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The 6th INTERNATIONAL CONFERENCE ON AGRICULTURE AND BIOINDUSTRY (ICAGRI)

"Promoting Agroecology and Climate-Smart Agriculture for Environmental Resilience, Biodiversity, and Sustainability"

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Preface

The 6th International Conference on Agriculture (ICAGRI) 2024 marks another significant milestone in our ongoing commitment to advancing sustainable agriculture. Building upon the success of our previous conferences, this year's event continues to bring together a diverse array of academics, researchers, policy makers, and professionals from around the globe.

Our theme, " *Promoting Agroecology and Climate-Smart Agriculture for Environmental Resilience, Biodiversity, and Sustainability*", highlight the critical importance of sustainable agricultural practices. We recognize that sustainable agriculture must be ecologically sound, economically valuable, and socially just. It requires strategies that respect diversity, employ integrative approaches, maintain a long-term perspective, and ensure equality and sustainability.

This year, we are pleased to report that the conference received 131 submitted papers. After a rigorous review process, 105 papers were accepted for presentation directly in Hermes Palace Hotel, Banda Aceh. We extend our heartfelt gratitude to all those who have contributed to the success of this conference. Special thanks go to: The Rector of Universitas Syiah Kuala, The Dean and Vice Dean of the Agriculture Faculty (FP USK), The Head of Research and Community Service Institution (LPPM) *Universitas Syiah Kuala*, Our national and international partners, Our esteemed keynote and invited speakers and All committee members for their dedication and hard work.

We are confident that the 6th ICAGRI 2024 will serve as a platform for meaningful discussions and collaborations, contributing significantly to the future of sustainable development in agriculture. We look forward to the insights and innovations that will emerge from this gathering of minds. As we conclude, we invite you to engage fully in the conference proceedings and to carry the spirit of collaboration and innovation back to your respective fields. We hope to see you again at the 7th ICAGRI 2025 conference.

Cordially yours,

Prof. Dr. Eka Meutia Sari
Chairperson of the 6th ICAGRI 2024

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Maize Water Footprint of Kampar Watershed to Bolster Sustainable Agriculture in Indonesia

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Abstract. Agriculture plays a significant role in driving water demand and degradation. Assessing sustainability is crucial for understanding the impact of current water use on future availability and preserving water quantity and quality. Maize cultivation, practiced in over 150 countries, ranks third in cereal production worldwide, following wheat and barley. This study focuses on the importance of watersheds in meeting agricultural water needs, specifically in the context of maize farming. The research was conducted in the Kampar watershed, Indonesia. The study utilized a quantitative methodology to assess the agricultural water footprint, applying the Penman-Monteith method alongside benefit transfer techniques. The water footprint of maize crops was calculated using the Cropwat 8.0 software. The results showed that the overall water footprint of agriculture in the Kampar watershed was 42.94 m^3 per ton. In the Kampar district, maize had a green water footprint of 8.67 m^3/ton, a blue water footprint of 7.93 m^3/ton, and a grey water footprint of 3.28 m^3/ton. In the Pelalawan district, the green water footprint was 15.5 m^3/ton, the blue water footprint was 1.33 m^3/ton, and the grey water footprint was 6.23 m^3/ton for maize. Assessing agriculture's water footprint provides valuable insights for climate-resilient crop development and anticipating regional shifts in the face of climate change.

1. Introduction

Agriculture is the primary consumer of water resources. Agricultural production accounts for a majority, specifically over 70%, of global water consumption [1-4]. To satisfy the growing need for food, fibre, and biofuels, it is imperative to achieve a nearly 50% increase in agricultural production by the year 2050, as compared to the levels observed in 2012. According to projections by Mekonnen & Gerbens-Leenes [5], the water footprint is anticipated to undergo a substantial increase of up to 22% by the year 2090, primarily because of climate change and land use change. The findings indicate that almost 57% of the worldwide blue water footprint is seen to be in non-compliance with the established environmental flow criteria. This situation is likely to want a greater quantity of water.

In some countries, maize is one of the three most important cereal crop species (after wheat and rice), and is formed over a wide range of regions [6-8]. Maize is a widely consumed dietary staple in Indonesia, second only to rice. The strategic nature of maize stems from its dual function as a significant supply of secondary carbohydrates, and as a raw material for animal feed. It is estimated that a majority of approximately 55% of domestic maize production is allocated for feed purposes, whereas only around 30% is utilised for direct human consumption. The remaining portion is allocated for various industrial applications and seed production. Maize output in Indonesia has fluctuating patterns throughout different provinces, characterised by periods of both growth and decline. In a broad sense, it can be observed that maize production in Indonesia had an overall increase [9,10]. The cultivation area for maize has experienced a notable expansion, namely from 10 million tons/ ha to 30 million tons/ ha over the period spanning from 1999 to 2018, or the past two decades, with an average annual growth rate of 3% [11]. Enhancing water-use efficiency through the optimization of planting density and irrigation regimes in maize cultivation plays a critical role in ensuring food security in the face of water scarcity.

The water footprint is categorized into three components: blue water, which refers to the consumption of surface and groundwater; green water, which represents the use of rainwater; and grey water, which indicates the amount needed to dilute pollutants. The water footprint (WF) serves as a quantitative measure that assesses both the volume of water consumed per crop unit and the associated water pollution. [11-12]. As such, the WF is recognized as a comprehensive indicator of the appropriation of freshwater resources [13]. Water footprint, which is analogous to the ecological footprint, is a measure that quantifies the utilisation of natural water resources within a specific region to fulfil the demands of its population. Hence, when evaluating the water footprint (WF), it becomes imperative to possess knowledge regarding the accessible water resources, while also considering the preservation of the ecological equilibrium [14]. In this regard, it is essential to account for an ecological flow that encompasses a range of 30% to 50% of the natural water supply [14-18].

Water footprint (WF) research has shown significant growth in recent times, with the WF technique being applied in many studies pertaining to water utilisation across diverse domains. The utilisation of agricultural product exploration approach was prevalent, as evidenced by numerous research conducted across diverse countries and focused on a range of agricultural products [19-20]. In their study, Madugundu et al. [22] employed Landsat-8 data to estimate the water footprint of carrot and maize crops in the desert climate of Saudi Arabia and Lathuillière et al. [23] undertook a water footprint assessment in the Xingu Basin of Brazil. The objective was to provide predictions regarding agricultural intensification until the year 2050, taking into consideration the potential effects of deforestation and climate change on water availability within the watershed. Khan et al. [24] assessed the blue and green water footprints (WF) as well as the consumption of blue and green water associated with various crops (including corn, rice, tobacco, wheat, barley, sugarcane, and sugar beet) in the Peshawar Basin, Pakistan. The results indicate that corn has the largest blue and green water footprint (WF) compared to other plant species. Likewise, Hai et al. and D. Wang et al. [24-25] examined the agricultural water-use efficiency by considering the water footprint of crop values in China. Esetlili et al. [6] had determination of Water Footprint for the cotton and maize production in the Küçük Menderes basin. In a recent study conducted by Wang et al. [26], the water footprint (WF) of the winter wheat – summer maize cropping system was assessed. Fotia & Tsirogiannis [27] introduced a straightforward and effective approach for evaluating and conveying the Water Footprint (WF) efficiency of a certain crop. The notion of the Water Footprint Score (WFS) is presented as a complete and standardised measure of farmers' effectiveness in managing water resources. Therefore, Elfkih et al. [28] conducted an assessment on the water consumption patterns across the entire value chain of the olive oil sector in Tunisia. This sector holds significant strategic importance within the country's agro-industrial landscape. However, the water footprint of maize in Indonesia has not been quantified by any previous studies. This study aims to analyze the water footprint of corn farming in the Kampar Watershed, Indonesia.

2. Materials and methods

2.1. Study area

This research was conducted in one of the watersheds in Indonesia, namely the Kampar Watershed, which covers five sub-districts in Kampar Regency, namely Tapung Hulu, Tapung Hilir, Koto Kampar Hulu, East Kampar, and Siak Hulu. The study also covers four Pelalawan Regency sub-districts: Teluk Meranti, Kuala Kampar, Bandar Petalangan, and Langgam (Figure 1). The reason for selecting these nine sub-districts was based on their dual role as the main maize-producing centers in their respective districts and their location in the Kampar watershed area.

