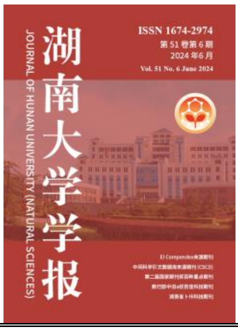

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Sustainable Water Resources Management: Groundwater Recharge Potential in the Mesuji-Tulang Bawang River Basin

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Abstract: This research aims to analyze groundwater recharge potential in the study area to support sustainable water resource management. This research was conducted in the Mesuji-Tulang Bawang River Basin in the provinces of Lampung and South Sumatera. However, the improvement in data availability will increase the accuracy of sustainable water resource management solutions. The methodology consists of hydrological data analysis and groundwater recharge potential calculation. The calculation used the method devised by IWACO, which has already been proven to be able to calculate the recharge in areas with dense populations. Four main values are considered important in this calculation: rainfall, population density, evapotranspiration, and land use. According to the findings, about 25% of the rainfall serves to replenish the groundwater in the study region. The estimated maximum groundwater recharge is 836 mm/y, which corresponds to the highest rainfall value of 3357 mm/y. Nevertheless, there are other areas with significantly lower groundwater recharge potentials of only 4 mm/y.

Keywords: sustainable management, river basin, groundwater.

可持续水资源管理：梅苏吉-图朗巴旺河流域地下水补给潜力

摘要：本研究旨在分析研究区域的地下水补给潜力，以支持可持续水资源管理。这项研究是在楠榜省和南苏门答腊省的梅苏吉-图朗巴旺河流域进行的。然而，数据可用性的提高将提高可持续水资源管理解决方案的准确性。该方法包括水文数据分析和地下水补给潜力计算。计算使用了伊瓦科设计的方法，该方法已被证明能够计算人口密集地区的补给量。该计算中认为有四个主要值很重要：降雨量、人口密度、蒸散量和土地利用。根据研究结果，大约25%的降雨量用于补充研究区域的地下水。估计的最大地下水补给量为836毫米/年，对应于最高降雨量3357毫米/年。然而，其他地区的地下水补给潜力要低得多，仅为 4 毫米/年。

关键词：可持续管理、河流流域、地下水。

1. Introduction

Population growth has increased stress on many natural resources, including water. The use of surface water and groundwater for human needs is increasing. Surface water and groundwater were previously managed separately. Currently, they are managed as a single entity under the jurisdiction of Law on Water Resources No. 17/2019 [1]. Based on this law, the groundwater and surface water are managed based on the river basin (Wilayah Sungai (WS)). The present course of action is favorable since the depletion of groundwater is an immediate consequence of the mishandling of surface water, leading to a situation where economically disadvantaged individuals are compelled to resort to extracting groundwater to meet their water requirements [2].

The management of water resources has yet to integrate all components into one united system, especially groundwater and surface water, despite moving in the right direction based on Law on Water Resources No. 17/2019. The full implementation of this law will ensure the sustainable use of water.

Integrated water resource management (IWRM) has been applied in many parts of the world, e.g., in Canada [3] and Uganda [4], with mixed results. The implementation in Canada could be considered successful because of several factors: enough funds, clear objectives, and the ability of the water management team to influence the government's decision [3]. On the contrary, the implementation of IWRM in Uganda is a failure due to a lack of funds, coordination, management, and law enforcement [4].

Research into IWRM has not yet been fully implemented in Indonesia. Indonesia has many transboundary WSs with specific conditions and problems. One important step in implementing the IWRM is investigating water availability in the desired area. To support this, this research focuses on the investigation of recharge potential in WS Mesuji-Tulang Bawang.

