Water Allocation Management Strategies for the Sustainability of the Tukad Oos Watershed in Gianyar Regency

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Abstract. Water allocation is the process of regulating water provision in a certain amount and time, based on water availability and user needs, according to the type of use and priority order. This requires integrating all water users' needs according to priorities, considering water availability. Tukad Oos plays a crucial role as a water source, meeting the needs of the surrounding population. The problem that occurs is the lack of integration of water utilisation patterns, especially for irrigation, where the use of water from upstream to downstream does not take into account the amount of water available. Therefore, it is necessary to conduct scientific research by considering the necessary analyses to analyze and evaluate the water balance that occurs in the Tukad Oos watershed. This study provides results that the potential availability of water in the Tukad Oos Watershed is currently 950.33 m^3/second/year with a reliability level of 80%. The condition of the water balance in the Tukad Oos Watershed generally shows a surplus value of water with an average total surplus discharge of 10.19 m^3/second at the outlet position. The water allocation management strategy in the Tukad Oos Watershed should prioritize fulfilling irrigation water needs by rearranging the existing cropping pattern and area, thereby integrating surface water use to maintain the watershed's sustainability.

Keywords: Strategy, Watershed, Water Allocation, Water Balance

1 Introduction

Water is one of the resources necessary for the livelihoods of many people and is an important element in life that needs to be protected in order to provide sustainable benefits (Lestari & Suprapto, 2017). Water resources are one of the main components needed by all living things. This component supports the balance between one ecosystem and another. The need for water by living things affects the quality and quantity of water. Uncontrolled utilisation of water resources causes water supply to decrease and water quality will decrease (Meyliska et al., 2024).

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Water allocation is an activity of regulating the provision of water in a certain volume/quantity and time based on the availability and need for water according to the type, volume, and time adjusted to the results of the agreement on the order of priority (Taufik et al., 2019). In fulfilling the balance between water availability and water demand, water management and allocation are required to provide and realise water needs for water users. The mechanism of managing and allocating water is by integrating all the needs of water users according to priorities based on water availability. This is done to seek efficiency from the utilisation of water resources (Meyliska et al., 2024).

Tukad Oos is one of the rivers located in Gianyar Regency, Bali Province, which has an important role as a water source in fulfilling clean water needs, irrigation, fisheries, tourism, and religious ceremonies. The existing river water is not only utilised for the needs around the Tukad Oos Watershed but also used by other areas outside the watershed. Based on data obtained from the Bali-Penida River Basin, Tukad Oos has a watershed area of 119.95 km2 and a main river length of 51.96 km. Tukad Oos is a perennial river, characterized by a year-round flow and a winding river channel morphology.

The problem that often occurs in the Tukad Oos Watershed is the lack of integration of water utilisation patterns, especially for irrigation, where the use of irrigation water from upstream to downstream does not pay attention to the amount of water availability in meeting needs according to priorities. If the function of the watershed as a place of rainfall, infiltration, and water storage is disrupted, causing damage to the river ecosystem or hydrological system will be disrupted (Meyliska et al., 2024). To maintain the preservation and sustainability of the watershed ecosystem, it is very important to carry out a water allocation management strategy in accordance with the conditions of availability and needs in the Tukad Oos watershed.

Population development increases water demand, so there is a need for alternative water sources to meet water needs for domestic, agricultural, and commercial needs (Sulistyani & Irianto, 2018). The main problem faced by water sources is the inability to meet the increasing demand for water in terms of quantity and the decline in water quality, especially for various purposes. Domestic needs, agriculture, industry, and other activities can hurt existing water resources (Setianto et al., 2016). To be able to produce an optimal water allocation management strategy, it is very necessary to have information about the amount of potential availability and demand in the system. The imbalance between water availability and demand must be known in advance, especially for farmers who often experience excess water in the rainy season, but experience water shortages during the dry season (Kustana & Setiawan, 2020).

A schematic model of the Saddang River Watershed water allocation using MS. Excell has been done to obtain an overview of the water allocation model in order to fulfill water needs and river maintenance (Musa et al., 2016). Optimisation of water use allocation based on water availability and operational costs in Batu City has also been carried out to determine the optimal water use formula based on the amount of water availability and the required water operational costs (Amalia et al., 2014). The use of hydrological models such as SWAT (Soil and Water Assessment Tool) was used to simulate water flow and water availability in the Tapung Kiri Watershed, to analyse

land use change and its impact on groundwater availability (Syauqi et al., 2016). In addition, a multi-objective optimisation model was used to consider various aspects, such as economic, social, and environmental, in water allocation by integrating socio-economic and environmental balance analysis to achieve optimal water allocation (Dong et al., 2022). Based on some of these studies, the author seeks to review water allocation management strategies for the sustainability of the Tukad Oos Watershed by reviewing the water balance that occurs.

