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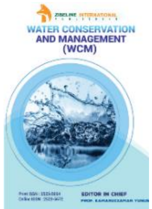

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RESEARCH ARTICLE

RAINWATER AS AN ALTERNATIVE SOURCE OF FRESH WATER IN TELUK AWUR VILLAGE, INDONESIA

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ABSTRACT

Teluk Awur Village is one of the coastal regions in Indonesia that as most region in the coastal area has a water resource problem. The groundwater is exposed to saltwater intrusion, while the surface water is also saline cause the shortage of fresh water. In response to water demand and resource limitations, the utilization of rainwater through rainwater harvesting technology may provide an alternative. Our study focuses on the feasibility and potential study of rainwater utilization as water resource in the village. This study finds that the average annual rainfall in the last two decades in Teluk Awur, approximately 2,109.06 mm, and it sufficient to be harvested to support the water demand in Teluk Awur that will be increasing along with the increase population. The potential for rainwater to be obtained is 25,308.72 m^3 by means it can contribute to 57% of the water demand by 2023 and around 45% by 2040. Even though the projected rainfall is predicted to decrease by around 10% to 20% but the utilization of rainwater as a water resource can preserve the groundwater for the future and thus might change the water cycle and maintain the rainfall.

KEYWORDS

Teluk Awur, rainwater, rainwater harvesting, rainfall, fresh water.

1. INTRODUCTION

The coastal zones are transitional zones between terrestrial and marine ecosystems, driven by socio-physical interactions between land and ocean (Government of Indonesia, 2007). Coastal socio-physical interactions include landscapes and natural resources such as water, soil, and other environmental facilities suitable for human activities, affecting population development (Ridolfi et al., 2017). One of the consequences is salinity issues, resulting in a scarcity of fresh water for the coastal region (Damonte & Boelens, 2019; Pramushinto, Rahajeng, and Ma'rif, 2013). Salinity occurs when seawater enters groundwater as a result of natural disasters such as sea level rise, flooding, and soil erosion, causing groundwater to become salty (Tauhid Ur Rahman et al., 2017). In fact, water scarcity can affect many aspect of life such as the lack of water for drinking water, aquaculture, and fishing; biodiversity and ecosystem loss; health, and social as well as political problems (Tauhid Ur Rahman et al., 2017). The saline water was found 53% in across the region of coastal area, indicating that the majority of population affected by the lack of the fresh water in their region (Tauhid Ur Rahman et al., 2017).

Residents in the northern city of Pekalongan, Indonesia, for example, rely on a subsurface water source that managed by a company to supply their water demands, but as the water quality is not as per the requirement, people returned to using deep groundwater sources (Dwi Sakti Kartika and Helmi, 2019). As a result, the use of deep groundwater becomes excessive and lead to land subsidence to the point where it is lower than sea level, making it even harder to obtain fresh water. In the context of water scarcity and escalating demand for water supply, rainwater harvesting is one possible alternative infrastructure that can save water by trapping it rather than letting it run off (Betasolo and Smith, 2020). The advantages of rainwater harvesting as an alternative to groundwater use in coastal areas include a rainwater harvesting system that provides an independent source of water, simple to maintain because it requires less time and effort, reduce the water bills, reduce the use of groundwater that can prevent floods and soil erosion (Das et al., 2018; Jasper Van Houselt, 2021; Sultana and Mallick, 2015). Meanwhile, the disadvantages are unpredictable rainfall, a high initial cost, regular maintenance because it may become a breeding ground for animals or algae growth, certain types of roofs that can leach chemicals or animal waste, and limited storage due to the small capacity (Das et al., 2018; Jasper Van Houselt, 2021).

