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Comparison of the NRECA and FJ Mock Methods for Raw Water Availability on a Very Small Island, Karimunjawa

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ABSTRACT: Karimunjawa Island, as one of the very small islands in Indonesia, faces serious challenges in meeting raw water needs due to limited surface water resources and high evaporation rates. Evaluating water availability is essential to support the needs of the local population and the tourism sector. This study aims to compare two methods of estimating raw water availability, namely the NRECA and FJ Mock methods, using data on rainfall, climatology, hydrology, geography, topography, population, vegetation, evapotranspiration, and infiltration. The analysis results show that the NRECA method produces a maximum discharge of 0.726 m³/s in January and a minimum discharge of 0.000 m³/s in August. Meanwhile, the FJ Mock method yields a maximum discharge of 0.927 m³/s in December and a minimum discharge of 0.004 m³/s in August. In addition to the analysis results, this journal also presents sample calculations using both methods. Based on the findings, the NRECA method is considered more suitable for application in small island areas with limited data and complex hydrogeological conditions.

Keywords: *NRECA; FJ Mock; Raw Water Availability; Small Island; Karimunjawa*

I. INTRODUCTION

Raw water availability is a crucial aspect of water resource management, particularly in regions with limited capacity such as small islands. Small islands typically have limited land area, minimal natural resources, and a high dependency on rainfall as the primary source of raw water. This condition is exacerbated by the risks of seawater intrusion and climate change, which affect rainfall patterns. According to Law No. 27 of 2007, later amended by Law No. 1 of 2014, a small island is defined as an island with an area of less than 2,000 km². Meanwhile, islands with an area of less than 100 km² are categorized as very small islands. In contrast, large islands are those with an area of more than 2,000 km² [1].

One example of a very small island facing challenges in raw water availability is Karimunjawa Island, an archipelago located in the Java Sea and part of Jepara Regency, Central Java Province, Indonesia. The island lies approximately 77.2 km from the city of Jepara and is part of a group of 27 islands, five of which are inhabited: Karimun Island, Kemujan Island, Parang Island, Nyamuk Island, and Cilik Island. According to the Central Bureau of Statistics (2023), the Karimunjawa region has a total area of 46.618 km², consisting of 26.74 km² of land and 57.35 km² of water. The population of the region is recorded at 10,609 people [2]. The main sources of raw water come from surface springs and shallow wells; however, their availability decreases during the dry season. Although significant seawater intrusion has not yet occurred, the increasing tourism activities and population growth are placing additional pressure on the region's water resources.

To support sustainable water management, hydrological analysis is needed to quantitatively evaluate water availability. Hydrological analysis is an important tool for assessing raw water availability. Various hydrological analysis methods have been developed to predict water flow and manage water resources effectively. Several previous studies have demonstrated the application of these methods in different regions. Setiyawan et al. (2017), in their study entitled *"Analysis of Water Availability Using the F.J. Mock Method in the Paddy Field Area of Poboya Village, Palu, Central Sulawesi,"* used the FJ Mock and Modified Penman methods to analyze the water balance in a catchment area of 46.642 km². The

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results showed that the available water flow of 0.383 m³/s was sufficient to meet the water demand of 0.0078 m³/s [3].

Rudi Saputri & Saves (2023), in their research entitled *"Analysis of Reliable Discharge Using the NRECA Method for Irrigation Water Demand and the Bagong Reservoir Water Balance in Trenggalek,"* compared the NRECA and FJ Mock methods in the Bagong watershed. The results indicated that the NRECA method produced a maximum discharge of 2.18 m³/s (April I) and a minimum of 0.00 m³/s, while the FJ Mock method produced a maximum discharge of 3.23 m³/s (December I) and the same minimum of 0.00 m³/s [4].

Hartono & Tahadjuddin (2024), in their study entitled *"Hydrological Analysis for Small and Non-Riverine Islands in Kisar Island, Southwest Maluku Regency Using the F.J. Mock and NRECA Methods,"* found that the NRECA method produced a flow pattern that was closer to field conditions compared to the F.J. Mock method [5].

Widyaningsih et al. (2021), in their study entitled *"Comparison of the F.J. Mock and NRECA Methods for Rainfall-Runoff Transformation in the Metro Watershed, Malang Regency, East Java,"* aimed to calculate runoff from rainfall in the Metro Watershed using the F.J. Mock and NRECA methods. The comparison of the calculation results from each method was conducted against rainfall data, since the AWLR data in the Metro sub-watershed was considered insufficient for use as observed discharge data in this study. Based on the analysis, the most suitable method for calculating rainfall-runoff in the Metro sub-watershed was the NRECA method, with a coefficient of determination (R^2) of 0.792 and a correlation coefficient (r) of 0.887.

On very small islands, the application of the F.J. Mock method can provide valuable insights into water flow patterns, which can be used to plan water management infrastructure such as dams, irrigation canals, and drainage systems. Therefore, this method can contribute to more efficient and sustainable water resource management [6].

Two commonly used methods are F.J. Mock and NRECA. Both have been applied in various regions with varying results. Several studies have indicated that the NRECA method tends to provide more accurate representations of actual field discharge conditions, whereas the F.J. Mock method is simpler and more suitable for data-scarce regions [7].