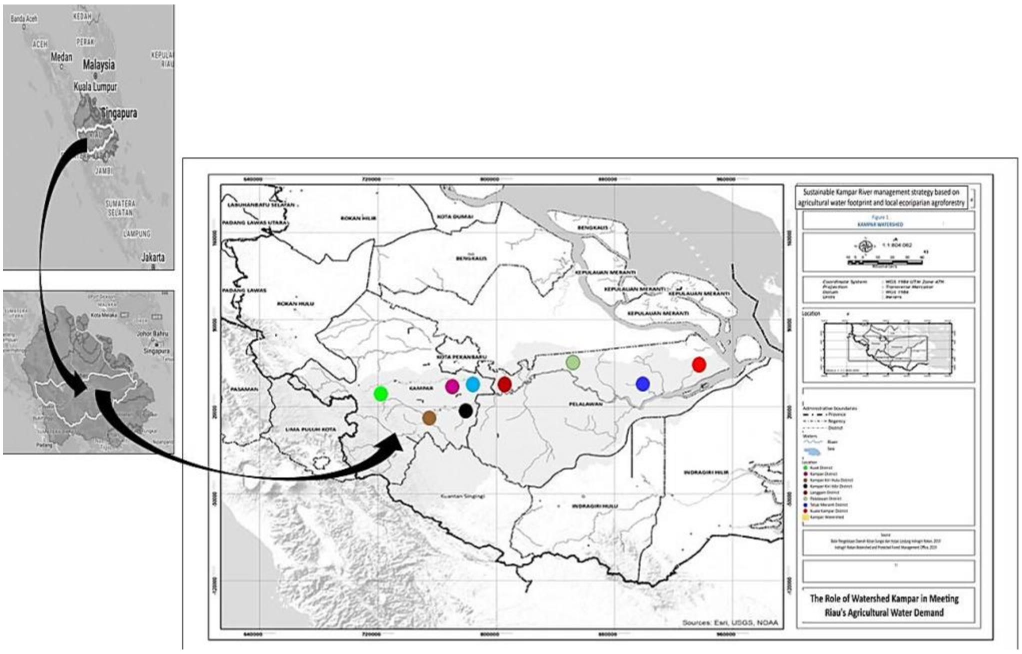


Figure 1. Research location

This study incorporates the comprehensive notion of Water Footprint (WF), using the Penman-Monteith method, encompassing indications of blue, green, and grey water, to assess the water requirements of maize plants. The average water footprint is often determined by dividing the total water usage, which includes blue, green, and grey water, by the productivity of the land. The outcome of this split yields the numerical representation of the water footprint associated with each distinct category of water. The green water footprint (WF) quantifies the amount of rainwater utilized during the crop's growth phase, while the blue WF represents the consumption of surface and groundwater resources. In contrast, the grey WF assesses the volume of freshwater necessary to dilute and assimilate pollutants, such as nutrients and pesticides, that infiltrate water sources or result from surface runoff in agricultural areas. This measurement is based on natural background levels and established water quality standards [13]. To calculate the crop of WF following Hoekstra et al. [13]. To determine the total water footprint (WF) associated with crop cultivation (WFcrop, m^3/year), the WFcrop per unit of production (m^3/ton) was multiplied by the annual crop yield (ton/year) reported by the Riau Planning and Statistics Authority for the period 2013 to 2022. The water footprint calculation model employed in this study is outlined as follows:

$$WFtotal = \text{blue } WF + \text{green } WF + \text{grey} WF \tag{1}$$

The procedure for calculating the numerical magnitude of each WF (blue, green, and grey) is as follows:

2.2. Blue water footprint of crops (WFblue)

The blue water footprint (WFblue) of crops within a specified geographical region was calculated using the following equations:

$$\mathrm{WF}_{proc,\ blue} = \frac{CWU\ blue}{Y}\ [\mathrm{m^3/ton}] \quad (2)$$

For calculation of crop blue water use (CWUblue) were used:

$$\text{CWUblue} = 10\ \times \sum_{d=1}^{lgp} \mathrm{ET}blue \quad (3)$$

The blue crop water use (CWU blue) refers to the amount of irrigation water used by the crop, which can come from sources such as groundwater and desalinated surface water. It is calculated by accumulating daily evapotranspiration over the entire growing period (lgp, days). The equations are multiplied by a factor of 10 to convert water depth (in mm) to water volume (in m3/ha). To determine the plant water requirements (CWR) for this study, the CROPWAT 8.0 decision support program developed by FAO [28] was used. This method relies on climate, rainfall, and crop data. Climate and rainfall data for the past ten years (2013–2022) from two weather stations (Kampar and Pelalawan) were obtained from the Riau Meteorological Department. Information such as planting and harvesting dates, maximum rooting depth, length of growing period (lgp, days), critical depletion, and yield response factors were gathered from local farms, mainly from the Riau Province Agricultural Service. Assuming optimal growing conditions, it is proposed that the water needs of the plants are fully met, leading to the alignment of actual evapotranspiration (ETc) with the crop water requirements (CWR), expressed as ETc = CWR. The calculation of ETc is performed based on the irrigation requirements (IR), with the estimated value of ETc being determined from:

$$\mathrm{ETblue} = \mathrm{IR} \quad (4)$$

$$\mathrm{IR} = \mathrm{ETc} - \mathrm{Peff} \quad (5)$$

The Effective Rainfall (Peff) is calculated using the USDA S.C. method in CROPWAT 8.0. If the effective rainfall is greater than the total plant evapotranspiration, the value of ETblue is set to zero. The ETc estimation is done using a time step of ten days throughout the entire growth season, using the following equation:

$$\mathrm{Etc} = \mathrm{Kc} \times \mathrm{ETo} \quad (6)$$

The crop coefficient (Kc) is a parameter that combines plant characteristics with the overall effect of soil evaporation. The Kc value for maize is sourced from the FAO and can be found in the CROPWAT 8.0 software. The reference evapotranspiration (ETo), measured in millimeters per month, was calculated using the Penman-Monteith method within the same software, based on climate data gathered from various agencies.

2.3. Green water footprint of crops (WFgreen)

$$\mathrm{WF}_{proc,\ green} = \frac{CWU\ green}{Y}\ [m^3\ /\mathrm{ton}] \quad (7)$$

The estimation of green water usage, known as CWU green, requires calculating crop evapotranspiration (ETc) and effective rainfall (Peff), both expressed in cubic meters per hectare (m^3/ha). This calculation is performed using the CROPWAT 8.0 software. The ETc modeling takes into account several climatic parameters, including average, maximum, and minimum monthly temperatures, relative humidity, wind speed, and sunshine duration. Effective rainfall (Peff) refers to the fraction of precipitation absorbed by the soil and available for plant use to meet their water needs. The CROPWAT model utilizes the USDA Soil Conservation Service method to compute Peff.

2.4. Grey water footprint of crops (WFgrey)

The concept of the grey water footprint pertains to a specific stage in the process that serves as an indicator of the concentration of polluted water involved in the agricultural production of maize crops [12]. The pollutant under consideration in this study is fertilizer, comprising urea and NPK (Phonska). Data indicates that approximately 15% of fertilizer residue is generated at the research location. The harvest area data has been obtained from the Riau Province Central Statistics Agency. Information on harvest frequency has been derived from survey results, while details regarding fertilizer usage have been sourced from the National Standardization Agency.