The location study focuses on the coastal environment of Teluk Awur Village in Jepara Regency, Indonesia. This village was selected because it is located on the north coast of Central Java Province and has the natural potential of Teluk Awur Beach, which is geared toward tourism. Nowadays, the regional-owned water provider company has provided Teluk Awur's freshwater demand through eight deep wells with a combined capacity of 47.50 liters per second (Jepara, 2020). However, in reality, the actual volume used is only 35.1 liters per second (Jepara, 2020). The water from several deep wells is collected in a reservoir before being channeled to Teluk Awur. Because it only comes from one source, using deep wells excessively could impact the lowering of groundwater, leading to more salinity and tidal flooding (Sony Adiya

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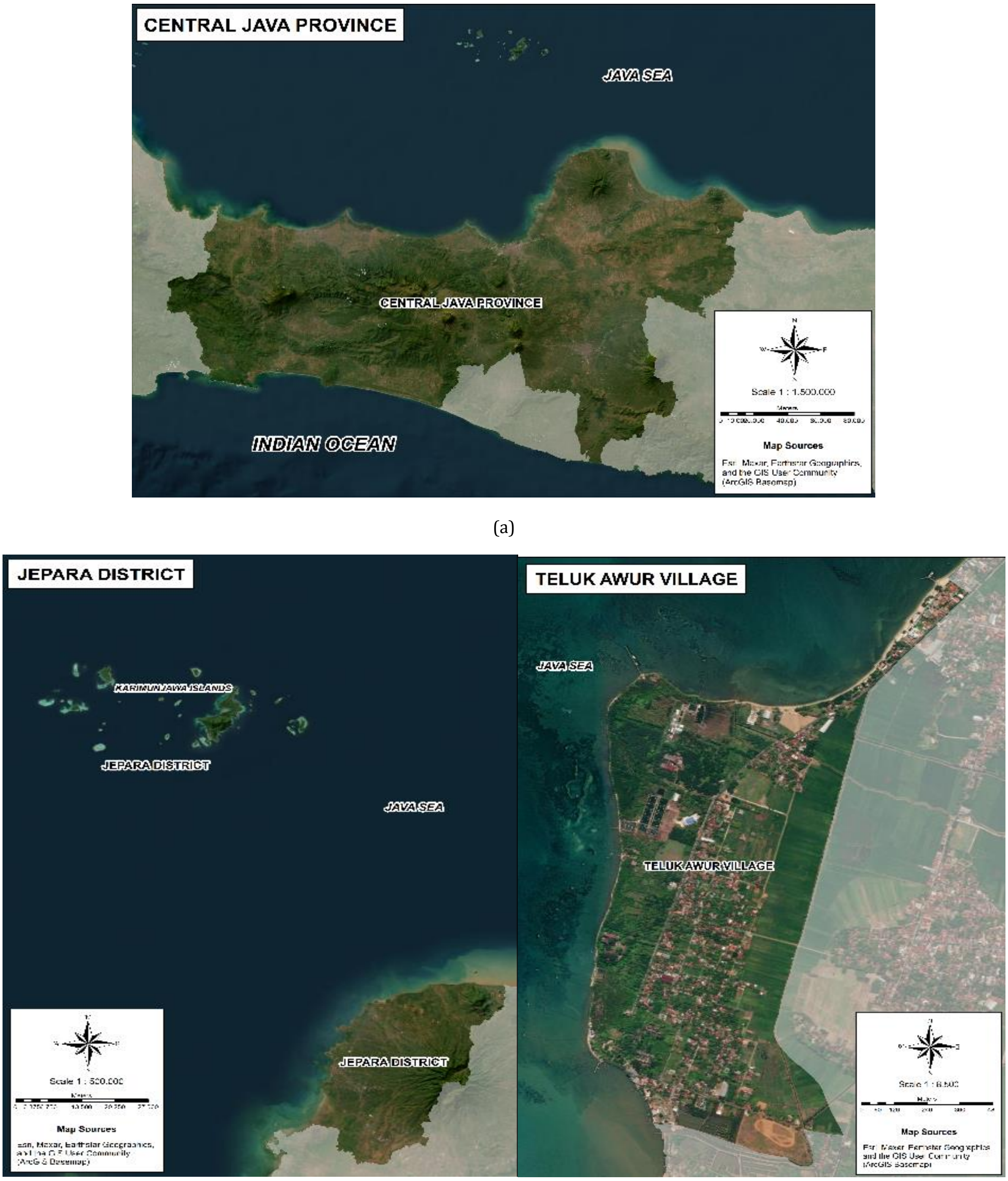
Putra, 2022). Currently, the water salinity level in the village is between 27.8 and 32.2 ppt (Hartati et al., 2021). Those level of salinity needs extensive and expensive water treatment facility before it can be use as sanitation or drinking water. The use of rainwater as a source of fresh water has never been considered by people in Jepara Regency (Jepara, 2020). Therefore, this study aims to investigate the potential of rainwater and its feasibility as raw water in Teluk Awur Village, Jepara, with known rainfall data for the last 20 years.