However, there has been limited research specifically comparing these two methods on very small islands such as Karimunjawa. Therefore, a comparative study is essential to determine the most appropriate approach for evaluating raw water availability in such regions. The findings of this study are expected to serve as a technical basis for water resource management recommendations in Karimunjawa and other small islands.

II. LITERATURE REVIEW

Hydrological Analysis

Hydrological analysis plays a vital role in understanding the hydrological cycle and water availability in a region, particularly through the processing of rainfall data [4]. According to Purwanto et al. (2019), such analysis serves as a foundation for determining the water balance in areas with limited water resources. This method is especially relevant for regions like Karimunjawa, which heavily depend on rainfall as their primary water input [5]. Rainfall is expressed in millimeters (mm) and can be calculated using various methods such as the arithmetic mean method, Thiessen polygon method, and isohyetal method [6]. In practice, these three methods are used to determine the average rainfall over a watershed area, forming the basis of hydrological analysis.

Rainfall

Rainfall, as the primary input in the hydrological cycle, plays a significant role in water discharge calculations and water resource planning. A study by Suprapto et al. (2020) indicated that rainfall variability greatly affects the availability of raw water on small islands in Indonesia. Therefore, rainfall analysis serves as the initial step in this research [7].

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Raw Water Availability

Raw water availability is defined as the volume of water discharge that can be sustainably utilized from natural sources such as rivers and reservoirs [8]. According to Wahyuni and Hasan (2018), evaluating raw water availability is crucial in regions with limited surface water resources, including small islands. In this context, a quantitative approach using *reliable discharge* serves as the primary indicator [9]. Reliable discharge is used to assess water availability, and several factors such as rainfall, evapotranspiration, geographic conditions, and soil type significantly influence it. Additionally, water demand from domestic, industrial, and agricultural sectors must also be taken into account.

Small Islands

Small islands, as defined by Law No. 27 of 2007 and amended by Law No. 1 of 2014, are islands with an area of less than 2,000 km² [10]. According to Arifin et al. (2022), small islands such as Karimunjawa face challenges in water management due to their high dependence on rainfall and limited water storage capacity. Therefore, this study focuses on evaluating raw water availability on very small islands with an area of less than 100 km² [11].

NRECA and FJ Mock Methods

The NRECA and FJ Mock methods are two commonly used approaches in studies estimating water availability. The NRECA method employs a quantitative approach based on rainfall and regional characteristics to estimate streamflow [12]. This method has been utilized by Lestari and Widodo (2017) to model water availability in remote areas with limited data [13]. Meanwhile, the FJ Mock method has been widely applied in water balance studies across various watersheds in Indonesia (Santosa et al., 2015) [14].

This study compares the two methods in the context of very small islands to assess which is more suitable for the hydrological characteristics of Karimunjawa. Both methods are particularly applicable in data-scarce regions such as small islands. The FJ Mock method, on the other hand, is based on the water balance principle and considers factors such as infiltration, runoff, and baseflow [15].

Evapotranspiration

Evapotranspiration, as one of the key components in water balance analysis, represents water loss through evaporation and plant transpiration. The Modified Penman method has been widely used in hydrological studies due to its comprehensive consideration of climatic variables (Misra et al., 2016). This study employs the method to estimate water loss on Karimunjawa Island [16].

III. RESEARCH METHODOLOGY

Research Location

This study was conducted on Karimunjawa Island, an archipelago located in the Java Sea and part of Jepara Regency, Central Java Province, Indonesia. The island is situated approximately 77.2 km from the town of Jepara and belongs to a cluster of 27 islands, of which five main islands are inhabited: Karimun Island, Kemujan Island, Parang Island, Nyamuk Island, and Cilik Island [13].

Research Data

The data used in this study consists of several key components. Rainfall data was obtained from the Meteorology, Climatology, and Geophysics Agency (BMKG), based on location and date of recording [14]. Climatological data, including air temperature, humidity, wind speed, and sunshine duration, were also sourced from BMKG. Geographical information such as location coordinates, elevation above sea level, land use, and soil type was obtained from the National Land Agency (BPN). Meanwhile, hydrological data—including river information, streamflow discharge, water level, flood volume, and runoff duration—were acquired from the River Basin Organization (BWS) as well as through direct calculations [15].