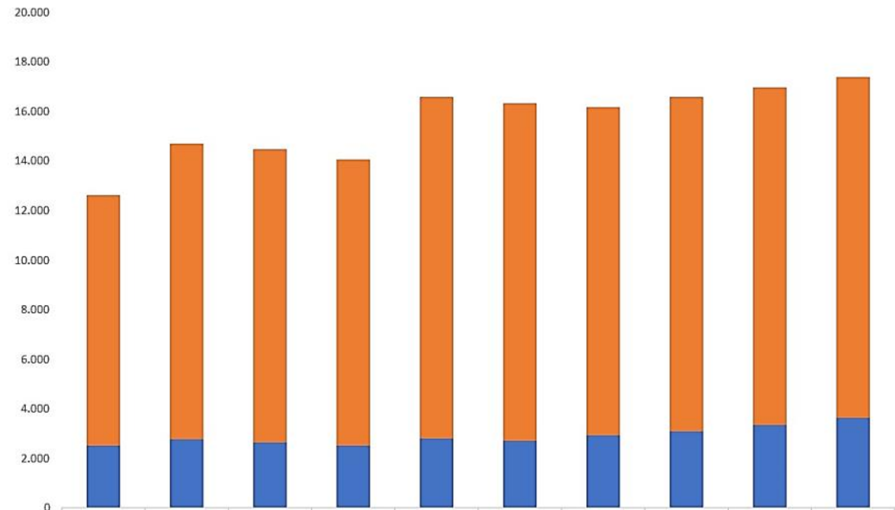
$$WF_{proc,\ grey} = \frac{L}{Cmax\ x\ Cnat}\ [m^3\ /\text{ton}] \quad (8)$$

Information:
WF = Water Footprint
CWU = Crop Water Use
Y = Yield
L = Amount of pollutant/fertilizer that enters the water (kg/year)
C_{max} = The maximum permissible pollutant concentration
C_{nat} = Concentration of pollutants that naturally exist in water bodies

The investigation processed data using CROPWAT and Excel [1, 2, 4]. The water footprint calculation involved assessing the Carrying Capacity of Water Resources (CCWR) in the Kampar Watershed using the Mock method, which considers various data points such as rainfall, evapotranspiration, water balance, and river flow.

3. Results and discussion

3.1. Maize productivity



	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Maize production (tons)	10.114	11.930	11.817	11.563	13.773	13.622	13.227	13.477	13.642	13.744
Cultivated plant area (ha)	2.522	2.768	2.662	2.511	2.817	2.712	2.937	3.110	3.348	3.644

Figure 2. Maize harvested area and productivity in Kampar Regency in 2013-2022

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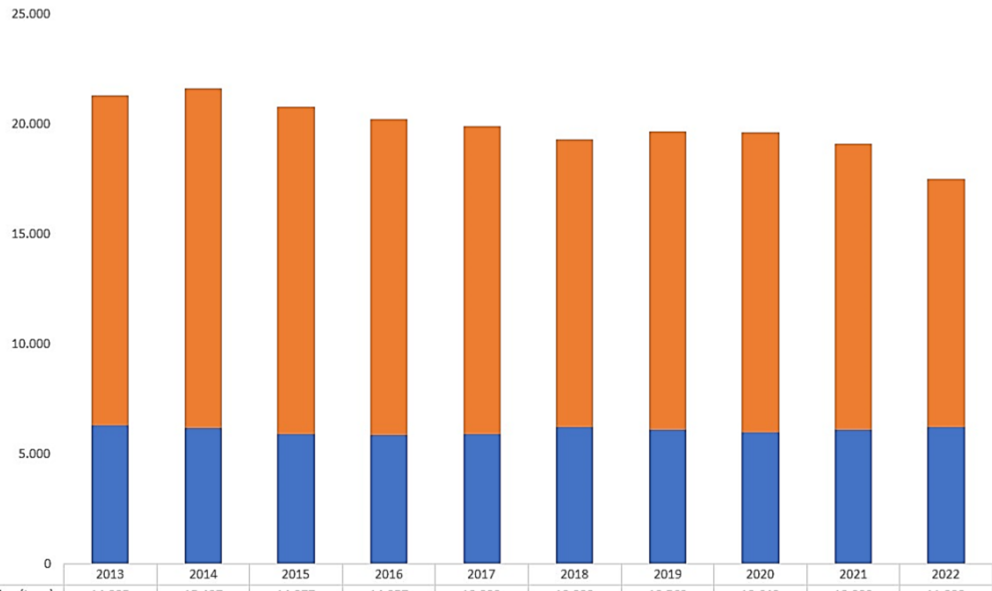
According to the data presented in Figure 2, there has been a consistent and notable growth in maize productivity within the Kampar region from 2013 to 2022. Furthermore, it is observed that this increase has resulted in a rather stable trend over the specified period. The year 2017 witnessed the highest level of productivity, reaching 13,773 tonnes, while the lowest level was observed in 2013, amounting to 10,114 tonnes. The augmentation of productivity yields on maize agricultural land can be impacted by the annual expansion of harvested land area. Based on the research results of Chandio et al. [29] the results of this study indicate that environmental factors such as CO^2 emissions, temperature, rainfall, as well as agricultural practices such as the area of cultivated land and use of fertilizers greatly influence corn production in Nepal. Understanding the relationship between these factors can help in planning and managing sustainable maize production. Consistent with the findings of Sampa et al. [30], who conducted a study in Bangladesh, it was determined that the primary determinant of maize productivity was the quality of the seeds used. According to Mazvimbakupa et al. [31], employing seeds that possess superior variations might enhance resistance against pests and diseases. Additionally, the utilisation of such seeds can lead to improved plant response to fertilizers, hence influencing both the quantity and quality of production.

The productivity of maize is subject to various factors, including temperature, rainfall, soil fertility, pests and diseases, weather variability, over-cultivation, extension contacts, market accessibility, land allocation for maize cultivation, farming experience, seed sowing techniques, fertilizer application rates, and the extent of agricultural land [27, 28, 30]. The process of plant growth can be influenced by variations in temperature. Elevated temperatures can adversely affect the water availability in plants and soil, hence impeding the growth of maize. According to the study conducted by Salika & Riffat [33] a rise in air temperature of 5°C is associated with a subsequent reduction in corn yield of 40%.



	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Maize production (tons)	14.995	15.427	14.877	14.357	13.992	13.089	13.562	13.648	12.982	11.288
Cultivated plant area (ha)	6.298	6.212	5.923	5.874	5.914	6.221	6.114	5.992	6.113	6.225

Figure 3. Maize harvested area and productivity in Pelalawan Regency in 2013-2022

In relation to Pelalawan Regency, it can be shown from Figure 3 that there has been a discernible decline in maize productivity between the years 2013 and 2022. The year 2014 witnessed the highest level of productivity, reaching 14,995 tonnes, while the year 2022 recorded the lowest level, amounting to 11,288 tonnes. According to Rustam [34], it was determined that the Pelalawan area exhibits the most significant decrease in grain output within Riau Province. The study's results also indicated that a significant factor contributing to the decrease in maize agricultural output in Pelalawan Regency was the presence of 13 distinct varieties of OTP (organisms that disrupt plant growth), including pigs, cob borers, and stem borers. This implies that the efficiency of corn cultivation in Pelalawan district is susceptible to disruptions caused by pests. Dube & Abebe [32] similarly discovered that insect infestation significantly impacts the production of maize agriculture in Ethiopia. To significantly enhance water, use efficiency in maize cultivation, it is crucial to establish an irrigation interval scenario and implement a planting hole system.

