Analysis of Potential River Estuaries to Support Development Programs Sustainable Raw Water Reserves in Bali Province

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Abstract. Population growth and the increasing number of tourists visiting Bali require an increase in clean water. Clean water services have so far been carried out by the Regional Drinking Water Company (RDWC) from infrastructure built by the Government through reservoirs/dams, ponds, long storage, and infrastructure built by RDWC through deep wells. The development that has been carried out by the Government is trying to increase raw water reserves so that the level of RDWC service can be improved. The problem faced is the conflict with irrigation water users if the extraction is carried out in the middle or upstream of rivers spread throughout Bali, therefore the development currently being carried out has targeted the river estuary to avoid conflicts that could occur. Compared to the increasing need for water, of course, the extraction of water at the estuary of this river is not sufficient for the increasing need for water, preliminary research and surveys show that there is still a lot of potential at the estuary that has not been utilized at this time. This research method is quantitative by conducting an inventory and measuring the potential at the river mouth whose discharge is no longer used for irrigation. The results of this study are mapping of river mouths and potential river discharge potentials throughout Bali. Based on the results of the study shows that potential rivers in Bali are spread across South Bali.

Keywords: Raw Water, River Estuary Potential, Water Needs

1 Introduction

Population growth and the increasing number of tourists to Bali have increased the need for clean water (Cole, 2012; Koop, 2015). The government has built several reservoirs/dams that function for irrigation and also clean water such as the Gerokgak, Palasari, Benel, Telaga Tunjung, Nusa Dua Estuary, Titab, Tamblang Reservoir, and the Sidan Reservoir which is currently under construction. In addition to reservoirs/dams, the government has also built reservoirs in dry areas, most of which are in Karangasem Regency, and made reservoirs downstream (long storage) in several areas such as downstream Penet River, downstream Petanu River, downstream Yeh Empas River, and downstream Ayung river. The existence of these buildings certainly

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has a positive impact on the availability of raw water to be distributed by RDWC to become clean water (Carrard et al., 2019). The use of water at the river estuary cannot be separated from efforts to avoid conflicts with irrigation in the middle and upstream parts of the river (Chakkaravarthy, 2019). Preliminary observations and research show that currently the eastern, western, and northern regions of Bali are areas with very limited water potential. Judging from the number of river basins (catchment area) currently available, Bali has 391 catchment areas with 58% of them being rivers that only have water during the rainy season (ephemeral river type) and rivers that only have water during the rainy season (intermittent river type). Rivers that are truly full of water throughout the year are 42%, most of which are in the southern Bali area (BWS Bali Penida, 2020).

The current problem is that the need for raw water continues to increase while the raw water available in Bali is not evenly distributed and not all areas have potential rivers that can be developed. Therefore, it is very necessary to analyze the number of potential rivers that can still be developed in downstream as an effort to provide raw water sustainably in Bali Province. Based on the description above, several problems can be conveyed as follows: the current clean water balance of Bali Province, the number of potential rivers that can be developed in Bali to support the development of raw water supply, and the strategy for developing this potential is linked to a sustainable clean water supply system.

Several studies have been conducted related to river management but those related to the analysis of water utilization at the river mouth for clean water reserves have not been conducted. Charlton (1991) conducted an analysis of river management on small-scale rivers in rural and urban areas in Ontario. This study stated that the socio-cultural role of the community influences river management patterns (Charlton & Tufgar, 1991). Teodosiu et al. (2003) conducted an analysis of river utilization and management for various purposes but did not specifically analyze the river estuary (Teodosiu et al., 2003). Van Buren, (2019) analyzed public participation in river development and construction (van Buuren et al., 2019). Alemu, (2016) conducted a study closely related to integrated river management with an emphasis on sediment transport along the river trunk (Alemu, 2016). Kilic (2020) analyzed limited water resources and the threat of water shortages in the future (Kilic, 2020). Mostert (2018) analyzed the history of river and watershed management from 1850 to the present (Mostert, 2018). There have been many changes and policies that have greatly influenced river management. The need for clean water in Bali is so important that the existence of water in river estuaries as irrigation waste becomes very important to be studied as an effort to increase Bali's raw water reserves in the future.

2 Methodology

2.1 Population Projection Calculation

Population projection is used to estimate the population for the future. This population estimate is used as a basis for calculating domestic water. To obtain the right projection method, it is necessary to conduct correlation tests and existing methods.