2. Materials and Methods

Hydrological cycles are cycles of water circulation on Earth (Fig. 1). Mismanagement of water is the primary cause of groundwater stress. Therefore, good integrated management of water resources is key to sustainable use of groundwater. Overall, water balance has the following formula:

$$P = ET + R_{off} \pm \Delta S \quad (1)$$

Explanation:

P - precipitation

ET - evapotranspiration

R_{off} - surface runoff

ΔS - storage change (highly affected by groundwater and surface water interaction)

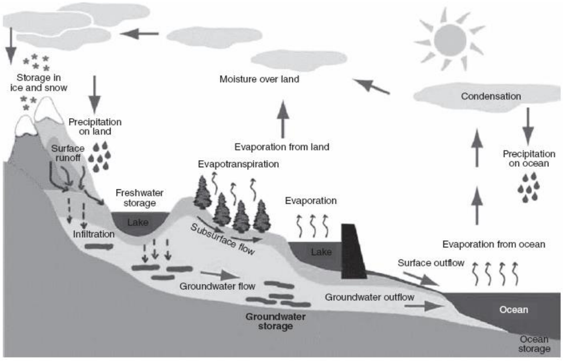

Fig. 1 Hydrological cycle [5]

2.1. Groundwater-Surface Water Interaction

Groundwater occupies a saturated subsurface zone. Groundwater is connected to surface water like rivers, lakes, swamps, or marshes. The interaction between groundwater and surface water can be natural (Fig. 2) or anthropogenic (Fig. 3). Anthropogenic interactions that affect surface and groundwater conditions are caused by human activities, including contamination and agriculture [6]. One result of the interaction between groundwater and surface water is the availability of river water during drought seasons. The presence of groundwater is highly affected by the groundwater recharge (Fig. 4). Groundwater recharge capacity is an important aspect of IWRM. Several methods can be employed to estimate groundwater recharge: the installation of lysimetric devices in the vadose zone, the calculation of catchment water budgets, the use of remote sensing techniques, the application of numerical models, and the measurement of groundwater fluctuations and radioisotopes.

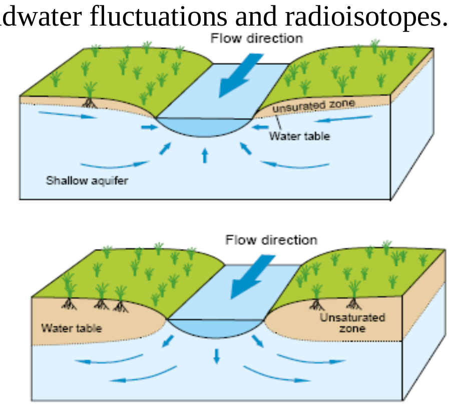

Fig. 2 Natural groundwater-surface water interactions [7]

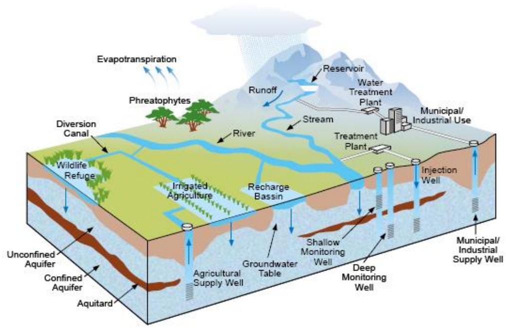

Fig. 3 Anthropogenic interactions between groundwater and surface

water [7]

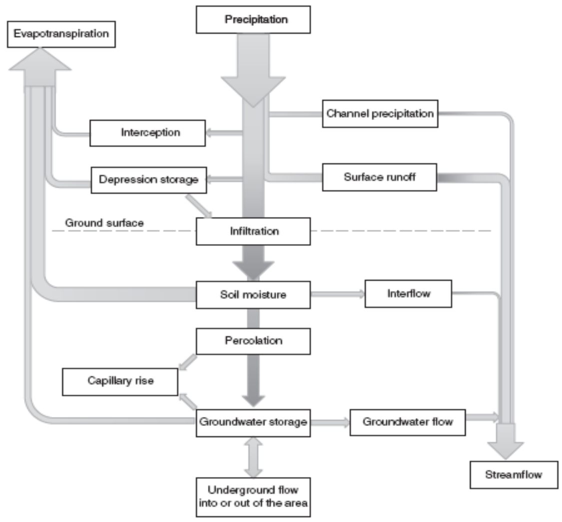

Fig. 4 Water balance and groundwater role in hydrology [6]

The effects of external factors cannot be understated. Agricultural activities that involve the use of external water sources can contribute to groundwater recharge, leading to increased evaporation beneath the surface and the salinization of the soil (Fig. 5).