From the explanation above, it can be seen that an integrated water allocation management strategy is needed in terms of its potential and utilisation. Therefore, it is crucial to conduct scientific research that considers the necessary analyses to evaluate the water balance in the Tukad Oos watershed. Knowing the water balance will make it easier to manage water allocation fairly and integrate water utilisation. Water balance conditions that show surplus values must be optimised properly so that they can be used to meet other water needs, while water balance conditions that show deficit values must be regulated so that water management can be integrated properly. Through this research, it is expected that findings/innovations will be obtained in the form of the results of the analysis of potential availability, needs, water balance, and conducting water allocation management strategies in the Tukad Oos Watershed in Gianyar Regency based on water utilisation priorities.

2 Methodology

The method used in this study is quantitative, using primary and secondary data analysis to solve the problem. To achieve the objectives of this study, we began by collecting primary data based on field surveys and secondary data obtained from relevant agencies. Primary data was obtained by conducting field surveys to determine the location of spring discharge measurements, identify river flow conditions in the Tukad Oos watershed, and assess water use along the watershed. Interviews were also conducted with local water users to understand the characteristics of water use practices currently in place.

Secondary data was obtained from relevant agencies, including rainfall data, climatological data, irrigation schemes, and existing cropping patterns applied during the study, which were obtained from relevant agencies. The rainfall data used consists of daily data from the Mambal Rainfall Station (1993–2018), the Tegalalang Rainfall Station (1992–2015), and the Pengotan Rainfall Station (1992–2017). These three rainfall stations are the closest rainfall stations to the research location and are managed by the Hydrology Unit of BWS Bali-Penida. Climatological data were obtained from the Tampaksiring Climatological Station, managed by the Denpasar Regional Meteorological, Climatological, and Geophysical Agency (BMKG) in 2016. The irrigation scheme is based on data released by the Public Works and Spatial Planning Department of Gianyar Regency, and the cropping pattern conditions were obtained from the Agriculture Department of Gianyar Regency in 2024. The crop types used in the analysis refer to the rice varieties planted in the rice fields during the study period, consistent with actual conditions.

All data was used in the analysis stage to determine the conditions and strategies for water allocation management in the Tukad Oos watershed. Water availability analysis was obtained by calculating the reliable discharge at each review point using the F.J. Mock Method. Irrigation water demand analysis was calculated using the Netto Field Water Requirement (NFR) KP-01 Method. After determining the available flow (input) and demand (output), an evaluation of the water balance conditions was conducted. The balance between available flow and demand can be seen through a positive or negative water balance (Wardana et al., 2024). In general, the water balance equation can be formulated as follows:

$$I = O \pm \Delta S \tag{1}$$

Where:
I = input
O = output
ΔS = change in water reserves

Potential discharge analysis is carried out after obtaining a positive water balance (surplus), which indicates that water discharge can still be optimised for other uses. A water balance showing a negative value (deficit) must be managed to ensure integrated water management. The results are then used as the basis for determining water allocation management strategies in the Tukad Oos Watershed in Gianyar Regency based on water utilisation priorities.

3 Result and Discussion

3.1 Result

Primary Data Collection. From the visit to the research site, it can be seen that the Tukad Oos Watershed is located in the administrative area of Gianyar Regency, where the upstream part of the watershed is located in Payangan and Tegalalang Subdistricts, the middle part of the watershed is in Ubud Subdistrict, and the downstream part is in Sukawati Subdistrict. The main river of the Tukad Oos Watershed empties into Ketewel Beach. The position of the Tukad Oos Watershed is geographically identified using Geographic Positioning System (GPS) equipment and is located at coordinates 8°15’39.82” Northing and 115°20’54.21” Easting to 8°37’20.07” Northing and 115°14’43.39” Easting.

Secondary Data Collection. Secondary data is obtained by collecting data sourced from relevant agencies. The secondary data collected to support this research are in the form of watershed topographic maps, rainfall data, climatological data, irrigation schemes, and existing cropping patterns applied during the study. These data will be used to analyse the availability and demand for irrigation water in the Tukad Oos Watershed.