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NRECA Method

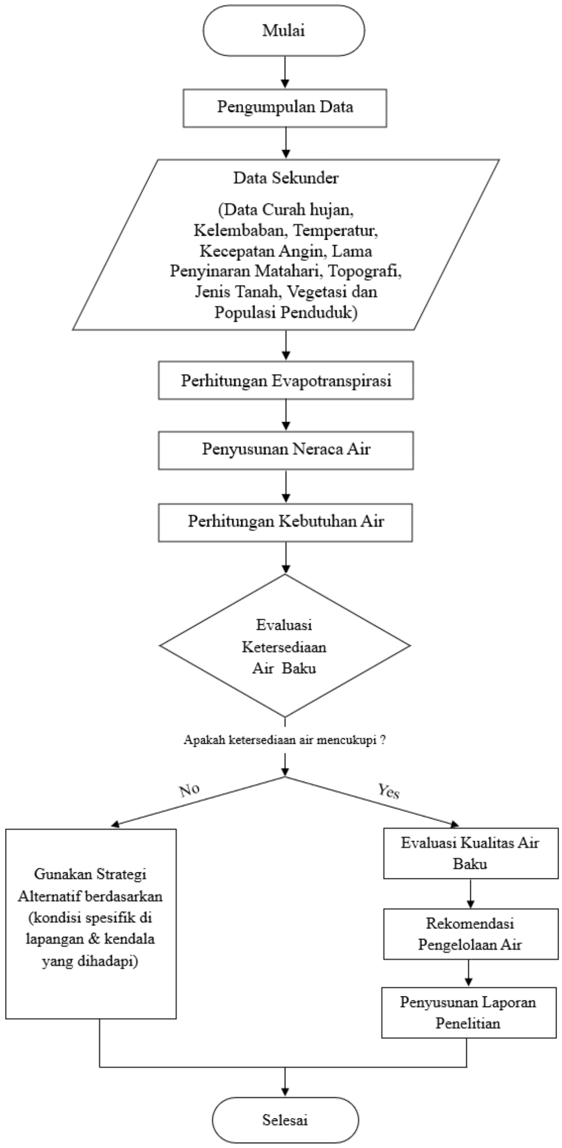

Figure 1. Flowchart of the NRECA Method

The NRECA method was developed by Norman Cran Ford to estimate daily and monthly streamflow data. It is a flow model designed to approximate or match the discharge value at a probability level (P) of 80% [16].

The general NRECA formula is: Water Availability = (P − ET) × C × A

Main Equations :

i. Calculating Actual Evapotranspiration (ET)
Actual evapotranspiration (ET) is calculated by multiplying the ET/ETo ratio by the potential evapotranspiration (ETo) value. The ET/ETo ratio represents the proportion of actual evapotranspiration that occurs compared to its maximum potential.

ii. Calculating Monthly Water Balance (WB)
The monthly water balance (WB) is obtained by subtracting actual evapotranspiration (ET) from monthly rainfall (Rb). The WB value reflects either a surplus or deficit of water in a given month.

iii. Calculating Effective Moisture (EM)

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Effective Moisture (EM) represents the excess soil moisture available after evapotranspiration demands have been met. This value is obtained by multiplying the excess moisture ratio (EMR) by the water balance (WB).

iv. Calculating Ground Water Storage (GWS)
Ground Water Storage (GWS) represents the amount of water retained in the soil as groundwater reserves. This value is calculated by multiplying the surface soil characteristic parameter (P1) by the effective moisture (EM).

v. Calculating Ground Water Flow (GWF)
Ground Water Flow (GWF) is the portion of water that slowly moves through the soil toward rivers or wells. This value is calculated by multiplying the deep soil parameter (P2) by the Ground Water Storage (GWS).

vi. Calculating Direct Flow (DF)
Direct Flow (DF), or surface runoff, is calculated by multiplying Effective Moisture (EM) with Ground Water Storage (GWS). This component represents the portion of rainfall that flows directly over the surface without being stored in the soil.

vii. Calculating Total Streamflow (Q)
Total streamflow represents the combination of direct flow (DF) and groundwater flow (GWF). This value indicates the total amount of water available as surface flow within a given month.

viii. Converting Streamflow to Water Discharge (Q in m^3/s)
The average streamflow discharge is calculated using a conversion formula that takes into account the land coefficient (C), annual rainfall (P), and catchment area (A). A constant of 31.54 is used to convert units from mm·ha/year to m^3/s.

ix. Calculating Soil Moisture Storage (S)
Soil moisture storage (S) is the difference between the monthly water balance (WB) and effective moisture (EM), representing the amount of water remaining stored in the soil.

x. Calculating Initial Soil Moisture (Wi)
The initial soil moisture (Wi) is calculated by dividing the previous soil moisture (Wo) by a nominal factor N, where N = 100 + 0.2. Wi represents the soil moisture condition at the beginning of the analysis period.

xi. Raw Water Availability (Q) = (P – ET) x C x A

xii. This formula is used to calculate raw water availability (Q) in cubic meters. The total rainfall is subtracted by actual evapotranspiration, then multiplied by the runoff coefficient and the catchment area in square kilometers, and finally multiplied by 10 (since 1 mm over 1 km^2 equals 1,000,000 liters or 1,000 m^3).

xiii. Water Demand = Population × Per Capita Demand × Number of Days / 1000

xiv. Monthly water demand is calculated by multiplying the total population by the daily per capita water demand and the number of days in a month, then dividing by 1,000 to convert the units into cubic meters.