1. Arithmetic
   We use this arithmetic formula if we assume that the population is always the same each year.

$$Pn = Po\,\{1 + (r \times n)\} \tag{1}$$

   Description:
   P_n = Population after n years.
   P_0 = Population in the initial year.
   r = Population growth rate.
   n = Period in years.

2. Geometric
   Calculation of population numbers using this formula uses the basis of compound interest on population growth (interest on interest).

$$Pn = Po\,(1 + r^n) \tag{2}$$

   Description:
   P_n = Population after n year.
   P_0 = Population in the initial year.
   r = Population growth rate.
   n = Period in year.

3. Eksponensial
   Use this formula if population growth is constant or continuous every day.

$$Pn = Po \times e^{rn} \tag{3}$$

   Description:
   P_n = Population after n years.
   P_0 = Population in the early years.
   r = Population growth rate.
   n = Period in year.
   e = Exponential Number = 2.7182818

2.2 Instantaneous Discharge Measurement

The principle of the implementation of instantaneous discharge measurement is to measure several aspects including wet cross-sectional area, flow velocity, and water level. Flow width measurement is carried out by measuring the width of the river directly. The type of width measuring instrument used must be adjusted to the width of the wet cross-section and the available assembly tools. The distance of each vertical on the wet cross-section must be measured from a fixed point. Measurements made by monitoring or from a width measurement boat can be done with a steel measuring cable (tagline). If the measurement is carried out from a transverse hanging cable or a bridge, the flow width measurement can be done by making a width interval that is measured using a ruler or steel tape. Flow depth measurement is carried out using a depth measuring instrument at each vertical whose distance has been determined. The distance between each vertical is attempted to be as close as possible so that the discharge in each sub-section of the cross-section is no more than 1/5 of the discharge of the entire wet cross-section. A sketch of the division of sections in instantaneous discharge measurements is shown in Figure 1 (Vasilevskyi, 2014).

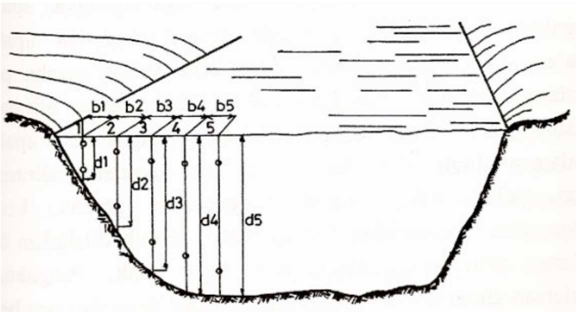

Figure 1. Sketch of wet cross-sectional area measurement

The type of flow depth measuring instrument depends on the depth of the flow and the available measuring instrument. The probe is used if the depth measurement is carried out by monitoring with a flow depth of <1.50 m.

To measure discharge, it is necessary to measure the average flow velocity at a cross-section of the river in question. The average flow velocity can be obtained by measuring the flow velocity at several points from several vertical segments on a cross-section using a current measuring instrument. The flow velocity at each point is calculated based on the number of propeller rotations over a certain period. To obtain accurate measurement results, the current measuring instrument and its equipment must be in good condition, the measurement location must meet the requirements, the measurement time must be sufficient and the condition of the meter/surveyor must be good. In determining the number of speed measurement points in each vertical, there are several approach methods, including the mathematical function approach, velocity curve graphic approach, Integration method, and semi-integration method

The distribution of flow velocity on a vertical line is considered to have a curve shape that is more or less parabolic, elliptical or other shapes. Based on this assumption, the average flow velocity in a vertical is only measured at several points and then the results are calculated arithmetically. The common methods for measuring flow velocity are as follows:

One-Point Method

0.60 Depth Method. In this method, the flow velocity measurement is carried out at the point 0.60 of the flow depth from the water surface. The measurement result at the point 0.6 of the flow depth is the average vertical velocity in question. This method is used with the following requirements:

1. if the water depth is between 0.25 and 0.76 m
2. if the flow carries a lot of garbage so that it is difficult to measure at a depth of 0.2 of the flow depth
3. if there is another reason why the measuring instrument cannot be placed at the point 0.8 of the flow depth
4. if the water level fluctuation is fast, the measurement must be carried out quickly too

0.50 Depth Method. The flow velocity is measured at a depth of 0.50 flow depth, the average velocity is calculated using the following equation:

$$J = C_1 \times V_{0.5} \quad (4)$$

Description:
J = average flow velocity
$V_{0.5}$ = speed at 0.5 depth
C_1 = constants are determined by calibration (depending on the type of instrument)

Method 0.20 Depth. The average flow velocity of the measured vertical line can be calculated using the formula

$$J = C_2 \times V_{0.2} \quad (5)$$

Description:
J = average flow velocity
$V_{0.2}$ = speed at 0.2 depth
C_2 = constants are determined by calibration (depending on the type of instrument)
The coefficient value commonly used to calculate the average speed by measuring 0.2 depth is 0.88, to be more precise, the coefficient must be calibrated at the measurement location.