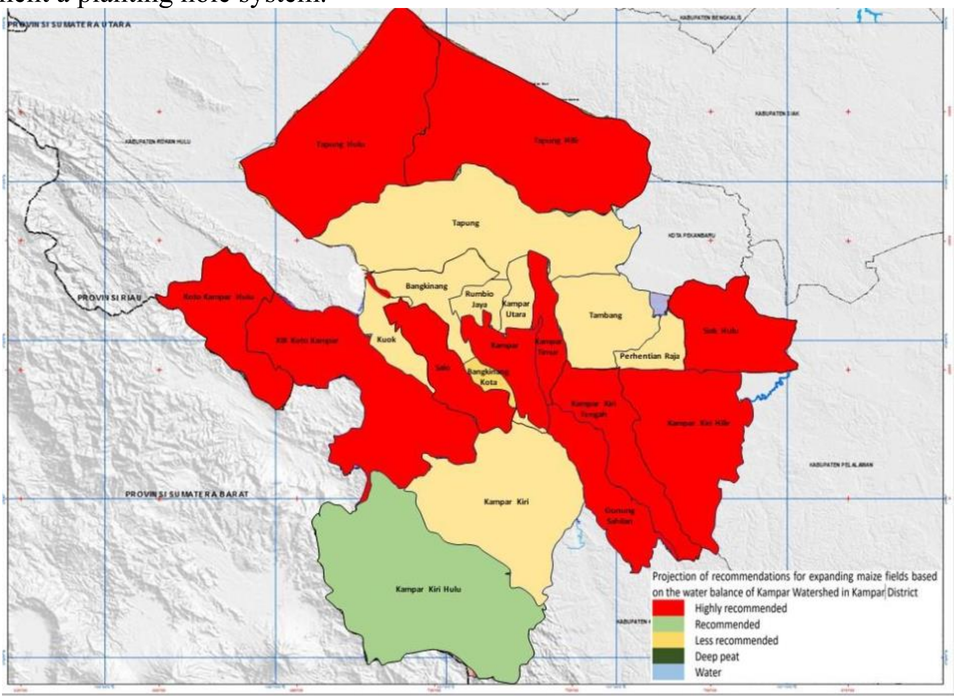


Figure 4. The recommendation to expand maize cultivation is projected based on the water balance analysis of the Kampar Watershed in Kampar District

Based on water balance analysis in the Kampar Watershed of Kampar District (Figure 4), it is projected that 11 sub-districts demonstrate high suitability for the establishment of maize production centers. These districts include Koto Kampar Hulu, XIII Koto Kampar, Salo, Kampar, Kampar Timur, Kampar Kiri Hilir, Kampar Kiri Tengah, Gunung Sahilan, Siak Hulu, Tapung Kiri, and Tapung Kanan. Notably, five of these sub-districts, namely Tapung Hulu, Tapung Hilir, Koto Kampar Hulu, Kampar Timur, and Siak Hulu, have consistently been key hubs for maize production in Kampar Regency. However, between 2018 and 2022, the area dedicated to maize cultivation has declined due to land being repurposed, particularly for palm oil plantations. Based on Ngadi & Nagata [35], Sudrajat et al. [36], Indonesia has emerged as the leading global producer of oil palm due to its substantial expansion of oil palm plantations. Nevertheless, there is concern that the extensive expansion of oil palm cultivation may pose a threat to the nation's food security.

Moreover, it is suggested that one district, namely Kampar Kiri Hulu, be designated as a maize centre for development purposes. The Hulu Koto Kampar and XIII Koto Kampar sub-districts exhibit a substantial water surplus owing to their geographical location in the upper sections of the Kampar Kanan River, which falls within the Kampar Watershed region. Related with Isyandi [37] found that the geographic condition of Kampar is a potential land for the development of food crop, included maize. Nevertheless, it is imperative to consider certain elements pertaining to the role of these two districts as protective and conservation areas for the Suligi Nature Reserve and the Bukit Bungkuk Nature Reserve. The mountainous topography of the Kampar Kiri Hulu District can be attributed to its location within the Bukit Barisan Mountain range, its proximity to the upper reaches of the Kampar Kiri River, and its inclusion within the Bukit Rimbang-Bukit Baling Wildlife Reserve area [38]. In addition, it should be noted that there exist nine sub-districts which are not deemed suitable for corn cultivation due to ongoing development activities focused on transforming these areas into oil palm plantations, industrial forest plantations, and other purposes. The sub-districts include Kuok, Bangkinang, Bangkinang Kota, Rumbio Jaya, Tapung, Tambang, Perhentian Raja, and Kampar Kiri. Tapung District, specifically Tapung Hulu, is intersected by two substantial rivers, known as the Tapung Kiri and Tapung Kanan rivers. These rivers subsequently merge and run downstream into the Siak River, ultimately forming the Siak Watershed [39].

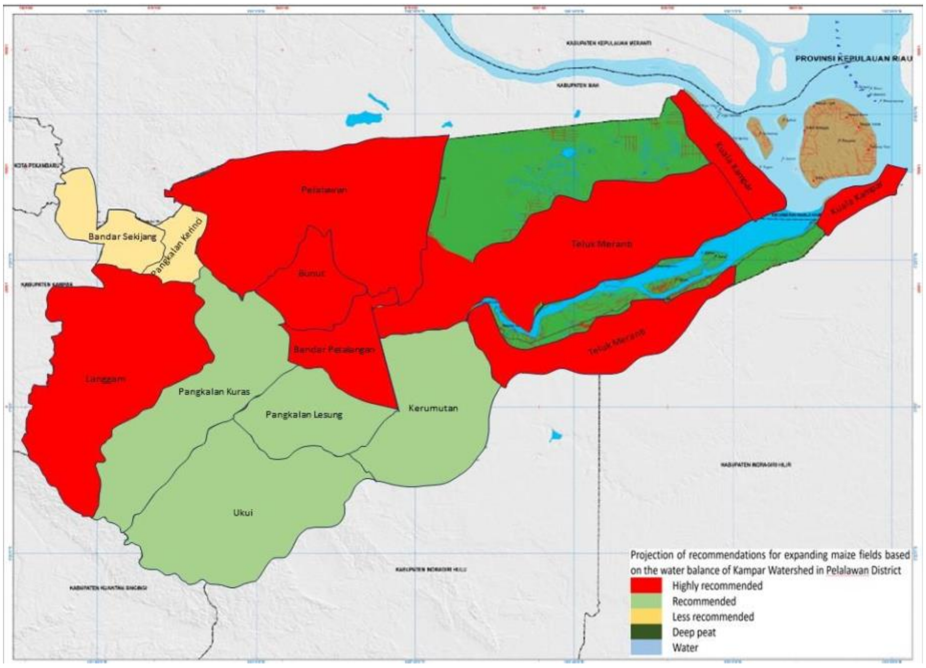


Figure 5. The recommendation to expand maize cultivation is projected based on the water balance analysis of the Kampar Watershed in Pelalawan District

Based on the projections from the water balance analysis of the Kampar Watershed in Pelalawan District (Figure 5), six districts—Teluk Meranti, Kuala Kampar, Pelalawan, Bunut, Bandar Petalangan, and Langgam—are recommended as potential maize production centers. Teluk Meranti and Kuala Kampar are already established maize production hubs within Pelalawan Regency, representing two of the six identified districts. However, in Teluk Meranti, a large portion of the land, approximately 63%, consists of deep peat, making it unsuitable for conversion to corn plantations due to its location within the protected areas of the Tasik Serkap Wildlife Reserve and the Tasik Besar Serkap Wildlife Reserve. Additionally, four districts—Pangkalan Kuras, Pangkalan Lesung, Ukui, and Kerumutan—have been identified as promising areas for further expansion and development of maize cultivation. However, it is important to note that both Kerumutan and Ukui include designated conservation areas, namely the Kerumutan Wildlife Sanctuary and Tesso Nilo National Park. Furthermore, two districts, Bandar Sekijang and Pangkalan Kerinci, are deemed unsuitable for maize production due to ongoing land conversions for oil palm plantations, industrial tree plantations, and other land uses.

3.2. Maize water footprint

The conducted research revealed that the cumulative water footprint (WF) associated with maize agricultural production in the vicinity of the Kampar watershed amounts to 42.92 m^3 per ton. Figure 6 illustrates the comparative analysis of the WF values pertaining to the colours green, blue, and grey in maize plants across the districts of Kampar, Pelalawan, and Kampar watershed.

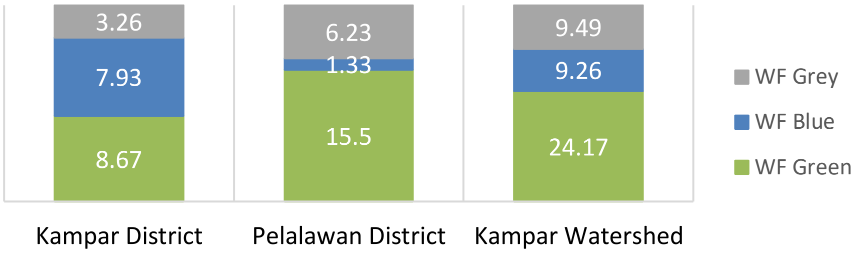


Figure 6. WF (green, blue, grey) values of corn plants in Kampar, Pelalawan, and Kampar watershed districts

According to Figure 6, the primary water footprint component utilised in corn cultivation within the Kampar watershed is the green water footprint, which amounts to 24.14 m^3 per ton. In contrast, the relative values for the footprint of blue and grey water are nearly identical, measuring 9.26 and 9.49 m^3 per ton. This indicates that rainwater is predominantly utilised for irrigation purposes in corn cultivation within the examined region. According to the research conducted by Arrien et al., [40], it has been determined that a significant proportion, specifically 89%, of maize cultivation in Argentina is attributed to green water footprint (WF). Tozzini et al. [3] and Gerbens-Leenes & Hoekstra [41] also observed a similar finding, namely that corn cultivation in several major maize-producing nations exhibits the greatest green water footprint (WF) value when compared to blue and grey WF values.