FJ Mock Method

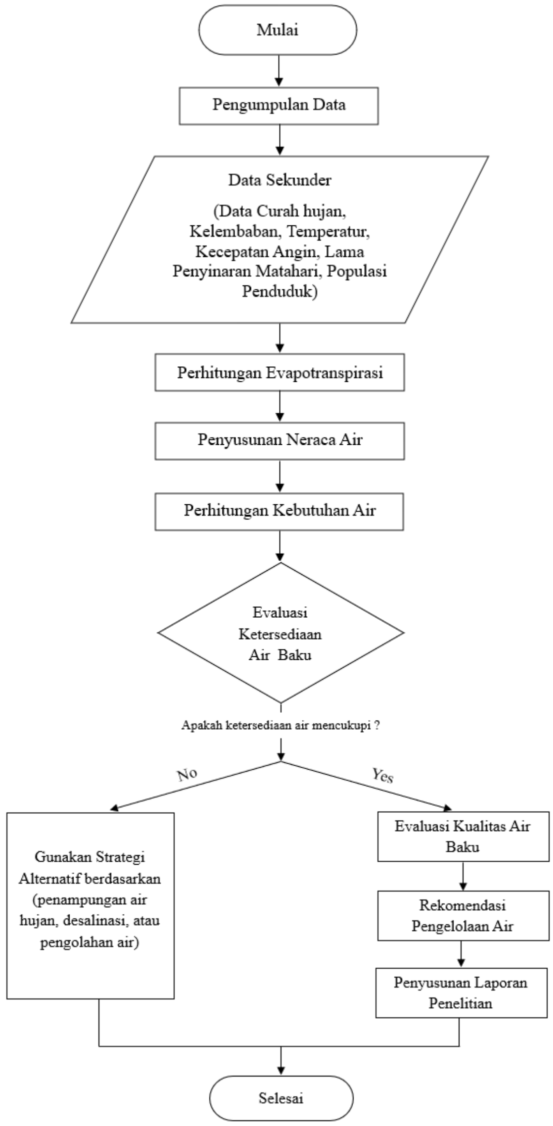

Figure 2. Flowchart of the FJ Mock Method

The FJ Mock method, developed by Dr. F.J. Mock, is designed to estimate river discharge within a watershed based on the water balance approach. In this method, precipitation falling over the catchment area is subject to various hydrological processes, primarily evapotranspiration. The evapotranspiration component in the FJ Mock method is influenced by several factors, including vegetation type, soil surface conditions, and the number of days within the calculation period [17].

General Formula of the FJ Mock Method, this model is based on monthly water balance calculations:

$P = Et + Q + \Delta S$

Where precipitation (P) is assumed to be allocated to actual evapotranspiration (ET), surface runoff (Q), and changes in groundwater storage (ΔS). This model was first developed by Mock (1973) and has since been widely used in water availability analysis, particularly in regions with limited data (Asdak, 2010; Sari & Suprayogi, 2016) [18].

Main Equations :

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i. $\Delta S = P - Et$
ii. This formula is used to calculate the change in water storage (ΔS), which is the difference between monthly precipitation (P) and actual evapotranspiration (ET). When precipitation exceeds evapotranspiration, the resulting water surplus can be utilized.
iii. $WS = \Delta S$ (jika $\Delta S > 0$), otherwise, $WS = 0$
iv. Water Surplus (WS) is calculated from ΔS. If ΔS is positive, then WS is equal to ΔS. However, if ΔS is negative (indicating a deficit), WS is assumed to be zero, as there is no water surplus.
v. Infiltration (I)
vi. Infiltration is the portion of water surplus that percolates into the soil. This value represents a certain proportion of WS and indicates the potential amount of water that contributes to groundwater recharge.
vii. Direct Runoff (DR) = WS – I
viii. Direct runoff is calculated by subtracting infiltration from the total water surplus. It represents the volume of water that flows directly over the surface toward rivers or reservoirs.
ix. Base Flow (BF) is a proportion of infiltration (I).
x. Base flow refers to the slow or sustained flow of water that originates from infiltration. Its value represents a portion of the infiltrated water (I), typically expressed as a certain percentage.
xi. Total Flow (R) = DR + BF
xii. Total flow is the sum of surface runoff and base flow. It represents the total amount of water available from both surface and subsurface flow.
xiii. Raw Water Availability (Q) = R × Area (km^2) × 10
xiv. This formula is used to calculate raw water availability (Q) in cubic meters. The total runoff (R) is multiplied by the area in square kilometers, and then multiplied by 10 (since 1 mm over 1 km^2 equals 1,000,000 liters or 1,000 m^3).
xv. Water Demand = Population × Per Capita Water Requirement × Days / 1000
xvi. Monthly water demand is calculated by multiplying the total population by the daily per capita water requirement and the number of days in a month, then dividing by 1,000 to convert the unit into cubic meters.
xvii. Sufficiency Percentage = (Q / Demand) × 100
xviii. This formula indicates the extent to which water availability meets the demand. If the result exceeds 100%, it means the water demand is fulfilled and there is a surplus.

The monthly rainfall data used in this study were obtained from the Central Java Climatology Station (2024) for the period 2015–2024, as presented in Table 1.