Two-Point Method. In this method, the flow velocity measurement is carried out at 0.2 and 0.8 points of flow depth from the water surface. This method is not recommended to be used to measure velocity with a flow depth of less than 0.76 m because at a depth of less than 0.76 the depth points at 0.8 and 0.3 will be less than 0.15 m both from the surface and from the bottom of the channel so that friction with the air and the bottom of the channel can be avoided. Figure 2 shows a sketch of the measurement.

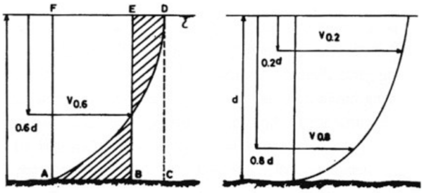

Figure 2. Sketch of the number of points for measuring vertical line flow velocity one point and two points methods

Three-Point Method. Flow velocity measurements are carried out at points 0.2; 0.6; and 0.8 flow depths from the water surface. This method is a combination of the two previous methods. The average velocity of each vertical is obtained by averaging the measurement results at 0.2 and 0.8 flow depths, and then the average results are averaged again with the measurement results at 0.6 flow depths. The reason this method is used is to obtain better average flow velocity data, namely if the distribution of velocity in the vertical direction is not normal, or the flow velocity at 0.8 depth is disturbed by friction of material at the bottom of the river channel so that it is not normal. This method applies if the measured water depth is not less than 0.76 meters.

2.3 Research Design

The research steps are arranged in stages and continuously so that all existing problems can be resolved. In general, the methods in this study are carried out as follows: Secondary data collection includes population data from BPS and water production data from RDWC of each Regency and City in Bali. Primary data collection includes direct measurements at the river mouth to determine the capacity of river water in the estuary section. The analysis consists of several steps like this analysis of population and its projections using arithmetic, geometric, and exponential methods. The method used later is the method that has the smallest deviation from the original conditions of the population based on Central Bureau of Statistics data. Analysis of water needs is calculated based on per capita water usage used in each region based on data from RDWC, analysis of water loss in each RDWC, analysis of clean water balance in each Regency/City, analysis of instantaneous discharge using direct measurement method based on several depth variations, analysis of clean water development using the method of conducting audiences with RDWC and public work department office of Regency/City and to the Bali Penida River Basin Office, analysis of water-prone areas in Bali Province, analysis of potential rivers and analysis of clean water supply development strategies in Bali Province.

3 Result and Discussion

3.1 Result

Surface water in rivers is divided into 3 (three) types based on river flow conditions, namely: Perennial River, namely a river with flow conditions throughout the year, intermittent River, namely a river that flows only during the rainy season and ephemeral River, namely a river that flows only during the rainy season. The rivers that are watersheds in Bali Province number 391 watersheds with an area of 5,636.66 km2 and a river length of 2,776 km. According to the Decree of the President Republic of Indonesia Number 12 of 2012 concerning the Determination of River Areas, the Bali-Penida River Area is a National Strategic River Area with Code Number 03.01.A3, consisting of 391 watersheds with a total River Basin Area of 5,636.66 km^2. Rivers are grouped into 3 groups, namely perennial (flowing throughout the year), intermittent (flowing during the rainy season), and ephemeral (flowing when it rains).

Mapping of potential rivers in the estuary area is done through a series of surveys and with instantaneous discharge measurements. The measurement results on several rivers are presented from a series of measurements that have been carried out. Table 1 shows potential rivers in Bali. Mapping of potential rivers in the estuary area is done through a series of surveys and with instantaneous discharge measurements. The measurement results on several rivers are presented from a series of measurements that have been carried out. Table 1 shows potential rivers in Bali.