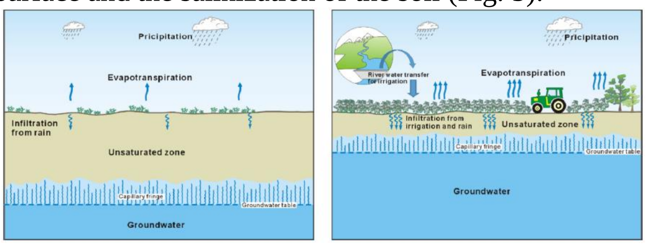

Fig. 5 Natural (left) and post-agriculture (right) groundwater conditions [8]

The effective management of integrated water resources requires clear interactions between surface water and groundwater. Although it may seem straightforward, achieving this balance is easier said than done. A numerical model can provide a clear picture of the interactions between surface water and groundwater [6]. The numerical models allow the clear interaction between these two systems to be modeled even with insufficient data.

2.2. Groundwater Recharge Calculation

Groundwater recharge is (rain)water infiltration into aquifers. The method employed for determining groundwater recharge potential was the IWACO technique, which was introduced in 1994 [9]. The proposed IWACO method has been adapted to the conditions of several land uses, even in cities (Fig. 6). Because of this, land use maps are essential in this calculation. The following formula was used to calculate the groundwater recharge potential:

$$R_{perv} = (1 - f_{impv}) * (P * (1 - k_{dsro}) - E_{act}) \quad (2)$$

$$R_{impv} = f_{impv} * k_{impv} * (P - Ea_{impv}) \quad (3)$$

Explanation:

R_{perv} - rainfall on the pervious surface

R_{impv} - rainfall on the impervious surface

f_{impv} - impervious surface percentage (directly correlated with population)

P - rainfall intensity

k_{dsro} - percentage of direct surface runoff in pervious soil

k_{impv} - percentage of rainfall on the impervious surface that infiltrates the subsurface

E_{act} - transpiration on the pervious surface

Ea_{impv} - transpiration on the impervious surface

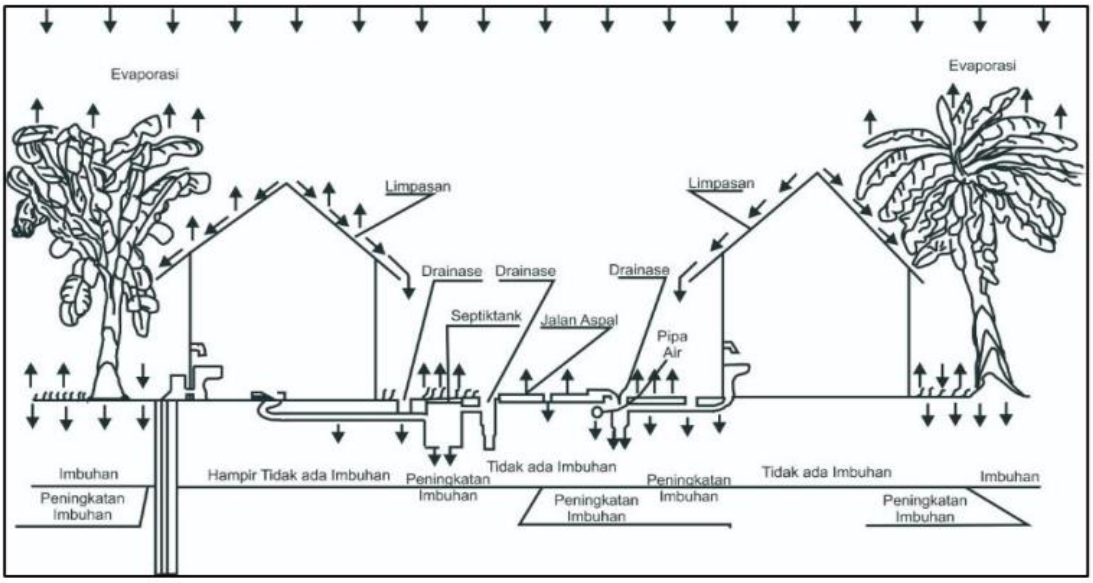

Fig. 6 Groundwater recharge mechanism in large cities [9]

2.3. IWRM

IWRM is an approach to managing water resources that emphasizes sustainability, equitable allocation, and regular monitoring of the condition of water resources. This approach was recommended by the Global Water Partnership in 1996 [4].