Table 1. Average Rainfall

Year	Annual Average (mm)	Annual Total (mm)
2015	89,79	1.077,5
2016	194,7	2.336,5
2017	225,4	2.704,4
2018	168,7	2.024,3
2019	104,1	1.249,4
2020	209,0	2.507,7
2021	206,4	2.476,8
2022	220,3	2.643,9
2023	147,4	1.768,7
2024	434,3	2.822,7

Based on rainfall data from 2015 to 2024, Karimunjawa Island exhibits significant annual variability in precipitation. The year with the highest rainfall was 2024, with a monthly average of 434.3 mm and a total annual rainfall of 2,822.7 mm. This indicates very high rainfall intensity, possibly due to changes in seasonal weather patterns or a wet climate condition. On the other hand, 2015 was recorded as the driest year, with a monthly average of only 89.79 mm and a total annual rainfall of 1,077.5 mm. The low rainfall in that year highlights the potential vulnerability in raw water availability, especially in small island areas that rely heavily on rainwater as their primary water source.

Overall, the average annual rainfall in Karimunjawa over the past ten years is approximately 2,070.1 mm. This value indicates that most years experience relatively high rainfall. This presents a significant opportunity for utilizing rainwater as a raw water source, particularly during the rainy season, which is crucial for supporting the needs of the community and activities on Karimunjawa Island. To address rainfall fluctuations, efficient water management strategies are necessary, such as rainwater harvesting and the construction of water storage facilities. Utilizing rainwater during the wet season can serve as a solution to overcome shortages in the dry season. In addition, rainfall monitoring and climate data–based planning are essential to ensure the sustainability of raw water availability on Karimunjawa Island.

DISCUSSION

Evapotranspiration Analysis

Evapotranspiration is a critical factor in predicting discharge based on rainfall and climatological data. This is because evapotranspiration significantly influences the amount of runoff generated in a watershed area. Evapotranspiration refers to the loss of water from land surfaces and water bodies in a watershed due to a combination of evaporation and transpiration processes [18].

The Penman equation used in this study is one of the empirical methods for calculating potential evapotranspiration by taking into account solar radiation, air humidity, and wind speed. The equation is formulated as follows:

$$ETo = C\,.(w\,.\,Rn + (1-w).f(u)\,.(ea - ed) \qquad (1)$$

(Asdak, 2010; Doorenbos & Pruitt, 1977).

Example Calculation (January)

Given :

Average Temperature (T) = 24,82°C

Average Relative Humidity (RH) = 76,02 %

Average Wind Speed (u) = 1,99 km/day

Average Sunshine Duration (ss) = 4,13 %

Calculation of Actual Vapor Pressure (ea) & Saturation Vapor Pressure (ed)

(ea) $= 35{,}7 + (\frac{37{,}8-35{,}8}{28-27}) x\ \mathrm{T} - 27$

$= 35{,}7 + \left(\frac{37{,}8-35{,}8}{28-27}\right) x\ 24{,}82 - 27 = 31{,}12$ mbar

(ed) $= \frac{ea\,.\,RH}{100}$

$= \frac{31{,}12-76{,}02}{100} = 23{,}66\ mbar$

(Ea – ed) $= 31{,}12 - 23{,}66 = 7{,}46\ mbar$

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Calculation of Wind Speed Factor f(u)

Wind Speed at 2 Meters (U_2) $= u \,.\, \left(\frac{\log(6{,}6)}{\log(12)}\right)$

$= 1{,}99 \,.\, \left(\frac{0{,}82}{1{,}08}\right) = 1{,}51\ km/day$

f(U) $= 0{,}27 \,.\, \left(1 + (\frac{U^2}{100})\right)$

$= 0{,}27 \,.\, \left(1 + (\frac{1{,}51}{100})\right) = 0{,}27\ km/day$

Calculation of Temperature Factor (w) and Comparator (1-w)

w $= \left(\frac{T}{T_{Total\ peryear}}\right)$

$= \left(\frac{24{,}82}{338{,}9}\right) = 0{,}07$

(1 - w) $= 1 - 0{,}07 = 0{,}93$

Calculation *Radiation Netto* (Rn)