2. THE STUDY AREA

2.1 Teluk Awur Village

This study is focused on Teluk Awur village, which is a coastal village along the northern coast of Java, Indonesia. The village has approximately 126.67 hectares of land area (Mustofa, 2018), as shown in Figure 1. The annual rainfall over the area varies between 1,100 mm and 3,000 mm. This area has light to moderate rainfall.



(a)

(b) (c)

Figure 1: Map of (a) Central Java Province (b) Jepara Regency and (c) Teluk Awur Village

2.2 Data collection

Rainfall data in Central Java, Jepara, and Teluk Awur were evaluated for the last 20 years (2002 – 2021). The average annual rainfall data for Central Java Province was taken from https://chrsdata.eng.uci.edu. The rainfall data for Jepara Regency from 2002 – 2019 was taken from https://climatecharts.net, and rainfall data in 2020 and 2021 was taken from https://jeparakab.bps.go.id. The rainfall data for Teluk Awur Village was taken from https://power.larc.nasa.gov. The annual number of rainy days is used to compute the rainwater supply. On the other hand, the estimated approach of the water consumption in Teluk Awur Village is estimated based on the population growth projections. The population of Teluk Awur Village in 2020 was 1,921 people (https://jeparakab.bps.go.id). The data will be used as a base for population projection calculation until 2040. While the water consumption per person was assumed around 60 liters per person per day (Jepara, 2020).

3. Methodology

The descriptive quantitative research method was used in this study. The annual average rainfall data in Teluk Awur is presented by comparing the precipitation data with several locations. The data was then used to predict the future rainfall to 2040. In order to find out the water demand in the future, the population projections of the village are calculated by geometric method. By utilizing the projection of rainfall and population the potential for rainwater harvesting in the village can be estimated. These analyses are crucial to understanding the feasibility of using rainwater in Teluk Awur to overcome the problem of water crisis caused by salinity and/or climate change. The limitations of this research are that it uses secondary data to access annual rainfall, population projections, and roof area, and accessing data on Teluk Awur.

3.1 Population projection

Population projection analysis is used to anticipate future population growth and development. The specific purpose of the population projection analysis is to determine the required water needs. The geometric method was chosen because it is simple and effective for capturing the overall population in the future. The population data used covers at least 20 years. The equation depicts the geometric method (Prihanto et al., 2018).

$$P_n = P_o(1+r)^n \quad (1)$$

where, P_n is the predicted year's population (people), P_o is the known year's population (people), r is the population growth rate, and n is the number of intervals. (Wigati et al., 2022).

3.2 Water demand of population

The purpose of calculating the daily clean water demand of the population per capita is to find out the need for water used by residents for potable and non-potable purposes. Rural people require 60 liters per capita per day (Jepara, 2020). Therefore, the daily clean water demands of the population per capita can be calculated with a formula, as shown below (BNPB, 2015).

$$Q_{md} = P_n \times q \times 365 \quad (2)$$

where Q_{md} is the total daily requirement for water (liters), P_n is the number of people, and q is the daily requirement per capita for water use (60 liters per person per day).