The procurement of data for groundwater-surface water interaction modeling is necessary as a starting point for the implementation of IWRM. To fully implement IWRM, we must understand that groundwater and surface water have different characteristics (Table 1). The implementation of IWRM requires support from various sectors, including appropriate policies, supporting regulations, adequate institutions, and competent management [4]. These sectors must support the achievement of IWRM objectives while implementing the four basic principles of water:

a. Clean water is a nonrenewable resource.

b. The effective development and management of water resources necessitate the active participation of all relevant stakeholders, including government agencies, water users, and water resource managers.

c. Women play an important role in water resource management.

d. Water is both an economic and social commodity.

Table 1 Difference between groundwater and surface water [7] (Own study)

Feature	Groundwater Resources & Aquifers	Surface Water Resources & Reservoirs
Hydrological Characteristics		
Storage	Very large	Small to moderate
Resource Areas	Relativity unrestricted	Restricted to water bodies
Recharge	Restricted to unconfined aquifers	Takes place everywhere with rainfall
Response to changes	Very slow	Rapid
Flow velocities	Low	Moderate to high
Residence time	Generally decades / centuries	Mainly weeks / months
Drought vulnerability	Generally low	Generally high
Evaporation losses	Low and localised	High for reservoirs
Resource evaluation	High cost and significant uncertainty	Lower cost and often less uncertainty
Abstraction impacts	Delayed and dispersed	Immediate
Natural quality	Generally (but not always) high	Variable
Pollution vulnerability	Variable natural protection	Largely unprotected
Pollution persistent	Often extreme	Mainly transitory
Socio-Economic Factors		
Public perseption of the resource	Mythical, unpredictable	Aesthetic, predictable
Development cost	Generally modest	Often high
Development risk	Less than often perceived	More than often assumed
Style of development	Mixed public and private, often by individuals	Largely public

There are three main pillars of IWRM: economic efficiency, ecosystem sustainability, and social equity (Fig. 7), with 13 keys for IWRM implementation (Fig. 8). Implementing IWRM is not without resistance. This is because IWRM is ambiguous regarding how it works because it has only goals but no clear steps to reach the goals in IWRM [10].

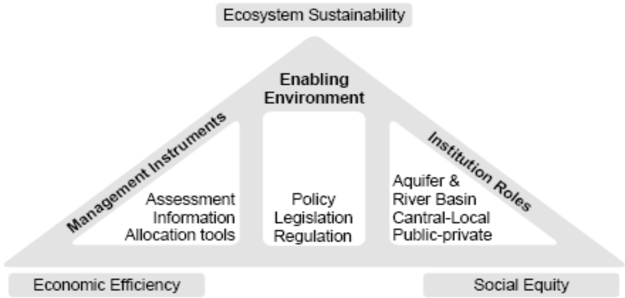

Fig. 7 Main IWRM pillars [7]

THE THIRTEEN KEY IWRM CHANGE AREAS

THE ENABLING ENVIRONMENT

1. Policies – setting goals for water use, protection and conservation.
2. Legislative framework – the rules to enforce to achieve policies and goals.
3. Financing and incentive structures – allocating financial resources to meet water needs.

INSTITUTIONAL ROLES

4. Creating an organizational framework – forms and functions.
5. Institutional capacity building – developing human resources.