Ra $= 16 + \left(\frac{16-16}{8-6}\right)\ x\ 6{,}4 - 6 = 15{,}86\ mm/day$

N $= 12 + \left(\frac{13-12}{10-5}\right)\ x\ 6{,}4 - 5 = 12{,}22\ mm/day$

N $= \frac{ss}{12} = \frac{4{,}13}{12} = 0{,}34\ mm/day$

n/N $= \frac{0{,}34}{12{,}22} = 0{,}03\ mm/day$

Rs $= (\,0{,}25 + 0{,}5\,.\ n)\,.\,Ra$

$= (\,0{,}25 + 0{,}5\,.\ 0{,}34)\,.\,15{,}86 = 4{,}19\ mm/day$

Rns $= (\,1 - 0{,}23)\,.\,Rs$

$= (\,1 - 0{,}23)\,.\,4{,}19 = 3{,}23\ mm/day$

f(T) $= 15 + \left(\frac{16-15}{26-24}\right)\,.\,T - 24$

$= 15 + \left(\frac{16-15}{26-24}\right)\,.\,24{,}82 - 24 = 15{,}61\ mm/day$

f(ed) $= 0{,}34 - (0{,}044\,.\,(ed)^{0{,}5})$

$= 0{,}34 - (0{,}044\,.\,(23{,}66)^{0{,}5}) = 0{,}13\ mm/day$

f(n/N) $= 0{,}1 + \left(0{,}9\,.\,\frac{n}{N}\right)$

$= 0{,}1 + (0{,}9\ x\ 0{,}03) = 0{,}13\ mm/day$

Rnl $= f(T) \,.\, f(ed) . f(\frac{n}{N})$

$= 15{,}61 \; x \; 0{,}13 \; x \; 0{,}13 = 0{,}25 \; mm/day$

Rn $= Rns - Rnl$

$= 3{,}23 - 0{,}25 = 2{,}98 \; mm/day$

Correction Factor Calculation

u $= \left(\frac{u\,.1000}{24.60.60}\right)$

$= \left(\frac{1{,}99\,.1000}{24.60.60}\right) = 0{,}02 \; m/sec$

Uday/Unight $= \frac{u}{0{,}5\,.u}$

$= \frac{0{,}02}{0{,}5\,.\;0{,}02} = 2 \; m/sec$

RH max = 90 %

Rs = 4,19 mm/day

C $= 0{,}88 + \left(\frac{0{,}94-0{,}88}{9-6}\right) . (Rs - 6)$

$= 0{,}88 + \left(\frac{0{,}94-0{,}88}{9-6}\right) . (4{,}19 - 6) = 0{,}87$

Perhitungan Eto

ETo $= C\,.(w\,.\;Rn + (1-w).f(u)\,.(ea - ed)$

$= 0{,}87\,.(0{,}07\,.\;2{,}98 + (0{,}93).0{,}27\,.7{,}46 = 1{,}84 \; mm/day$

Ep $= ETo\,.31$

$= 1{,}84\,.31 = 56{,}93 \; mm/month$

Table 2. Evapotranspiration (ETo) Calculation Results

No.	Description	Jan	Feb	Mar	Apr	Mei	Jun	Jul	Ags	Sep	Okt	Nop	Des
1	Average Temperature (T)	24.82	27.37	27.96	28.65	29.26	28.58	28.16	28.35	29.06	29.52	28.89	28.26
2	Air Humidity (RH/100)	76.02	85.53	83.80	80.52	75.90	75.89	72.97	71.40	69.92	73.36	78.82	82.00
3	ea	31.12	36.48	37.71	39.16	40.44	39.01	38.14	38.53	40.03	40.99	39.66	38.35
4	ed	23.66	31.20	31.60	31.53	30.69	29.60	27.83	27.51	27.99	30.07	31.26	31.45
5	(ea-ed)	7.46	5.28	6.11	7.63	9.75	9.41	10.31	11.02	12.04	10.92	8.40	6.90
6	U_2	1.51	1.81	1.48	1.59	1.82	1.57	1.74	1.87	1.62	1.64	1.56	1.46
7	f(U)	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.28	0.27	0.27	0.27	0.27

8	(1 - w)	0.93	0.92	0.92	0.92	0.91	0.92	0.92	0.92	0.91	0.91	0.91	0.92
9	w	0.07	0.08	0.08	0.08	0.09	0.08	0.08	0.08	0.09	0.09	0.09	0.08
10	(1-w).f(U).(ea-ed)	1.90	1.33	1.54	1.92	2.45	2.36	2.60	2.78	3.02	2.74	2.11	1.73
11	Ra	15.86	16.02	15.58	14.64	13.34	12.72	13.02	13.94	14.98	15.72	16.40	15.76
12	N	12.22	12.27	12.30	12.06	11.98	11.88	11.86	11.93	12.00	12.17	12.22	12.32
13	n/N	0.03	0.03	0.04	0.04	0.05	0.05	0.06	0.06	0.06	0.05	0.04	0.03
14	(0.25+0.5n/N)	0.26	0.27	0.27	0.27	0.28	0.28	0.28	0.28	0.28	0.28	0.27	0.27
15	Rs	4.19	4.26	4.19	3.99	3.68	3.50	3.62	3.90	4.18	4.33	4.42	4.19
16	Rns	3.23	3.28	3.22	3.07	2.83	2.70	2.79	3.00	3.22	3.33	3.40	3.22
17	f(T)	15.61	13.06	13.60	16.43	16.55	16.42	16.33	16.37	16.51	16.60	16.48	16.35
18	f(ed)	0.13	0.09	0.09	0.14	0.15	0.15	0.15	0.15	0.15	0.15	0.14	0.13
19	f(n/N)	0.13	0.13	0.13	0.14	0.15	0.15	0.15	0.15	0.15	0.15	0.14	0.13
20	Rnl=f(T).f(ed).f(n/N)	0.25	0.16	0.17	0.32	0.35	0.35	0.37	0.38	0.38	0.35	0.30	0.27
21	Rn=Rns-Rnl	2.98	3.12	3.06	2.75	2.48	2.35	2.42	2.62	2.84	2.98	3.10	2.96
22	w.Rn	0.22	0.25	0.25	0.23	0.21	0.20	0.20	0.22	0.24	0.26	0.26	0.25
23	Uday	0.02	0.03	0.02	0.02	0.03	0.02	0.03	0.03	0.02	0.02	0.02	0.02
24	Uday/Unight	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
25	C	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87
26	ETo=C[w.Rn + (1-w).f(U).(ea-ed)]	1.84	1.38	1.55	1.88	2.33	2.24	2.45	2.62	2.84	2.61	2.06	1.72
27	Ep (Potential Evapotranspiration)	56.93	42.69	48.16	58.17	72.21	69.45	75.83	81.09	88.16	80.86	63.96	53.39