Watershed Topography Map. The topographic map of the Tukad Oos Watershed is based on data obtained from the Geospatial Information Agency (BIG) in the form of the 2025 *Rupa Bumi Indonesia* (RBI) Map. The topographic map of the Tukad Oos Watershed is used to determine the characteristics of the watershed, consisting of the area of the watershed (A), the length of the main river, and the runoff coefficient (C) obtained from existing land cover conditions. The outlet point of the Tukad Oos Watershed, used as a review point in this study, is the location of the Cengcengan Dam, a retrieval building situated at the most downstream position in Tukad Oos.

Distribution of Weir Positions in the Tukad Oos Watershed. Based on data obtained from BWS Bali-Penida, it is explained that there are 37 irrigation areas (D.I.) located in the Tukad Oos Watershed, where 32 D.I. are under the authority of the Central Government and 5 D.I. are under the authority of the Regional Government. A map showing the distribution of all irrigation areas located in the Tukad Oos Watershed can be seen in Figure 1.

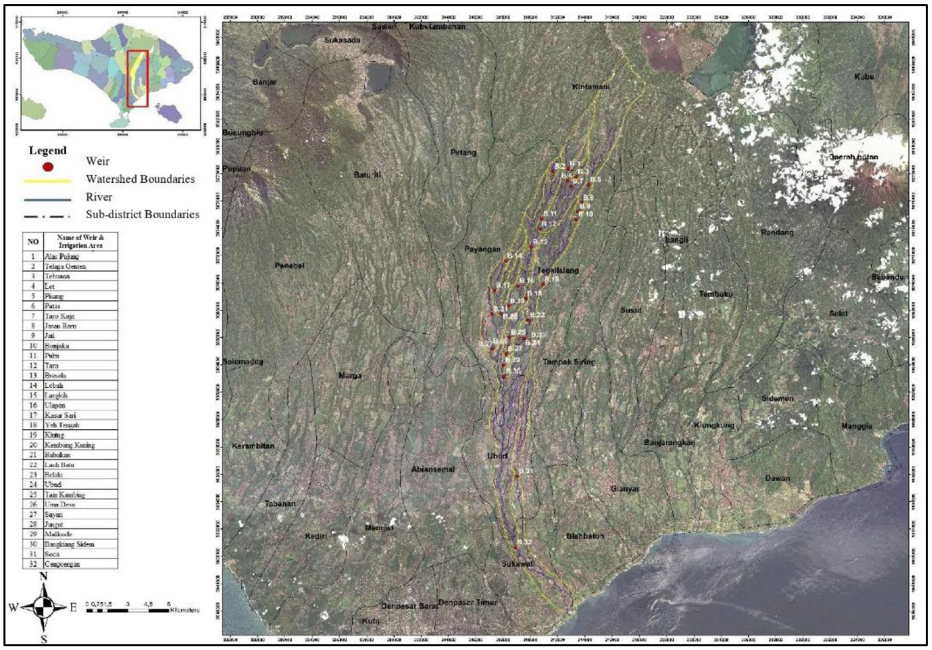

Figure 1. Map of Weir Positions in the Tukad Oos Watershed

Rainfall Data. The rainfall data used is relatively complete and has a data length of more than ten years of observation. Rainfall data at the Mambal Rainfall Station has been recorded for 26 years, from 1993 to 2018. Rainfall data at the Tegalalang Rainfall Station is available for 24 years, from 1992 to 2015. Rainfall data available at the Pengotan Rainfall Station is recorded for 26 years, from 1992 to 2017. Rainfall conditions at the study site can be determined using the Theissen Method, which

involves creating a polygon line from rainfall recording stations around the watershed and dividing it into areas defined by the polygons of each station.

Cropping Pattern Data. Based on data obtained from the Agriculture Office of Gianyar Regency, it is known that the Tukad Oos Watershed consists of several irrigation areas that have a fairly uniform planting pattern, in general, in the first growing season the irrigation system in the Tukad Oos Watershed can be planted with 100% paddy, in the second growing season paddy planting remains at 100%, but in the third growing season (dry season) several irrigation areas apply paddy planting with an average of 30% only, the rest of the irrigated land tends to be planted with secondary crops or even not planted (fallow).

Irrigation Water Requirement Analysis. Based on the results of the calculation of Netto Field Requirements (NFR) in accordance with the applicable Irrigation Planning Criteria Standards (KP-01), the maximum irrigation water requirement at the intake varies greatly, starting from the lowest of 1.03 litres/sec/hectare and the highest of 1.53 litres/sec/hectare. This indicates that the total amount of irrigation water required for agricultural activities in the Tukad Oos Watershed must be allocated in accordance with the area of irrigated land in each irrigation area and the applied cropping pattern.