The green water footprint (WF) value of corn growing in Kampar district is recorded as 8.67 m^3/ton, which is somewhat like the blue WF value of 7.93 m^3/ton. The grey waste fraction with the lowest numerical value among the other components is recorded as 3.26 cubic meters per metric ton. This observation aligns with the conclusions drawn by Bulsink et al. [42], who found that the grey value represents the least significant wavefront component in maize cultivation practices in Indonesia. The diminished worth of wastewater (WF grey) exhibits positive ecological implications. However, the anticipated escalation in fertilizer usage may have an influence on the augmentation of grey's value. Duan et al. [43] reported that the average annual water footprint (WF) for maize production was 1029 m^3/ton, with 51% attributed to green water, 21% to blue water, and 28% to grey water. The highest water footprints for maize production were observed in Liaoning Province, followed by moderate values in Heilongjiang Province, and the lowest in Jilin Province, indicating substantial regional variations across the 36 main maize-producing prefectures in Northeast China. In the Kampar region, the green water footprint for maize cultivation was recorded at 8.67 m^3/ton, slightly exceeding the blue water footprint of 7.93 m^3/ton. The grey waste fraction component with the lowest numerical value among the other components is 3.26 cubic meters per ton. This observation aligns with the conclusions made by Bulsink et al. [42] which indicate that the grey value represents the least significant water footprint component in maize cultivation practices in Indonesia. The diminished magnitude of water footprint (WF) in grey water has positive implications for environmental sustainability. However, it is anticipated that the future escalation in fertilizer usage will have a consequential effect on the augmentation of grey water value. According to the study conducted by Duan et al. [43], the mean annual water footprint (WF) for maize production was determined to be 1029 m^3/ton. The water footprint (WF) allocation was distributed in the following manner: 51% for green water, 21% for blue water, and 28% for grey water. The water footprint (WF) associated with maize cultivation had the highest values in Liaoning Province, intermediate values in Heilongjiang Province, and the lowest values in Jilin Province. The study identified notable disparities in the calculated water footprints (WFs) across the 36 key maize production prefectures in Northeast China.

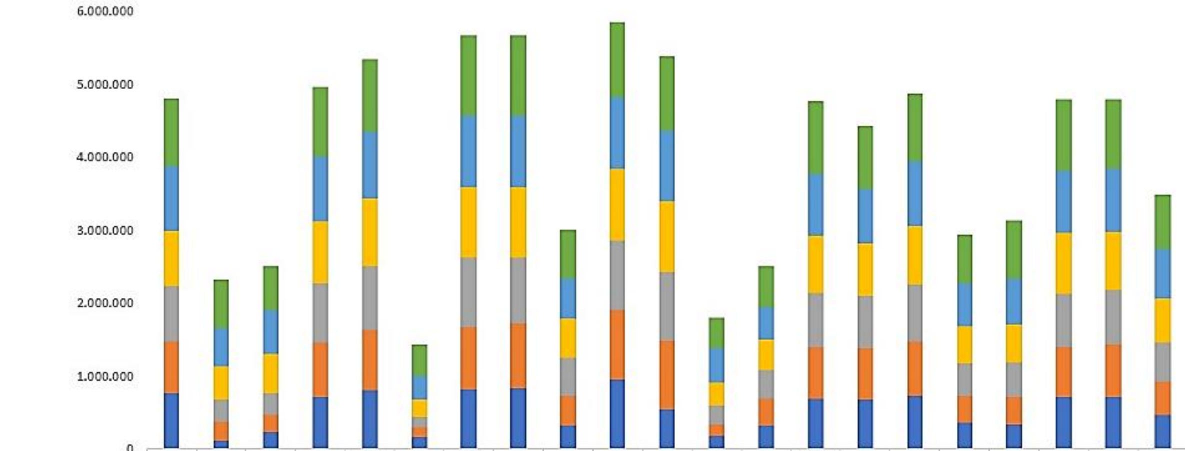
The green water footprint (WF) value in maize cultivation within the Pelalawan district is recorded at 15.5 m^3/ton, which significantly surpasses the blue and grey WF values. The water footprint (WF) value associated with maize production in the Pelalawan district is merely 1.33 m^3 per ton. The diminished blue water footprint (WF) can be attributed to precipitation in the Pelalawan district, which provides ample water for maize cultivation, hence reducing the reliance on supplementary irrigation from groundwater reservoirs. In a study by Han et al. [7], the yearly average total water footprint (WF) of wheat and maize production is estimated to be 20.1 billion m^3 year−1 (composed of 52% green, 29% blue, and 19% grey water) and 15.1 billion m^3 year−1 (composed of 73% green, 3% blue, and 24% grey water), respectively. The proportion of grey water footprint (WF) is significantly higher than the global average, although wheat has a greater unit WF (1580 m^3 t−1) compared to maize (1275 m^3 t−1). The data reveals that the water use efficiency of both wheat and maize, as measured by the unit WF, has exhibited a consistent pattern of exponential decline. This suggests that efforts to enhance water utilisation have been successful. The spatial distribution of the WF unit exhibits heterogeneity, with larger proportions observed in Tianjin and Huanghua, while lesser proportions are found in the Southern Haihe River Basin. Therefore Tozzini et al. [3] revealed that the mean annual total water footprint values for soybean, corn, and wheat crops in the Pergamino district, located in the province of Buenos Aires, for the period of 2013-2018 were determined to be 1,388 l·kg−1, 693 l·kg−1, and 1,249 l·kg−1, respectively. The reference values observed were below the global average. The results collected from this study have provided valuable insights for further analysis and advancement in understanding the utilisation of water productivity in grain production. According to Ewaid et al. [44], Jamshidi et al. [45], Song et al. [46], low precipitation results in plants requiring additional irrigation, which has a significant impact on the high value of blue water footprint (WF).

Modifications in crop composition have a direct impact on the utilisation of irrigation resources, commonly referred to as water footprint in terms of blue water consumption (WFblue). Additionally, such alterations also have an indirect influence on the release of environmental contaminants, which may be quantified by the measurement of grey water footprint (WFgrey). Modifications to crop composition have a direct impact on the utilisation of irrigation resources, commonly referred to as water footprint in terms of blue water consumption (WFblue). Additionally, these alterations have an indirect influence on the release of environmental contaminants, which may be quantified by the measurement of grey water footprint (WFgrey). If there is a persistent decrease in precipitation and a simultaneous increase in temperature over a period, it is guaranteed that these climatic changes will have an impact on the water footprint (WF) of agricultural output [41, 42]. The examination of these consequences warrants a comprehensive analysis, which has the potential to yield useful insights for the field of water resource management.

3.3. Maize water footprint sustainability

Maize plants exhibit a notable degree of resilience when faced with limited water availability during both the vegetative and maturity stages [43-45]. Nevertheless, in the event of water scarcity occ.urring from the flowering phase until seed filling, it can lead to desiccation of the female flowers/cobs, thereby impeding the seed filling process and adversely impacting production [52]. Consequently, it is imperative to ensure an adequate water supply to uphold the long-term viability of corn cultivation. Enhancing water productivity can be achieved by adopting a modest yet efficient approach to water usage [5, 47]. This can be accomplished by implementing strategies such as integrated soil and water management, in conjunction with advancements in plant breeding techniques.