Table 2 presents the results of monthly climate component calculations used in estimating potential evapotranspiration (ETo) based on the Modified Penman method. The components shown include average temperature, relative humidity, saturated vapor pressure (ea and ed), vapor pressure deficit (ea-ed), wind speed (U_2), solar radiation (Ra, Rs, Rns), as well as other correction parameters such as w, f(U), and C. The highest monthly ETo value occurred in September at 2.84 mm/day, while the lowest was in February at 1.38 mm/day, which aligns with the seasonal climate pattern in tropical regions, where dry months tend to generate higher evaporation. Monthly potential evapotranspiration (Ep) values also show a similar pattern, with the highest in September (88.16 mm) and the lowest in February (42.69 mm). The information in Table 2 serves as an essential basis for water balance analysis to assess water availability and demand in the study area.

NRECA Analysis Results

Based on the calculation results for January, the average monthly rainfall (Rb) was 267.16 mm and the potential evapotranspiration (PET) was 56.93 mm. The actual evapotranspiration (AET) was obtained using a ratio of 0.80, resulting in AET = 0.80 × 56.93 = 45.55 mm. Next, the monthly water balance (WB) was calculated from the difference between rainfall and AET, which is WB = 267.16 – 45.55 = 221.61 mm. Excess Moisture (EM) was calculated using a ratio of 0.60, giving EM = 0.60 × 221.61 = 132.97 mm. Ground Water Storage (GWS), with a surface soil parameter (P1) of 0.4, resulted in GWS = 0.4 × 132.97 = 53.19 mm. Ground Water Flow (GWF) was calculated using P2 = 0.5, resulting in GWF = 0.5 × 53.19 = 26.59 mm. Direct Flow (DF) was obtained from the difference between EM and GWS, which is DF = 132.97 – 53.19 = 79.78 mm, so the total flow (Q1) = DF + GWF = 79.78 + 26.59 = 106.37 mm. With a catchment area of 46.62 hectares, the total discharge (Q2) = 106.37 × 46.62 × 10 = 4,953.98 m^3.

Raw water availability was calculated using the formula (Rb – AET) × C × A, with a land coefficient (C) of 0.5, resulting in availability = (267.16 – 56.93) × 0.5 × 46.62 = 49,004.18 m³. Raw water demand was calculated based on a population of 10,609 people with a consumption of 60 liters per day for 31 days, i.e. (10,609 × 60 × 31) / 1000 = 19,732.74 m³. Therefore, the difference between availability and demand is 49,004.18 – 19,732.74 = 29,271.44 m³, indicating a surplus of raw water in that month.

A recapitulation of the results of raw water availability and demand calculations using the NRECA method is presented in Table 3. This table contains monthly data reflecting the estimated reliable discharge as an indicator of water availability, as well as raw water demand from various sectors. The data is used to evaluate the balance between water supply and demand in the study area. Through the analysis in Table 3, critical months where water availability falls below demand can be identified, forming the basis for formulating sustainable raw water resource management strategies on Karimunjawa Island.

Table 3. Recapitulation of Raw Water Availability and Demand Using the NRECA Method

Month	Raw Water Availability (m³)	Raw Water Demand (m³)	Difference (m³)	Water Sufficiency Percentage (%)	Description
January	758611.16	19732.74	738878.42	3844.429	surplus
February	1072615.09	17823.12	1054791.97	6018.111	surplus
March	573589.09	19732.74	553856.35	2906.789	surplus
April	570149.66	19096.20	551053.46	2985.671	surplus
May	270848.09	19732.74	251115.35	1372.582	surplus
June	127796.09	19096.20	108699.89	669.223	surplus
July	-30955.47	19732.74	-50688.21	-156.874	defisit
August	-114657.61	19732.74	-134390.35	-581.053	defisit
September	87610.80	19096.20	68514.60	458.787	surplus
October	312176.65	19732.74	292443.91	1582.024	surplus
November	659011.61	19096.20	639915.41	3451.009	surplus
December	698169.33	19732.74	678436.59	3538.127	surplus

The analysis results show that raw water availability on Karimunjawa Island experiences significant fluctuations throughout the year. A water surplus occurs from January to April, as well as in November and December, with availability exceeding the monthly demand. The highest surplus was recorded in February, where water availability reached 70,476.45 m³, or 395.42% of the demand. This indicates a large potential for rainwater utilization during the rainy season. Meanwhile, a water deficit occurs from May to October, with the most critical conditions in July and August, where there was no water availability at all (0 m³). The water sufficiency percentage during these deficit months is very low, even reaching 0%, thus unable to meet the population's needs. This condition underscores the importance of sustainable water management, such as rainwater harvesting during the rainy season for use in the dry season, or considering alternative sources like deep wells and desalination.