3.3 Potential for rainwater harvesting

An annual rainwater catchment potential approach is used to fulfill the water requirements of the rainwater harvesting process. The following equation depicts the potential volume of rainwater that can be collected (Pratama and Hanif, 2022).

$$V_h = C \times th \times A \quad (3)$$

where V_h denotes the volume of rainwater harvesting (liters) and C is the runoff coefficient based on land use. The value of C is between 0.25 and 0.4 because the study location is in a rural setting (Pratama and Hanif, 2022). The symbol th denotes the annual rainfall (mm). The rainfall in Teluk Awur Village is based on average annual rainfall. The symbol A is the cross-sectional area of the rain catcher roof (m^2), and it is assumed that the average roof area in the study location is 30 m^2.

4. Results and Discussions

4.1 Rainfall Data in Teluk Awur Village

As mentioned in previous section, Teluk Awur village, Jepara Regency is located in the Central Java Province of Indonesia. Central Java has experienced the growth of coastal areas in both the north and south, in which the location is in the humid tropics, with a climate affected by the Inter-tropical Convergence Zone (ITCZ) and governed by the Southeast Asian monsoonal wind system (Widyatmanti, 2015). Central Java's location near the southern end of the equator, combined with the ITCZ dynamic, results in a distinct climate and local weather. The annual mean temperature ranges from 24°C to 28.5°C, while the relative humidity ranges from 73% to 86%. The coastal areas have higher temperatures and relative humidity than the rest of Central Java (Widyatmanti, 2015). The average annual rainfall on the coast is 3000 mm and 3200 mm in the uplands (Widyatmanti, 2015). The average rainfall in the Central Java region follows a diurnal trend, with the rain intensity increasing in the morning and decreasing in the afternoon (Fianggoro et al., 2021).

The monsoon influences the pattern of climate in Central Java, particularly its rainfall. The fundamental feature of the monsoon climate is the change in air pressure from Central Asia to Australia every half-year, accompanied by changes in wind direction and seasons (Setiyono et al., 2022). When the monsoon winds approach Central Java Province, their speed slows (Maulana et al., 2022). The monsoon wind influences the rainfall on Central Java's north shore. Although the wind swings further west, this wind brings rainfall over the coast and out to sea (Maulana et al., 2022). Central Java has monsoon winds, with the rainy season extending from October to March and the dry season extending from April to September (Putri et al., 2021).

Table 1 and Figure 2 show the changes in trends over the last 20 years, from 2002 to 2022 of precipitation data in Central Java Province, Jepara Regency, and Teluk Awur Village. Overall, the average rainfall in Teluk Awur Village is the lowest in comparison to the averages of Jepara Regency and Central Java Province. However, the rainfall in Teluk Awur has increased over the last five years, approaching the level of average rainfall in Central Java Province. The following paragraphs provide further details on the rainfall in Teluk Awur Village.

Table 1: Precipitation data in Central Java, Jepara, and Teluk Awur

Year	Precipitation (mm)		
	Central Java	Jepara	Teluk Awur
2002	2273.63	2344.2	1170.70
2003	2175.55	3045.2	1745.51
2004	2363.32	2785.6	1819.34
2005	2341.37	3484.0	1845.70
2006	2539.16	2413.8	2035.55
2007	2737.92	2517.1	1792.97
2008	2860.20	2467.6	2315.04
2009	2262.21	2331.3	2125.20
2010	4345.06	3572.2	3084.96
2011	2942.72	2416.2	1898.44
2012	2771.94	2582.1	2025.00
2013	3242.53	2906.1	2467.97
2014	2383.60	2573.0	2304.49
2015	1997.31	2246.5	1898.44
2016	3357.78	3314.3	2362.50
2017	2499.56	2839.7	2467.97
2018	2240.41	2251.6	1935.35
2019	1905.47	2688.5	1745.51
2020	2694.04	4343.0	2615.62
2021	2902.02	3109.0	2524.96