MANAGEMENT INSTRUMENTS

6. Water resources assessment – understanding resources and needs.
7. Plans for IWRM – combining development options, resource use and human interaction.
8. Demand management – using water more efficiently.
9. Social change instruments – encouraging a water-oriented civil society.
10. Conflict resolution – managing disputes, ensuring sharing of water.
11. Regulatory instruments – allocation and water use limits.
12. Economic instruments – using value and prices for efficiency and equity.
13. Information management and exchange– improving knowledge for better water management.

Fig. 8 Keys to implementing IWRM [7]

2.4. Research Locations

The Mesuji-Tulang Bawang River Basin, located in the provinces of Lampung and South Sumatera, serves as the research site. According to data from the Environmental and Forestry Agency for 2019 [10], the primary land use in the Mesuji-Tulang Bawang River Basin is agricultural activity. There are 18 rain gauge stations located in the basin, as shown in Fig. 9 and Table 2. Furthermore, there is a single climatology station in the basin, known as Rantau Nipis climatology station, which is responsible for collecting temperature data only.

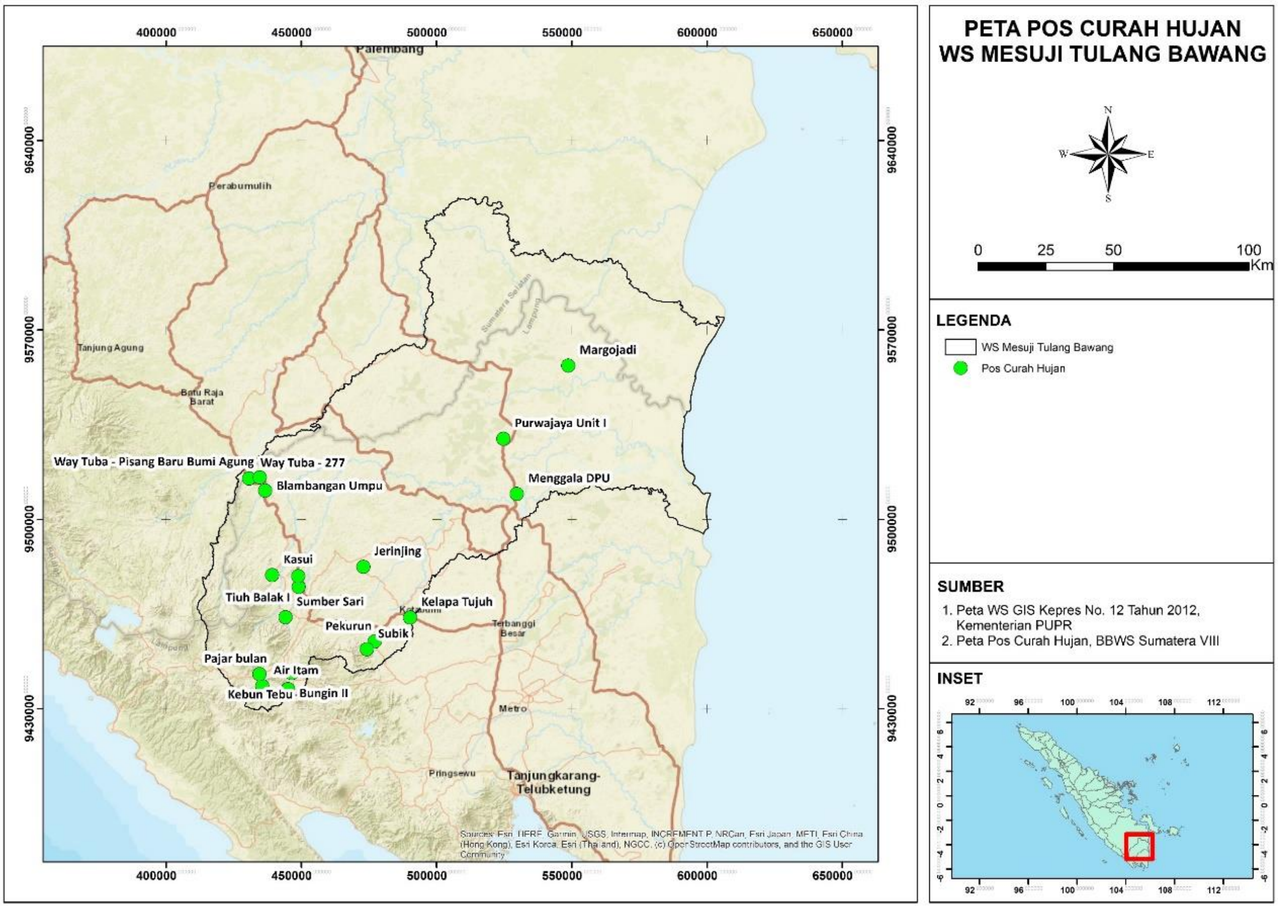

Fig. 9 Rain gauge stations in the Mesuji-Tulang Bawang River Basin (Own study)

Table 2 Rain gauge stations in the Mesuji-Tulang Bawang River Basin (Own study)

No.	Rain Gauge Station Names	X	Y
1	Air Itam	-5.08058	104.4185
2	Baradatu (Basecamp)	-4.74903	104.5401
3	Blambangan Umpu	-4.42725	104.4284