Understanding the temporal variations in water abundance and scarcity within a given region is crucial for effectively managing cropping patterns and scheduling irrigation activities. By utilising water balance calculations as a foundation for decision-making, it is anticipated that the implementation of such management strategies will lead to enhanced agricultural productivity and sustainability. The application of climate or weather forecasts for the purpose of predicting optimal planting seasons and cropping patterns involves the assessment of rainfall patterns and the water balance within a given geographical region. The analysis of rainfall and evapotranspiration is crucial for estimating water availability and identifying periods of water excess or deficit in each area. This information is obtained through water balance calculations. The water balance provides an assessment of the quantity of water utilised and anticipated future water requirements. The subsequent water balance analysis pertains to maize cultivation in the Kampar and Pelalawan Regencies throughout the period spanning from 2022 to 2043.

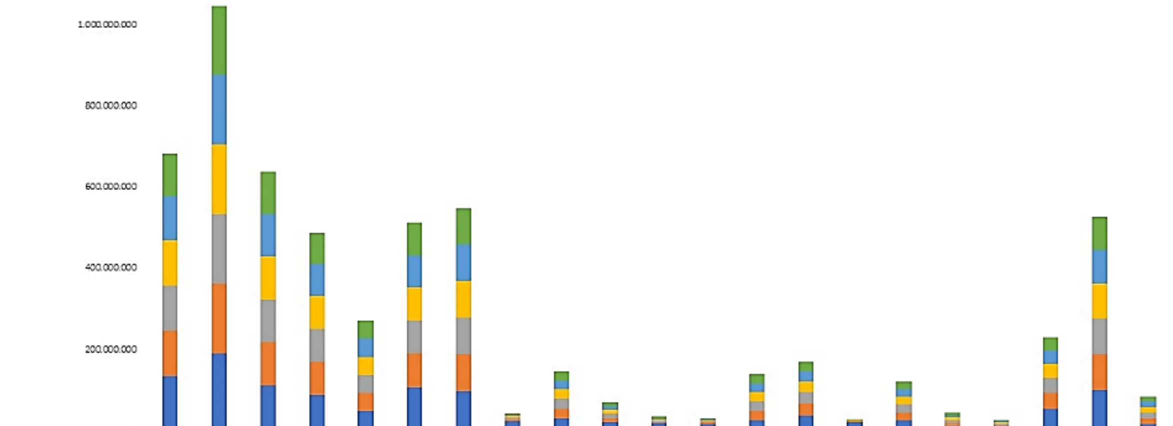


	Kampar Kiri	Kampar Kiri Hulu	Kampar Kiri Hilir	Gunung Sahilan	Kampar Kiri Tengah	XIII Koto Kampar	Koto Kampar Hulu	Kuok	Salo	Tapung	Tapung Hulu
Water used (m3/year) 2043	935.193	674.128	601.094	952.559	993.538	428.090	1.093.773	1.098.245	671.708	1.036.076	1.021.087
Water used (m3/year) 2038	885.039	516.085	599.541	895.510	925.236	328.506	980.737	980.114	550.324	983.398	978.794
Water used (m3/year) 2033	760.127	458.049	538.818	851.861	916.938	240.611	968.955	963.594	533.080	974.246	965.027
Water used (m3/year) 2028	759.332	300.024	307.688	807.718	888.646	134.256	958.323	898.539	520.165	962.238	943.147
Water used (m3/year) 2023	714.025	268.670	234.254	743.403	817.616	131.449	849.564	892.796	405.591	950.387	940.796
Water used (m3/year) 2022	762.744	108.267	227.561	717.921	807.812	171.281	821.887	834.661	328.711	950.323	542.182

	Tapung Hilir	Bangkinang Kota	Bangkinang Seberang	Kampar	Kampar Utara	Rumbio Jaya	Kampar Utara	Tambang	Siak Hulu	Perhentian Raja
Water used (m3/year) 2043	414.554	563.910	993.464	860.977	938.827	663.537	797.244	980.757	957.251	745.992
Water used (m3/year) 2038	473.307	439.139	841.864	743.869	884.247	589.680	622.849	854.440	868.345	673.983
Water used (m3/year) 2033	304.408	417.837	792.258	729.609	793.983	516.752	519.543	836.151	796.119	603.442
Water used (m3/year) 2028	271.588	399.650	744.484	717.949	787.207	444.676	477.230	724.896	738.304	534.240
Water used (m3/year) 2023	154.142	365.719	707.527	700.375	753.718	364.980	385.123	690.445	724.802	462.225
Water used (m3/year) 2022	177.921	317.681	687.922	677.622	722.779	358.127	329.775	710.427	716.512	463.498

Figure 7. Projection of water use balance (m^3/year) for maize in 2022-2043 in the Kampar Watershed in Kampar Regency

The water usage prediction (m^3/year) for maize cultivation in the Kampar watershed, located in Kampar Regency, is significantly impacted by the extent of the maize planting area. This influence is particularly pronounced in various sub-districts that have historically served as major maize-producing hubs, as depicted in Figure 7. The forecasts for each year are influenced by the development of the maize growing area in Kampar Regency (Figure 4). When comparing Figure 8 to the projection of water availability (m^3/year) for the period of 2022-2043 in the Kampar Watershed located in Kampar Regency, it becomes evident that there is a significant surplus of water availability. This observation indicates that the expansion of the maize planting area in the District of Kampar will not encounter any obstacles in terms of water availability (as depicted in Figure 9). Consequently, this district has the potential to achieve self-sufficiency in maize production, thereby enabling the development of downstream derivatives due to the ample supply of maize.



	Kampar Kiri	Kampar Kiri Hulu	Kampar Kiri Hilir	Gunung Sahilan	Kampar Kiri Tengah	XIII Koto Kampar	Koto Kampar Hulu	Kuok	Salo	Tapung	Tapung Hulu
Available Water (m3/year) 2043	106.662.14	170.681.65	104.955.08	78.063.063	45.213.381	79.549.567	89.785.612	1.234.692	22.571.376	9.354.176	2.702.356
Available Water (m3/year) 2038	108.312.29	171.039.69	105.286.17	79.120.112	44.981.683	80.249.152	89.898.647	2.402.823	22.892.760	9.675.855	3.004.649
Available Water (m3/year) 2033	109.937.20	171.397.73	105.617.31	80.163.761	44.749.982	80.947.046	90.010.429	3.569.343	23.210.004	9.976.007	3.258.416
Available Water (m3/year) 2028	111.538.00	171.755.76	105.948.44	81.207.904	44.518.273	81.643.401	90.121.061	4.734.398	23.522.919	10.258.014	3.480.296
Available Water (m3/year) 2023	113.183.30	172.087.11	106.321.87	82.272.219	44.289.304	82.446.208	90.229.820	6.140.142	23.837.492	10.539.866	3.682.647
Available Water (m3/year) 2022	133.197.33	189.355.78	110.556.13	87.015.622	48.106.919	106.577.65	98.079.384	22.032.937	30.243.084	20.590.253	17.623.443

	Tapung Hilir	Bangkinang Kota	Bangkinang Seberang	Kampar	Kampar Utara	Rumbio Jaya	Kampar Utara	Tambang	Siak Hulu	Perhentian Raja
Available Water (m3/year) 2043	1.136.431	22.319.036	23.795.444	1.629.733	18.447.493	6.529.736	2.120.943	31.943.348	81.821.323	13.485.127
Available Water (m3/year) 2038	504.816	22.443.806	25.147.044	0	18.702.073	6.603.594	2.395.338	33.569.664	83.510.230	13.557.136
Available Water (m3/year) 2033	2.073.715	22.565.109	26.496.650	1.201.635	18.952.337	6.676.522	2.668.644	35.187.953	85.182.455	13.627.678
Available Water (m3/year) 2028	3.606.534	22.683.295	27.844.424	1.113.295	19.199.113	6.748.597	2.940.957	36.799.208	86.840.271	13.696.879
Available Water (m3/year) 2023	5.123.980	22.817.227	29.181.381	2.130.869	19.432.602	6.828.294	3.233.064	38.433.660	88.463.772	13.768.894
Available Water (m3/year) 2022	15.278.122	25.782.946	36.888.908	19.831.244	25.186.320	11.193.273	11.618.187	54.124.104	100.378.57	16.231.119