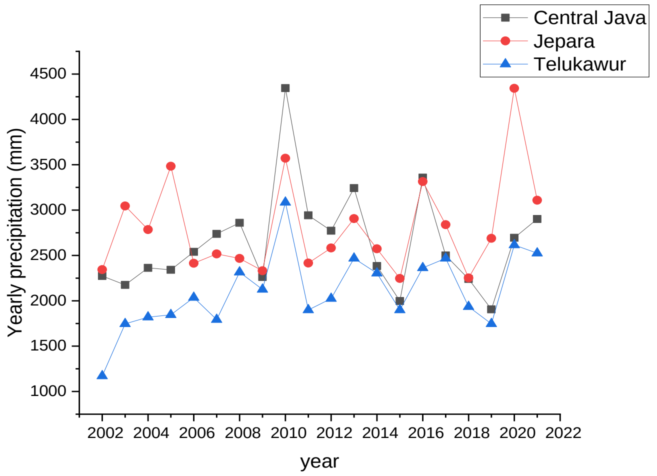


Figure 2: Annual precipitation graph over the last 20 years

The lower rainfall trend in Teluk Awur Village is due to the low altitude of seaside area, which causes the air temperature to be warmer

(Hermawan and Švajlenka, 2022). Because coastal air pressure is higher, air molecules travel swiftly and collide with one another. The monsoon winds influence the relatively high humidity on parts of Java Island in August, September, and October (Gede et al., 2022). However, the tendency of rainfall in Teluk Awur Village in this period continuously increased and was even more consistent than in Jepara Regency and Central Java Province.

Precipitation in these three locations dropped in 2009. This is due to a rainfall anomaly on the island of Sumatera, Java, and the southern half of Kalimantan Island from June to August (Nurdiati et al., 2022). The El-Nino Southern Oscillation (ENSO) and positive Idian Ocean Dipole (IOD) phenomena are to blame for rainfall anomaly (Nurdiati et al., 2022). The ENSO and positive IOD phenomena affect decreasing rainfall in Central Java Province, so drought years occur. ENSO is a phenomenon characterized by anomalous sea surface temperatures in the Pacific Ocean (Nurdiati et al., 2022). ENSO increases the length of the dry season and decreases rainfall (Nurdiati et al., 2022). At the time, Indonesia, particularly Central Java Province, was hit by a moderate El Nino (Nurdiati et al., 2022). The rainy season arrived in late December that year.

The year 2010 had the most rainfall in all three locations, as well as the most in all data. This is due to the La Nina phenomenon that is affecting Indonesia (Nurdiati et al., 2022). In contrast to El Nino, La Nina reduces the length of the dry season (Nurdiati et al., 2022). The sea surface temperature rises by 0.5°C - 2°C as a result of this phenomenon. As a result, air blows more forcefully from the Central Pacific to the Western Pacific or Indonesia. According to the Indonesian Meteorology and Geophysics Agency (BMKG), rainfall in all provinces in Indonesia increased beyond 50 mm/day due to water vapor accumulation, increasing the potential for rain clouds to form. The warm climate in the Indian Ocean may have also contributed to the lower rainfall in 2010 (Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor et al., 2013).

In 2011, rainfall in Teluk Awur fell precipitously. The rainfall in Jepara Regency and Central Java Province also experienced the same situation. In 2011, the rainfall of Teluk Awur decreased from 3,084.96 mm to 1,898.44 mm. This is due to the weak sea surface temperature anomaly (SSTA) during the La Nina phenomenon. In addition, the positive IOD of the sea surface temperature anomaly develops during the dissipation phase of La Nina along the north coast of Sumatera-Java (Lee et al., 2022).