4	Bungin II	-5.09061	104.5041
5	Jerinjing	-4.68192	104.7554
6	Kasui	-4.70947	104.4516
7	Kebun Tebu	-5.03789	104.5164
8	Kelapa Tujuh	-4.85156	104.9113
9	Margojadi	-4.00939	105.4385
10	Menggala DPU	-4.43856	105.2671
11	Pajar bulan	-5.04088	104.4087
12	Pekurun	-4.93214	104.793
13	Purwajaya Unit I	-4.25408	105.2225
14	Subik	-4.95772	104.7673
15	Sumber Sari	-4.85069	104.4956
16	Tiuh Balak I	-4.7135	104.5383
17	Way Tuba - 277	-4.38667	104.3748
18	Way Tuba - Pisang Baru Bumi Agung	-4.38303	104.4104

2.5. Methods

The purpose of this research was to investigate the recharge potential in the Mesuji-Tulang Bawang River Basin (Fig. 10).

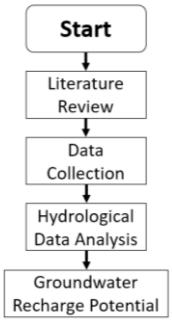

Fig. 10 Research flow chart (Own study)

3. Results and Discussion

In this section, we present a prototype for water resources management based on a single river basin, with plans to extend the study to additional basins in the future. This analysis focuses on hydrological data and groundwater recharge potential for a better understanding of water resources management that integrates surface water and groundwater.

3.1. Hydrological Data Analysis

The Isohyet method was applied to calculate the yearly average rainfall value for the Mesuji-Tulang Bawang River Basin (Fig. 11). The maximum rainfall over the research area was 3357 mm/y; the lowest rainfall was 1812 mm/y. Additionally, the evapotranspiration potential was calculated by the Thornwhite method using the temperature data from

Rantau Nipis climatological station (Table 3).

