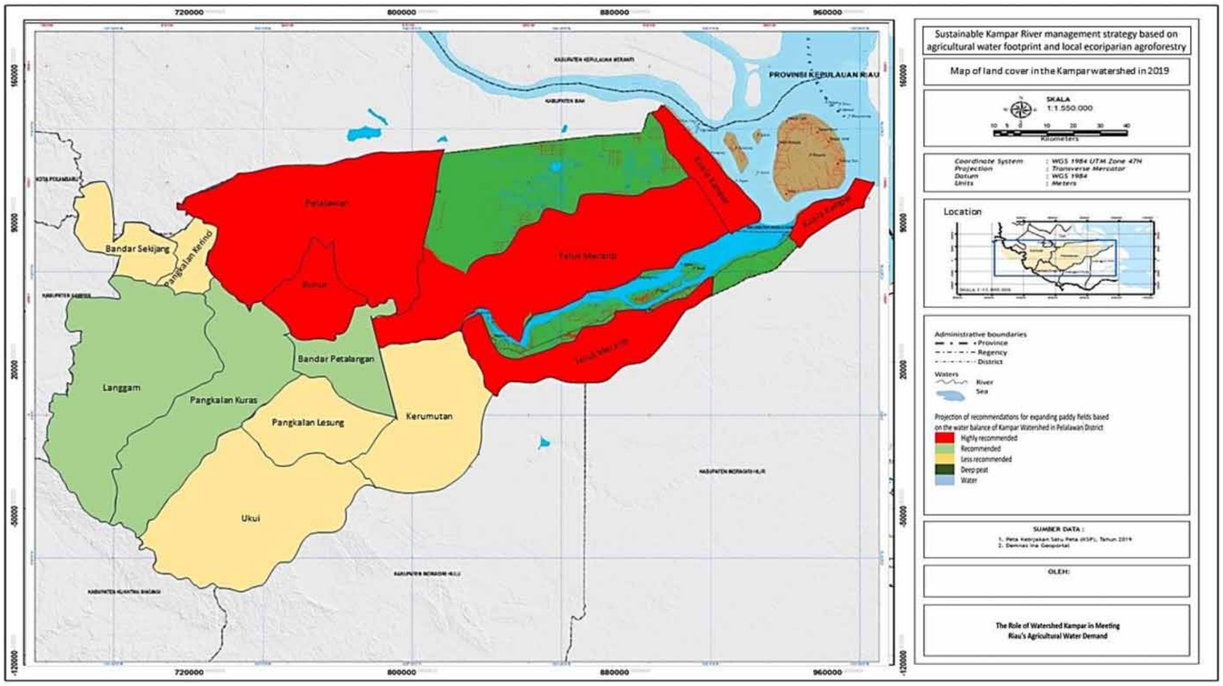


Figure 9 | Projection of recommendations for expanding rice fields based on the water balance of the Kampar watershed in the Pelalawan district.

growth and climate change, there is an expected increase in the demand for water. This will lead to an increasingly severe water scarcity. The consequences of climate change on water resources can pose significant threats to guaranteeing a continuous water supply for various purposes, particularly agricultural use. Land conversion worsens the problem of water scarcity. The research conducted by Shahid *et al.* (2018, 2021) showed that changes in land use in the Soan watershed resulted in a significant decrease in runoff in all water catchment areas. The study's most significant finding was the conversion of land for agricultural purposes. Hence, the growth of agricultural land inside the watershed results in the availability of water.

According to the study conducted by Darfia & Rahmalina (2019), droughts in the Kampar watershed occur often and usually last from July to September. A pronounced drought typically transpires over the period spanning from July to August. The future agricultural issue in the Kampar watershed is a direct result of climate change. Climate change is projected to result in higher water consumption, hastened fruit and seed maturation, reduced harvest quality, and decreased yield of food crops (Fahad *et al.* 2017). Addressing this issue necessitates the adoption of multiple solutions, one of which is the integration of water-saving technologies.

Implementing a variety of water-saving technologies can enhance water efficiency and proactively address water scarcity concerns. Agricultural enterprises have implemented a range of water-saving methods, including the use of intelligent irrigation systems that are integrated with sensors and connected to the Internet of Things (Mallareddy *et al.* 2023). The implementation of improved irrigation techniques is anticipated to have a significant impact on the agriculture sector of the Kampar watershed. According to previous research conducted by Fereres & García-Vila (2013), irrigated agriculture often produces an output level that is at least twice as high as that of rain-fed agriculture. Kumari *et al.* (2021) identified many options for reducing water usage in rice fields: (1) intensive land puddling and precise leveling greatly decrease seepage and percolation; (2) applying compost or green manures aids in reducing evaporation, percolation, and seepage; (3) maintaining saturated soil under leveled field conditions can cut evaporation losses by 50%; and (4) implementing rainwater harvesting can significantly decrease surface runoff during the wet season. Furthermore, the adaptation of agriculture to climate change can be accomplished by the implementation of sustainable irrigation techniques (Rosa 2022).

Naazie *et al.* (2023) discovered multiple strategies in soil and water management with the objective of adjusting crop production to climate change. The methods encompassed in this category involve activities such as land preparation, utilization of organic or compost fertilizers, trimming of crop, crop rotation, and implementation of cover cropping. The utilization of cover cropping has demonstrated efficacy in the preservation of soil fertility, conservation of moisture, mitigation of erosion, and sustenance of microbial activity within the soil (El-Naggar *et al.* 2021). Moreover, by employing intensification techniques, it is possible to achieve water savings of up to 30% as compared to conventional methods (Liesdiana *et al.* 2019).

Furthermore, the careful choice of plant species is of utmost importance. The study conducted by Saediman *et al.* (2021) revealed that rice farmers employ a strategy of selecting distinct plant *k* varieties based on the specific planting season as a means of adapting to climate change. Farmers in Cialam Jaya, located in South Sulawesi, cultivate high-quality rice varieties such as *Mekongga*, *Ciherang*, and *Inpari*. These cultivars possess natural resistance against pests and diseases. During the second planting season, farmers additionally cultivate the Trisakti variety, which is known for its shorter lifespan and reduced water consumption. Shorter maturation varieties are appropriate for the subsequent planting season to preempt potential water scarcity between September and November. Meanwhile, according to a study by Maity *et al.* (2023), climate variables may not always directly reduce seed productivity. However, they can alter the biochemical composition of seeds, hence reducing their value for planting.

4. CONCLUSION

Based on the research findings, the utilization of blue water for rice cultivation in the Kampar watershed is greater in comparison to other WF components. The increased utilization of water resources from both surface water and groundwater in this agricultural setting highlights the necessity for the implementation of more water-saving irrigation systems, such as furrow irrigation, drip irrigation, and sprinkler irrigation. The purpose of implementing these techniques is to forecast a potential reduction in water availability during the dry season, despite the fact that, according to water balance analysis, the water supply from the Kampar watershed is still sufficient to meet the water needs for rice cultivation in the study area. The WF data obtained from this research can provide further information for the efficient use of water resources, promoting both health and sustainability in the future, particularly in the study area. The WF concept is not the exclusive factor utilized in water management decision-making processes, as it covers multiple components within the sustainability framework for each sector. Nevertheless, its incorporation offers promising opportunities for making substantial contributions. In future research endeavors, our objective is to devise suitable water management strategies in the realm of water resource management to efficiently tackle these estimations.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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