From 2012 to 2019, the rainfall in Teluk Awur fluctuated in the range of 2,000 mm to 1,700 mm. The same pattern of rainfall was also evident in Jepara Regency and Central Java Province. The usual and modest El-Nino phenomena was responsible for the decrease in precipitation in 2014 and 2015 (Nurdiati et al., 2022). The typical air temperature in Teluk Awur is relatively high, with an air humidity of 70% to 90% (BNPB, 2015).

The surge of rainfall in 2016 began in May, during the regular dry season (Ridwan, 2016). Tropical cyclones and the Madden-Julian Oscillation also influence the intensity of heavy rainfall, causing the rainy season to arrive early (Ridwan, 2016). La Nina also occurred that year, but had little impact (Ridwan, 2016). There was a La Nina phenomenon in 2017, although it was on a small scale. There was a regular scale of El Nino in 2018 (Nurdiati et al., 2022), and there was a weak El Nino phenomenon with a positive IOD in 2019 (Nurdiati et al., 2022). In 2020 and 2021, the rainfall in Teluk Awur slightly decreased from 2,615.62 mm to 2,524.96 mm because there was a convergence anomaly, which is the emrgence of a cyclonic low-pressure center in the northern Indian Ocean. Furthermore, it was attributed to the creation of the Australian monsoon wind in Nusa Tenggara and its environs (www.lapan.go.id). Based on this rainfall data, the average annual rainfall in Central Java Province, Jepara Regency, and Teluk Awur Village for the last 20 years were 2,641.79 mm, 2,811.55 mm, and 2,109.06 mm, respectively.

4.2 Projection of future rainfall

Low rainfall in Jepara in 2019 – 2023 is defined as 1,500 – 2,000 mm/year. The rainfall in Jepara is expected to diminish to 1,000 – 1,500 mm/year in 2024 – 2028 (Nurrohman et al., 2021). The BMKG Climate Change Information Center provides data and spatial maps of projected changes in rainfall parameters, particularly for Central Java, at a medium resolution of about 20 km and a high resolution of about 5 km, based on the IPCC RCP 4.5 scenario, which is the result of a regional climate model simulation from 2006 – 2040. The distribution is for the future period (2032 – 2040). Figure 3 illustrates the projected change in seasonal rainfall of Central Java from 2032 – 2040 compared to 2006 – 2014. According to rainfall projection statistics, Jepara has witnessed a 10% - 20% decrease in rainfall, particularly in Teluk Awur. Light to moderate rain is typical in Teluk Awur between January and February, according to historical data.