Reliable Discharge Analysis. After determining the rainfall in the Tukad Oos Watershed, the reliable discharge obtained from each irrigation water intake structure in the river through existing weirs is calculated. The reliable discharge calculation is performed by converting the regional rainfall into discharge. The method used for this conversion or calculation employs the method provided by F.J. Mock. With this method, the probability of potential inflow or flow rate in the river can be calculated, thereby determining the reliable flow rate to be used. The calculation of the reliable flow rate for irrigation uses a probability of 80% or Q_{80}.

Based on the results of the reliable discharge calculations, it is known that several irrigation areas in the Tukad Oos Watershed have relatively small reliable discharges. This is because the catchment areas of each weir are relatively small. In contrast, irrigation areas with large catchment areas will also have relatively larger reliable discharges. The current water availability in the Tukad Oos Watershed has a potential of 950,331.85 litres/sec or 950.33 m3/sec/year.

Water Balance Analysis. Based on the results of the analysis of the reliable discharge (Q_{80}), which is the available discharge (inflow) and the irrigation water demand discharge in accordance with the planting pattern applied (outflow), a relationship between the reliable discharge and the demand discharge is produced, which is called the water balance. The available flow is based on the calculation of the reliable flow of the river with an 80% probability. In contrast, the utilisation flow is the result of calculating the irrigation water demand for each half-month period. Surplus or deficit conditions can be seen from the difference between the available flow and the

utilisation flow according to its allocation. The calculation of the water balance is carried out sequentially from upstream to downstream, taking into account that excess water from the dam in the upstream section will be diverted downstream for reuse. The water balance in the Tukad Oos Watershed is mostly in surplus, but five irrigation areas experience water deficits. These five irrigation areas are Puakan, Yeh Tengah, Uma Desa, Lauh Batu, and Belalu. Water deficits occur during the third planting season, from June to October. These five irrigation areas have relatively small service areas and are located in the upper to middle reaches of the Tukad Oos Watershed river system. Looking at the water balance at the Tukad Oos estuary, it can be seen that there is still residual water flow throughout the year with an average discharge of 10,187.52 litres/sec or 10.19 m^3/sec. The lowest flow rate recorded at the outlet of the Tukad Oos river basin is 4.31 m^3/sec, occurring in July, while the highest flow rate is 17.15 m^3/sec, occurring in January. The water allocation scheme in the Tukad Oos Watershed is presented in the form of a diagram as shown in Figure 2.

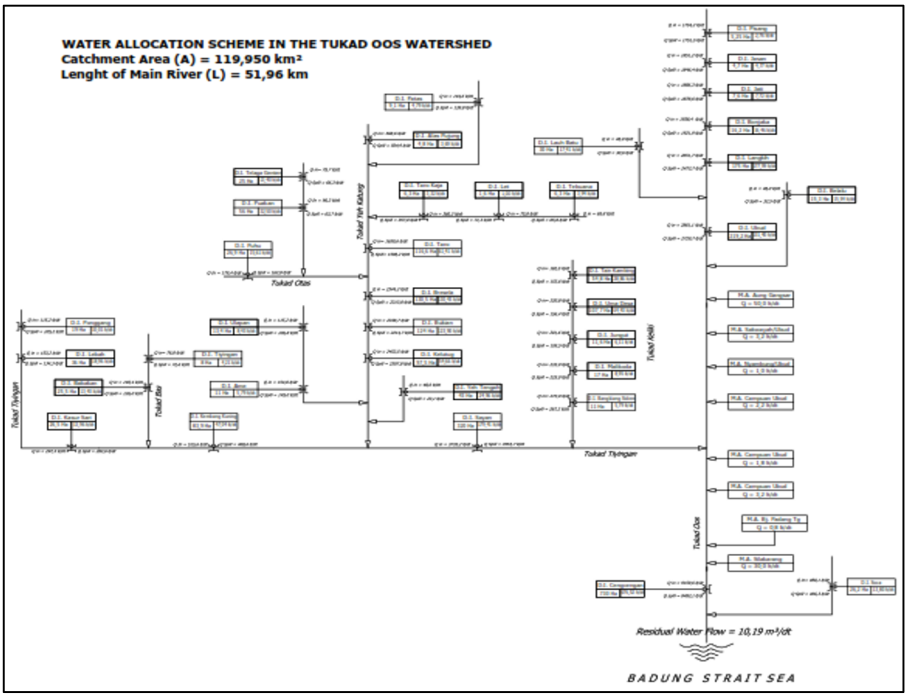

Figure 2. Water Allocation Scheme in the Tukad Oos Watershed

Analysis of Optimisable Discharge Potential. The water balance conditions in the Tukad Oos Watershed generally show a water surplus with a total surplus flow of 10.19 m3/second at the outlet. This indicates that the Tukad Oos Watershed currently still has potential for development. However, based on the water balance conditions at each water intake structure within the watershed, there are still five irrigation areas experiencing water deficits. Based on water balance calculations, the potential for developing the Tukad Oos Watershed can be determined by creating a graph based on the remaining water flow from utilisation (irrigation). The potential remaining utilisation flow can be illustrated in a graph, as shown in Figure 3.