FJ Mock Analysis Results

Based on the calculations for January, the average monthly rainfall (P) was recorded at 267.16 mm, while evapotranspiration (Et) was 56.93 mm, resulting in a change in water storage (ΔS) of 210.23 mm. Since the ΔS value is positive, the entire amount is considered as water surplus (WS). From this surplus, infiltration amounted to 84.09 mm, so the direct runoff (DR) was 126.14 mm. Additionally, there was a base flow (BF) of 42.05 mm, making the total surface flow (R) the sum of DR and BF, which is 168.18 mm. With an area of 42.62 km², the total runoff volume (Q) generated was 7,840,668.82 m³. Meanwhile, water demand was calculated based on a population of 10,609 people, with a consumption of 60 liters per day over 31 days, resulting in a total demand of 19,732.74 m³. Therefore, the difference between availability and demand was 7,820,936.08 m³, or a sufficiency percentage of 39,734.31%, indicating a water surplus condition in the area.

A recapitulation of raw water availability calculations using the FJ Mock method is presented in Table 4. This table displays monthly water balance outputs, including estimates of runoff, evapotranspiration, and changes in groundwater storage for each month. The data in Table 4 is used to assess the dynamics of water availability based on the water balance approach, which considers rainfall input and various water loss factors. These results are important for comparing the effectiveness of the FJ Mock method with the NRECA method in estimating raw water availability, especially in the context of small island areas like Karimunjawa, which have unique hydrological characteristics and data limitations.

Table 4. Results of FJ Mock Method Analysis

Month	Raw Water Availability (m³)	Raw Water Demand (m³)	Difference (m³)	Water Sufficiency Percentage (%)	Description
Januari	1685802.58	19732.74	1666069.84	8543.175	surplus
Februari	2383589.10	17823.12	2365765.98	13373.579	surplus
Maret	1274642.42	19732.74	1254909.68	6459.531	surplus
April	1149276.07	19096.20	1130179.87	6018.350	surplus
Mei	719607.82	19732.74	699875.08	3646.771	surplus
Juni	283991.30	19096.20	264895.10	1487.161	surplus
Juli	0.00	19732.74	-19732.74	0.000	defisit
Agustus	0.00	19732.74	-19732.74	0.000	defisit
September	194690.68	19096.20	175594.48	1019.526	surplus
Oktober	693725.89	19732.74	673993.15	3515.609	surplus
November	1464470.25	19096.20	1445374.05	7668.909	surplus
Desember	1551487.40	19732.74	1531754.66	7862.504	surplus

The calculation results show that Karimunjawa Island experiences a surplus of raw water almost throughout the year, except in July and August when water availability is completely insufficient (deficit). The highest surplus occurs in February, amounting to 11,258,409.04 m³, caused by high rainfall and low evapotranspiration. Conversely, the most severe deficit happens in July and August with zero water availability, while demand remains high, resulting in a deficit of -19,732.74 m³ each month.

Months with surplus include January through June and September through December, while deficit months are July and August. The average monthly water availability far exceeds demand, providing potential for storage or utilization during the dry season. However, in July and August, all water needs cannot be met from surface sources, highlighting the importance of rainwater harvesting or alternative sources such as bore wells or desalination.

Technical Comparison of NRECA and FJ Mock Methods

The NRECA and FJ Mock methods show different estimates of raw water availability. FJ Mock produces higher discharge values because it considers more components of the water balance, such as runoff, infiltration, and changes in water storage. Its advantage lies in being more detailed and responsive to rainfall variations, but it requires complete and accurate data.

In contrast, the NRECA method is simpler and more conservative, making it more suitable for areas with limited data, such as small islands. Although its results tend to be lower, this method provides realistic and safe estimates as a basis for planning.

Overall, the NRECA method is recommended for initial evaluation in data-scarce areas, while FJ Mock can be used as a complementary approach when more comprehensive data is available, resulting in a more thorough analysis.

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IV. CONCLUSION

Based on the calculation and analysis results, the NRECA method produced a maximum discharge of 0.726 m³/s in January and a minimum discharge of 0.000 m³/s in August. The highest raw water availability using this method occurred in February at 52,653.33 m³, while the largest deficit was in July and August with a deficit value of -19,732.74 m³ due to insufficient water availability to meet the population's needs.

Meanwhile, the FJ Mock method yielded a maximum discharge of 0.927 m³/s in December and a minimum discharge of 0.004 m³/s in August. The highest surplus using the FJ Mock method was also in February, reaching 11,258,409.04 m³, and the largest deficit occurred in July and August with the same deficit value as the NRECA method, -19,732.74 m³.

In general, both methods show that Karimunjawa Island experiences a raw water surplus during the rainy season (January–June and September–December) but a deficit during the dry season (July and August). Compared to each other, the FJ Mock method produces higher discharge values and is more sensitive to rainfall, whereas the NRECA method provides more conservative and realistic results, making it more suitable for small island areas with limited data and complex hydrogeological conditions like Karimunjawa.

Therefore, the NRECA method is recommended for conservative evaluation of raw water availability on very small islands, while the FJ Mock method can be used as a complementary approach when more detailed data is available. These findings can serve as a basis for formulating water conservation policies, planning rainwater storage, developing seasonal clean water supply infrastructure, and adjusting community water consumption.

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