Table 1. Summary of instantaneous discharge measurement results

No.	River name	Regency	Instantaneous discharge measurement results (liter/second)
1	Jangga	Karangasem	610.00
2	Unda	Klungkung	2,813.49
3	Telagawaja	Klungkung	8,408.14
4	Sangsang	Gianyar	2,950.00
5	Pakerisan	Gianyar	2,590.00
6	Yeh Leh	Tabanan	850.00
7	Pulukan	Jembrana	1,520.00
8	Medewi	Jembrana	920.00
9	Bilukpoh	Jembrana	460.00
10	Yeh Sumbul	Jembrana	1,280.00
11	Yeh Hoo	Tabanan	950.00
12	Yeh Empas	Tabanan	6,150.00
13	Jinah	Klungkung	930.00
14	Bubuh	Klungkung	1,560.00
15	Melangit	Gianyar	2,230.00
16	Petanu	Gianyar	5,020.00
17	Oos	Gianyar	3,380.00
18	Ayung	Denpasar	2,250.00
19	Badung	Denpasar	3,890.00
20	Mati	Badung	5,020.00

No.	River name	Regency	Instantaneous discharge measurement results (liter/second)
		Amount (l/s)	53,781.63
		Amount (m3/dt)	53.78

3.2 Discussion

Water needs are calculated based on data and water development plans in Bali as well as needs based on current conditions in each Regency/City in Bali as in Table 2.

Tabel 2. Bali Province water balance in 2050

No.	Regency	Availability (liter/second)	Demand (liter/second)
1	Badung	1807.69	2,855.96
2	Bangli	333.45	5,68.33
3	Buleleng	1544.50	1,830.13
4	Gianyar	1099.28	1,617.17
5	Jembrana	340.75	619.25
6	Karangasem	454.54	987.41
7	Klunglung	1,158.40	461.22
8	Denpasar	1,969.24	2,557.79
9	Tabanan	1,102.19	1,282.18
	Amount	9,810.04	12,779.44

Based on the existing data, it shows that in 2050, except for Klungkung Regency, all will experience a water deficit. Klungkung Regency will not experience a deficit because in 2030, the plan to develop the utilization of the Unda River at the estuary can be realized with a capacity of up to 100 liters/second.

3.3 Development Strategy

The development of water resources for the fulfillment of sustainable clean water has been outlined by the Bali Provincial Government to reduce the use of groundwater, therefore the utilization of water in the estuary area is very important to be done. Based on the existing data, several things can be conveyed as follows:

1. Fulfillment of water in the eastern part, namely in the central and eastern parts of Karangasem Regency, is constrained by limited water potential because in this area there are almost no rivers with large capacities that can be utilized. Alternatives that can be done are utilizing Jangga River (with a capacity of around 300 liters/second) and utilizing the Unda River estuary reservoir to be channeled to the eastern part of Karangasem Regency (estimated discharge of around 400 liters/second).
2. Fulfillment of water in the northern part, namely the eastern and central parts of Buleleng Regency, is also faced with the unavailability of rivers with adequate capacity. Long-term alternatives by utilizing the potential of Lake Batur.

3. Potential in the western part, namely Jembrana Regency by utilizing regional water from Balian River and several other potential rivers, namely Yeh Sumbul, Medewi, Pulukan, and Yeh Ho.
4. The Central Region, namely Tabanan Regency, can still utilize several rivers such as Balian and Yeh Empas.
5. The Central and Southern parts of Bali, namely the cities of Denpasar, Badung, Gianyar, and Klungkung can utilize several potential rivers such as Bubuh, Jinah, Pakerisan, Sangsang, and Mati.

4 Conclusion

Based on the results of the analysis that has been carried out, several things can be concluded as follows:

1. The water balance in Bali Province in 2023 shows that water availability is 8,810.04 liters/second while the need is 8,431.99 liters/second. In general, there is an excess because this analysis has taken into account the addition of 1,750 liters/second from the Sidan reservoir. Meanwhile, in 2050, water availability in Bali will reach 9,810.04 liters/second because there is additional water from the Muara Unda Reservoir of 1000 liters/second with a water requirement of 12,779.44 liters/second. Both in 2023 and in 2050. When viewed from each Regency/City both in 2023 and 2050, it shows that most areas are experiencing water shortages.
2. Based on the results of observations and measurements of instantaneous discharge throughout Bali, there are 20 potential rivers whose water can still be used for clean water development with an estimated discharge of 53,781.63 liters/second. This potential is certainly very large, but its utilization is constrained by various things such as elevation factors and expensive network development.
3. Based on the potential of the existing river estuaries, most of them are in the southern part of Bali, so the recommended strategy is to utilize estuary water regionally in the southern part which can meet the water needs for several areas in the southern and central parts of Bali. For the eastern, northern, and western regions, the potential is very small because the utilization of estuary water requires more expensive infrastructure and networks. After all, the existence of the river is far from these areas.

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