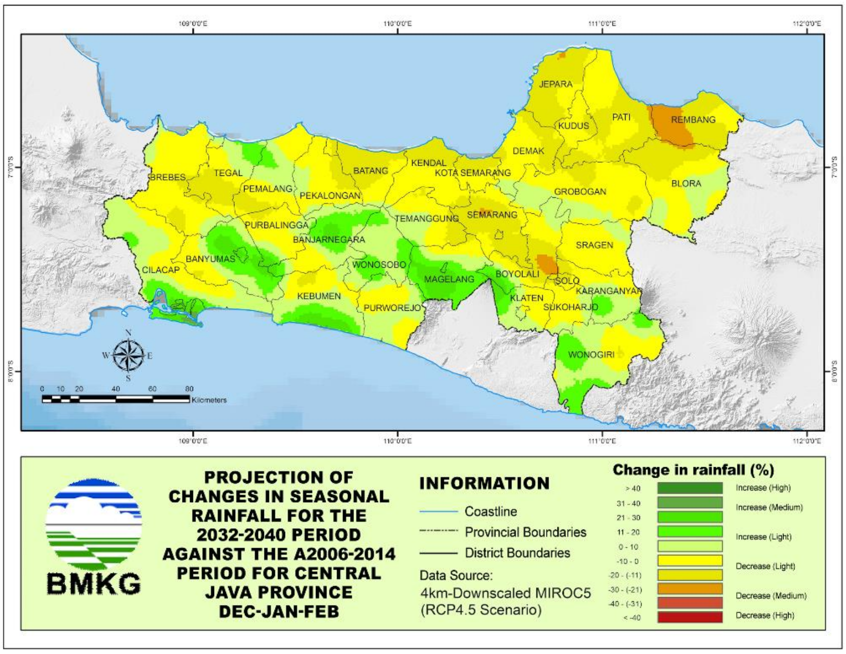


Figure 3: Rainfall projections for Central Java Province from 2032 to 2040 (www.bmkg.go.id)

According to the IPCC special report on Climate Change and Land, warming on land has been occurring at a faster rate than the world average. The average temperature over land was 1.53°C higher between 2006 and 2015 than between 1,850 and 1,900 and 0.06°C greater than the global average temperature change. A rise in temperature and/or a decrease in seasonal rainfall influences the growth season shift and reduces the availability of freshwater (IPCC, 2019). Climate change is affecting more locations as temperatures rise and precipitation changes (Parmesan et al., 2022). According to the IPCC Report on the Impact, Adaptation, and Vulnerability of Climate Change, rising air temperatures and variations in rainfall can alter the hydrological system, altering both the the quantity and quality of water supply (Ara Begum et al., 2022). This causes drought because of an increase in evaporation, resulting in a decline in natural resources followed by a decrease in the volume of water (Awadh et al., 2021).

The interplay of heating, variations in rainfall, and changes in wind strength can alter the salinity and stratification of the water column, changing its oxygen content (Cooley et al., 2022). Reduced rainfall affects energy usage as countries become more reliant on water supply sources (such as desalination and groundwater pumping) (Tse-Hei Lee, 2020). A decrease in precipitation is one sign of climate change, which can have an impact on all aspects of life. Water output from any water source will vary in general. Water discharge tends to rise during the rainy season and fall during the dry season (Jepara, 2020). A decrease in rainfall can also induce changes in water discharge so that the fulfilment of future rainwater demand will also be different. This has an impact on rainwater availability, which is predicted to decline in the near and distant future compared to the recent average availability (Imteaz and Moniruzzaman, 2020).

4.3 Teluk Awur Village's Estimated Population

In order to find out the water demand in Teluk Awur village, the population projection is estimated. Teluk Awur's yearly population growth rate is 1.37% based on equation (1), according to demographic forecasts for 2020 and 2040. Table 2 and Figure 4 indicate the population forecast for Teluk Awur. The population in 2040 is expected to be 2,524 people. The greater the population density, the greater the need for fresh water.

Table 2: Estimated population of Teluk Awur

Year	Population (people)	Year	Population (people)
2020	1,921	2030	2,201
2021	1,947	2031	2,232
2022	1,974	2032	2,262
2023	2,001	2033	2,294
2024	2,028	2034	2,325
2025	2,056	2035	2,357
2026	2,084	2036	2,389
2027	2,113	2037	2,422
2028	2,142	2038	2,456
2029	2,172	2039	2,489