From the graph in Figure 3, it can be explained that the potential development discharge of residual water has a fluctuating value depending on the amount of discharge that must be met first. The downward trend in discharge occurs from April to September, indicating that this period is the dry season. The highest potential development flow rate occurs in January at 17,147.19 litres/sec or 17.15 m³/sec, as this month is the rainy season when water availability in the Tukad Oos Watershed increases, while water use in rice fields is relatively low because irrigation water needs are met by available rainfall. The lowest potential development flow rate occurs in July at 4,300.36 litres/sec or 4.30 m³/sec, as during this month, there is still irrigation water usage activity in some irrigation areas that must be met, where planting conditions are still in the Padi-II planting period and entering the Palawija planting period. This results in higher water usage, especially since the dry season has begun during that month. The average potential flow rate that can be optimised in the Tukad Oos Watershed over the course of a year is 10.19 m³/second.

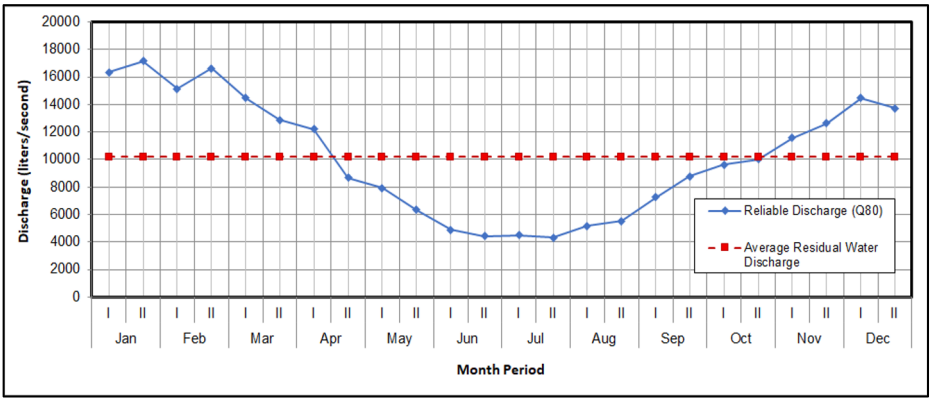

Figure 3. Graph of Potential Residual Utilisation Discharge in Tukad Oos Watershed

3.2 Discussion

With the knowledge of the water balance in the Tukad Oos Watershed and its optimisable potential, the utilisation of surface water in the watershed can be developed for other purposes, considering that there is still potential flow that can be utilised at the outlet. The development of surface water utilisation must be carried out in an integrated manner, prioritising the fulfilment of irrigation water needs first, as no utilisation for clean water needs has yet been implemented in the Tukad Oos Watershed. Based on the water balance conditions, it is evident that there are still irrigation areas experiencing water deficits, so the water allocation management strategy in the Tukad Oos Watershed must prioritise the fulfilment of irrigation water needs first. To achieve optimal water allocation, the existing cropping patterns and cultivated areas across all irrigation areas in the Tukad Oos Watershed can be re-adjusted, thereby integrating surface water utilisation in the Tukad Oos Watershed to ensure its sustainability.

4 Conclusion

Based on the results of the analysis conducted, it can be concluded that:

1. The current water availability potential in the Tukad Oos Watershed is 950,331.85 litres/sec/year or 950.33 m^3/sec/year with a reliability rate of 80%.
2. The water balance conditions in the Tukad Oos Watershed generally show a water surplus with a total surplus flow of 10.19 m^3/sec at the outlet. This means that the Tukad Oos Watershed still has potential for development. However, based on the water balance conditions at each water intake structure within the basin, there are still five irrigation areas experiencing irrigation water shortages or water deficits.
3. Water allocation management strategies in the Tukad Oos Watershed must prioritise meeting irrigation water needs. To achieve optimal water allocation, the cropping patterns and cultivated areas across all irrigation areas in the Tukad Oos Watershed can be re-adjusted, thereby integrating surface water utilisation in the Tukad Oos Watershed to ensure its sustainability.

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