Figure 8. Projected balance of water availability (m^3/year) for 2022-2043 in the Kampar Watershed in Kampar Regency

When advocating for more environmentally friendly diets, it is crucial to consider these WFs. For most food items, green water (rainwater) constitutes the largest component of WFs, while blue (irrigation) and grey (polluted) water footprints are generally smaller. However, it is important to recognize the significant environmental impacts posed by blue and grey water. Notably, 57% of the global blue water footprint is unsustainable, driven largely by six crops: wheat, rice, cotton, sugarcane, fodder, and maize. These unsustainable practices are concentrated in the U.S. and much of Asia. With expected population growth and dietary shifts, such as increased crop consumption, water demand is projected to rise significantly [5,54]. In their study, Gheewala et al. [55] observed significant disparities in crop water requirements across various geographies, which can be attributed to a multitude of reasons. Nevertheless, according to the existing farming systems, it can be observed that the Northeastern region exhibits the most substantial need for water, encompassing both green water (i.e., rainwater) and blue water (i.e., irrigation water). Rice (paddy) cultivation necessitates the greatest volume of irrigation water, around 10,489 million m^3/year, surpassing other crops such as maize, sugarcane, oil palm, and cassava. Haruna et al. [8] found in their study that one potential method for enhancing water use efficiency in maize cultivation involves the establishment of an irrigation interval scenario and the implementation of a planting hole system.

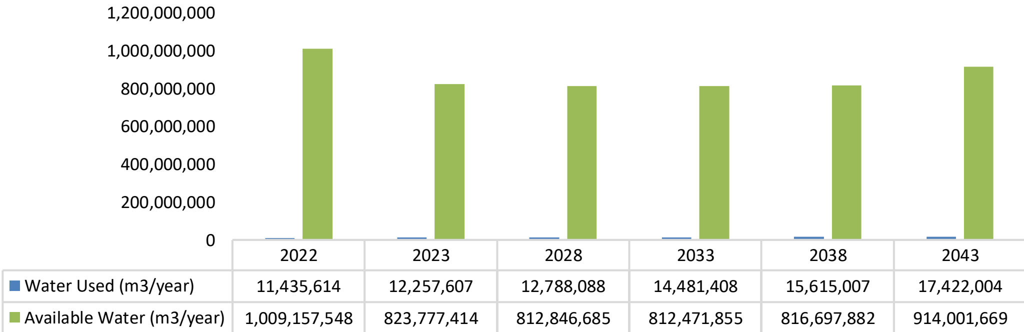
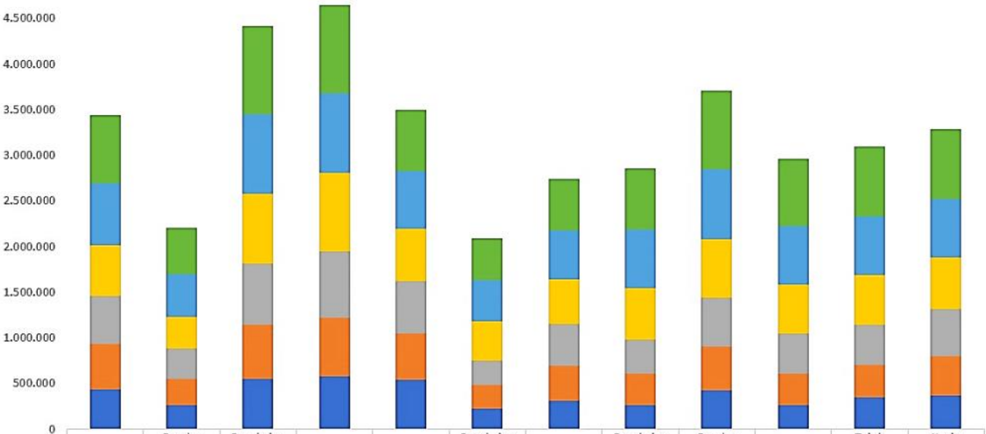


Figure 9. Comparison of projected water balance between water used (m^3/year) and water availability (m^3/year) in 2022-2043 in the Kampar Watershed in Kampar Regency

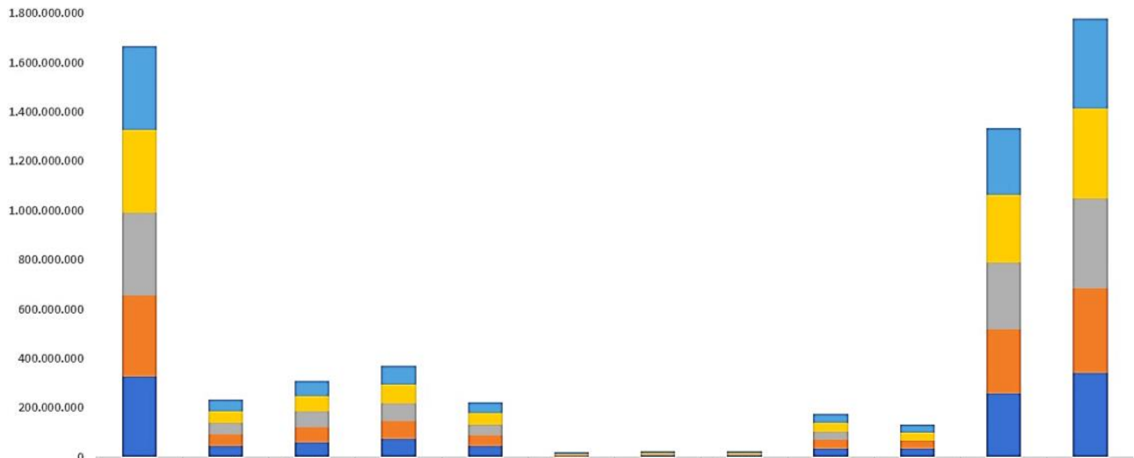
The influence of the corn planting area on the projection of water use (m^3/year) for maize in the Kampar Watershed in Pelalawan Regency during the period of 2022-2043 is evident when examining Figure 10. This influence is particularly pronounced in several sub-districts that have historically served as significant centres for maize production. The forecasts for each year are influenced by the development of the corn growing area in Pelalawan Regency, as depicted in Figure 5. When examining Figure 11, it becomes evident that the projection of water availability (measured in m^3/year) for the period of 2022-2043 in the Kampar Watershed located in Pelalawan Regency reveals a substantial surplus. This observation indicates that the expansion of the maize cultivation area in Pelalawan Regency will not encounter any hindrances in terms of water availability (as depicted in Figure 12). Consequently, this region has the potential to achieve self-sufficiency in corn production, thereby enabling the development of downstream derivatives due to the abundant corn supply. This discovery presents a contrasting perspective to the outcomes of a study conducted by Duffková et al. [56] in the Czech Republic, that the maize-agriculture growing area (AGA) experienced the most severe water deficit among all crops. This can be attributed to the combination of insufficient rainfall and high crop water demand (CWRs).