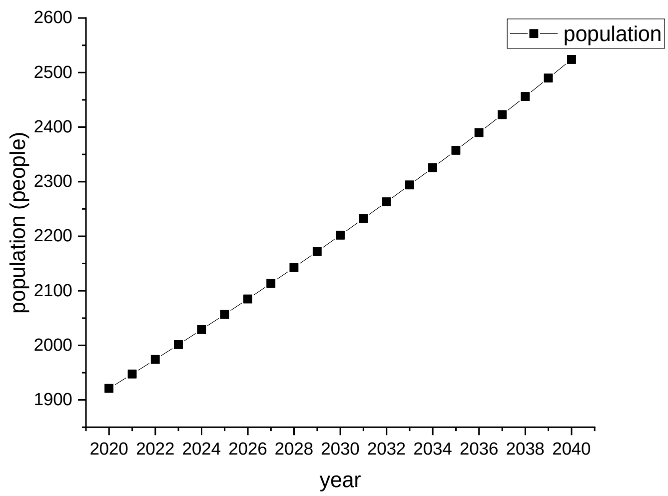


Figure 4: Graph of Teluk Awur population forecast until 2040

4.4 Potential of rainwater harvesting

The potential of rainwater harvesting in Teluk Awur Village was estimated by assuming that the roof area in the village only covers the roofs of houses (excluding the roofs of hotels and inns). The yearly rainfall data, total roof area, and a runoff coefficient (efficiency) of 0.4 were used to compute the potential amount of rainwater that could be gathered from each roof for rainfall. Equation (3) is used to appraise the potential volume of rainwater collected. The total roof area of Teluk Awur Village is assumed to be at least 30 m^2. The roofs of houses in Teluk Awur can accommodate a minimum of 25,308.72 m^3 of rainwater. If the rainfall and roof area are larger, the potential for rainwater will also be large in each household. A larger roof area will increase the storage of rainwater in the tank, but a more significant increase occurs with a roof area of 100 – 200 m^2 (Balasundram et al., 2023). Meanwhile, the water demand calculation each year is based on equation (2) as presented in Table 3. The water demand varies according to the year due to population growth, which affects the percentage of potential savings in water. The potential for saving water in 2023 and 2040 is 57.75% and 45.79% respectively.

As mentioned in the previous section, the rainfall in Jepara Regency is predicted to decrease by 10% to 20%, especially in Teluk Awur. This will affect the reliability of rainwater harvesting's water supply due to forecasted climate change. As a result of these changes in reliability, advocated for larger storage tank to compensate for rainwater harvesting performance reductions and supply water demand during dry periods under projected climate change (Alamdari et al., 2018). Apart from that, it is feasible to utilize the rainwater through rainwater harvesting as a source of fresh water in Teluk Awur village. The rainwater harvesting system can be an alternative for the water scarcity in the coastal area especially to fulfil the demand of water for domestic use that is less saline with simple operation, high adaption, low cost and less energy consumption.

Table 3: Water demand and potential savings in Teluk Awur

Year	Population (people)	Q_{md} (m^3)	Potential savings (%)
2020	1,921	42,069.9	60.16
2021	1,947	42,639.3	59.35
2022	1,974	43,230.6	58.54
2023	2,001	43,821.9	57.75
2024	2,028	44,413.2	56.98
2025	2,056	45,639.6	56.21
2026	2,084	45,639.6	55.45
2027	2,113	46,274.7	54.69
2028	2,142	46,909.8	53.95
2029	2,172	47,566.8	53.21
2030	2,201	48,201.9	52.51
2031	2,232	48,880.8	51.78
2032	2,262	49,537.8	51.09
2033	2,294	50,238.6	50.38
2034	2,325	50,917.5	49.70
2035	2,357	51,618.3	49.03
2036	2,389	52,319.1	48.37
2037	2,422	53,041.8	47.71
2038	2,456	53,786.4	47.05
2039	2,489	54,509.1	46.43
2040	2,524	55,275.6	45.79

5. Conclusions

Rainwater has the potential to be used as a source of fresh water in Jepara Regency, especially in Teluk Awur via rainwater harvesting technology. This alternative is feasible to be implemented in the coastal region as this region continue to be exposed with the shortage of fresh water due to saltwater intrusion that make the surface water become saline. Rainfall potential in the village is around 2,109.06 mm, with the potential estimation of water around 25,308.72 m^3 per year. By the continues growth of population it still can manage to provide 45-60% water demand of the village.

Statement of Novelty

Rainwater is a prospective water resource for coastal communities in Teluk Awur village, Jepara Regency, Indonesia. The research was undertaken to provide an alternative by utilizing rainwater in coastal areas. Utilization of rainwater will be used to meet requirement for clean water in the village.

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