	Langgam	Bandar Sekijang	Pangkalan Kerinci	Pelalawan	Bunut	Pangkalan Kuras	Ukui	Pangkalan Lesung	Bandar Petalangan	Kerumutan	Teluk Meranti	Kuala Kampar
Water used (m3/tahun) 2043	746.364	512.666	964.664	963.666	664.647	462.666	566.344	677.346	863.627	746.266	768.262	764.337
Water used (m3/tahun) 2038	676.246	464.442	872.646	866.632	636.346	444.766	533.746	642.334	762.434	634.467	637.626	636.276
Water used (m3/tahun) 2033	562.336	346.363	767.666	863.763	577.647	436.626	482.644	564.664	644.272	534.346	542.633	567.246
Water used (m3/tahun) 2028	526.443	334.766	667.434	726.637	566.646	266.646	466.342	367.646	532.366	443.347	444.366	522.234
Water used (m3/tahun) 2023	494.236	287.244	598.126	644.424	512.772	255.721	376.334	344.288	478.991	344.227	357.721	425.662
Water used (m3/tahun) 2022	434.236	262.446	546.664	577.268	536.636	222.466	312.889	263.666	426.663	262.476	343.446	367.662

Figure 10. Projection of water use balance (m^3/year) for maize in 2022-2043 in the Kampar Watershed in Pelalawan Regency

When crops are not getting enough soil water, it causes a deficit in the water balance (WB), resulting in a negative WB. Although the water balance (WB) may be balanced (zero) during the growth period, it is not necessary for the crop water requirement (CWR) to be adequately supplied due to an uneven temporal distribution of water sources [49, 50]. The diminishing supply of water for crop cultivation necessitates the use of effective strategies for managing agricultural land. This involves optimising the soil water balance through appropriate tillage practices, employing drought-resistant crop rotation techniques, and implementing efficient irrigation management [51, 52]. While irrigation has the potential to enhance crop productivity, it is important to note that it typically leads to an increase in the water footprint (WF) of crops. In regions experiencing water scarcity, it is crucial to enhance water utilisation efficiency to mitigate the overexploitation of groundwater resources. The implementation of deficit irrigation has been extensively employed to save groundwater resources through improved consideration of agricultural output and water consumption [57-58].



	Langgam	Bandar Sekijang	Pangkalan Kerinci	Pelalawan	Bunut	Pangkalan Kuras	Ukui	Pangkalan Lesung	Bandar Petalangan	Kerumutan	Teluk Meranti	Kuala Kampar
2038	337.433.364	47.623.711	62.767.646	76.332.333	44.673.674	4.333.636	4.876.447	5.113.734	35.423.662	33.464.766	272.346.363	363.746.277
2033	336.646.326	47.112.664	62.232.436	74.364.663	44.646.673	3.987.646	4.667.644	4.666.444	35.332.224	33.126.226	272.112.246	363.713.455
2028	335.647.223	46.666.327	61.544.263	73.326.624	44.637.364	3.665.366	4.642.666	4.644.467	34.876.636	0	271.644.423	363.666.663
2023	327.374.426	46.444.662	61.336.732	73.363.336	44.376.424	3.342.766	4.344.264	4.342.343	34.746.463	32.646.766	259.446.327	342.876.336
2022	327.335.733	46.366.811	61.319.952	73.328.852	44.299.421	3.201.884	4.199.567	4.307.734	34.703.771	32.577.898	259.008.782	342.544.217

Figure 11. Projected balance of water availability (m^3/year) for 2022-2043 in the Kampar Watershed in Pelalawan Regency

Establishment of a water balance serves as a fundamental framework for assessing the potential of climate, soil, and plants, thereby facilitating the strategic planning of agricultural production [60]. The purpose of this study is to present significant data regarding the net quantity of water that can be obtained, the monetary value of the excess water that cannot be accommodated, and the timing of water balancing occurrences. Hence, these data can serve as a foundation for the strategic development and administration of diverse undertakings, such as the construction of a reservoir for the purpose of water retention and distribution, as well as the exploration of potential applications of natural water resources for a multitude of other endeavours.

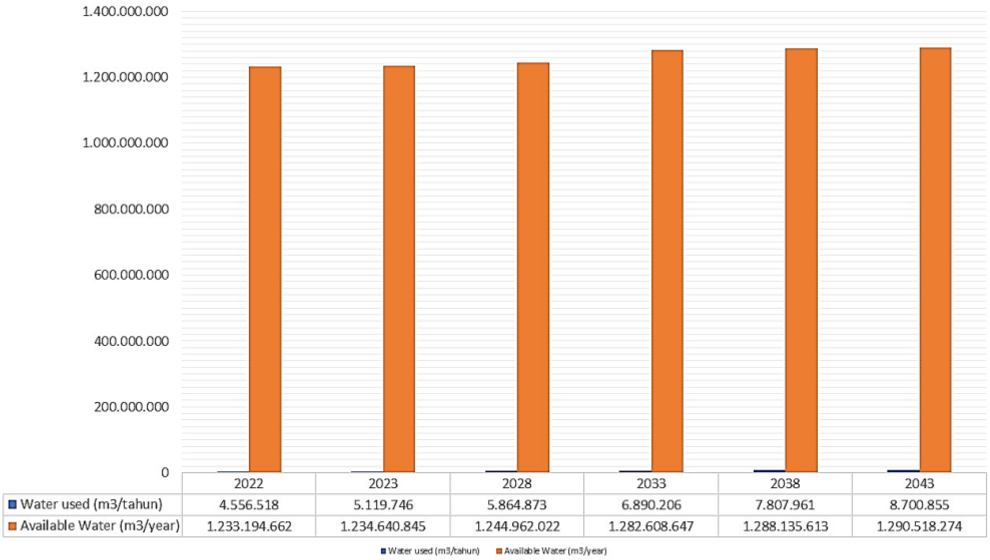


Figure 12. Comparison of projected water balance between water used (m^3/year) and water availability (m^3/year) in 2022-2043 in the Kampar Watershed in Pelalawan Regency

Based on the analysis of Figure 4-12, it can be inferred that the Kampar Watershed is expected to have a substantial water supply for the next two decades, until the year 2043. This projection suggests that there is potential for significant expansion of the maize planting area in Kampar and Pelalawan Regencies, enabling these districts to become self-sufficient as a prominent corn producing hub within Riau Province. According to Stricevic et al. [59], their simulations suggest that during the 2020s, there would be negligible alterations in irrigation requirements and crop output resulting from the advancement of sowing dates and the overall shift of the growing season towards early spring. The negative consequences of climate change are projected to intensify in the coming decades, with a somewhat greater impact expected by the 2050s and a more substantial impact by the 2080s. This escalation can be attributed to a decline in summer precipitation levels. In comparison to the reference period, it is anticipated that irrigation demands in the 2080s will witness an almost 100% rise, namely from 100 to 200 mm, while concurrently resulting in a potential yield gain of up to 30%. In the coming years, maize water productivity is projected to remain at elevated levels, surpassing current rates for both rainfed and irrigated systems. This trend is attributed to a combination of factors, including a contraction in the growing season, reduced crop evapotranspiration, and increased atmospheric CO^2 concentrations. Expected changes in precipitation patterns, with more rainfall in early spring followed by a decline in the May-June period, are likely to raise the blue-to-green water ratio, which may yield positive environmental outcomes. Moreover, the productivity of blue water resources is expected to improve. Shi et al. [56] concluded that optimizing maize planting density, irrigation volumes, and the allocation of farmland can simultaneously enhance food security and promote more efficient use of water and land resources. Furthermore, it is noteworthy that factors such as water price, the origin of irrigation water, the adoption of irrigation technology, as well as the educational background and farming experience of farmers, exhibit substantial beneficial effects on the efficiency of irrigation water utilisation [4,61].

4. Conclusions

The findings indicated that the overall water footprint of agriculture in the Kampar watershed was 42.94 m^3 per ton. In Kampar district, the water footprint for maize production comprised 8.67 m^3/ton of green water, 7.93 m^3/ton of blue water, and 3.28 m^3/ton of grey water. In Pelalawan district, maize had a green water footprint of 15.5 m^3/ton, a blue water footprint of 1.33 m^3/ton, and a grey water footprint of 6.23 m^3/ton. The Kampar watershed is projected to maintain significant water resources over the next two decades, up to 2043. This forecast suggests substantial potential for expanding maize cultivation in Kampar and Pelalawan districts, which could position these regions as self-sufficient centers for maize production within Riau Province. To improve the sustainability of water resources, reducing fertilizer use is essential. Additionally, implementing efficient irrigation techniques is a promising strategy for optimizing water use, particularly in areas with abundant water supplies.

The spatial disparities in maize production's water footprint can be mostly attributed to variances in climatic conditions, soil quality, availability of irrigation facilities, and maize output. The analysis of the spatial distribution of water footprints (WFs) can contribute to establishing a scientific foundation for optimizing the distribution of maize production. This, in turn, enables the formulation of policies aimed at reducing the water footprint associated with maize production. Hence, it is imperative to consider the sustainability and rationale behind maize cultivation, since it has the potential to pose risks to local ecosystems and human well-being. These risks include the contamination of water resources and exacerbation of water scarcity.

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