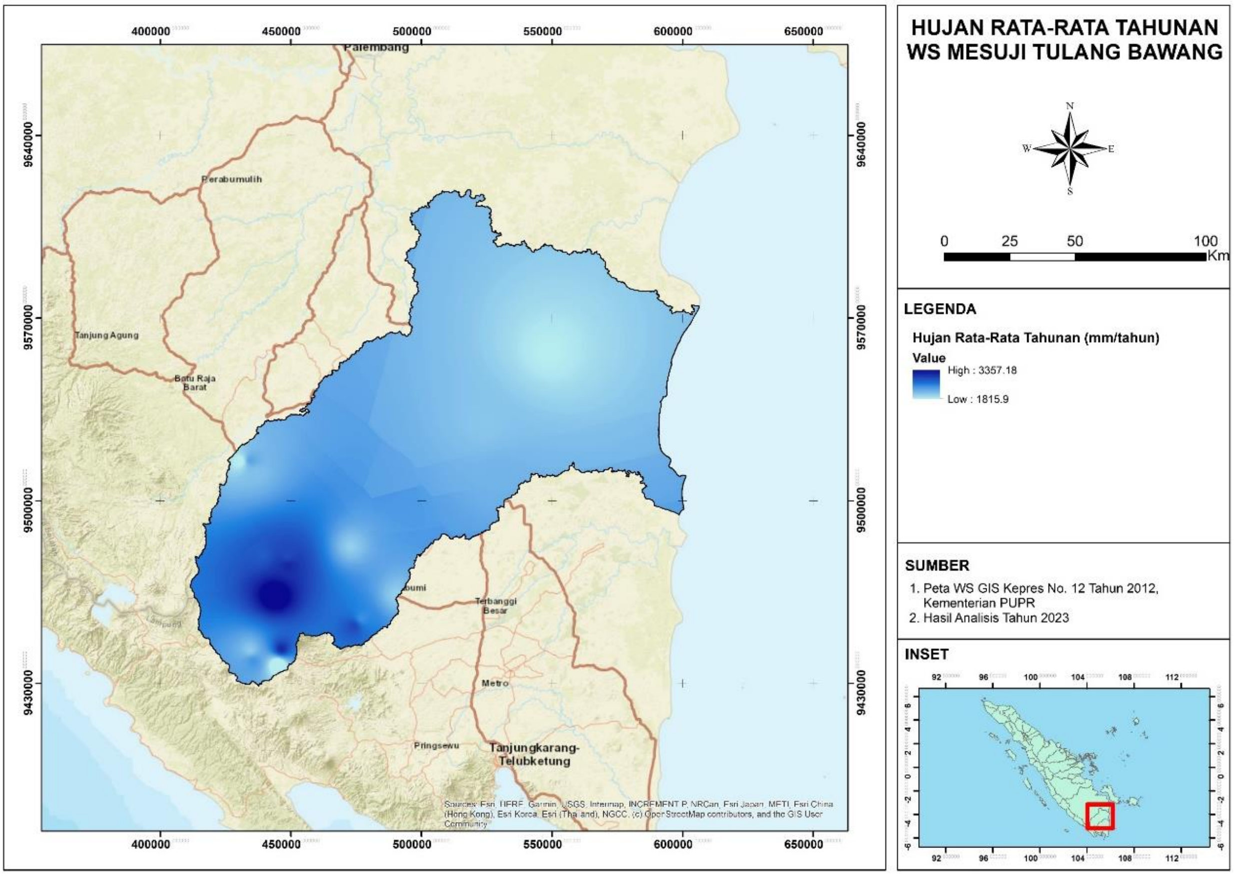

Fig. 11 Average yearly rainfall over the Mesuji-Tulang Bawang River Basin (Own study)

Table 3 Evapotranspiration potential in the Mesuji-Tulang Bawang River Basin (Own study)

Month	t(^{0}C)	$I=\left(\frac{t}{5}\right)^{1.514}$	$PET=1.6\left(10.^{t}/_{I}\right)^{a}$	Corrected	PE=PET*corrected	Total Days	PE	PE
			cm/30 days	$\frac{S.Tz}{30x12}$	cm/month		mm/day	mm/month
Jan.	25.7	11.93	11.98	1.06	12.70	31	4.1	127
Feb.	25.5	11.79	11.66	0.95	11.08	28	3.96	111
Mar.	25.3	11.65	11.32	1.04	11.77	31	3.8	118
Apr.	25.8	12.01	12.19	1	12.19	30	4.06	122
May	25.7	11.89	11.89	1.02	12.13	31	3.91	121
Jun.	25.8	11.97	12.07	0.99	11.95	30	3.98	119
Jul.	25.5	11.78	11.63	1.02	11.86	31	3.83	119
Aug.	32.3	16.83	27.33	1.09	29.79	31	9.61	298
Sept.	25.2	11.59	11.18	1	11.18	30	3.73	112
Oct.	25.3	11.66	11.34	1.05	11.91	31	3.84	119
Nov.	26.1	12.18	12.59	1.03	12.97	30	4.32	130
Dec.	26.1	12.23	12.73	1.04	13.24	31	4.27	132

3.2. Groundwater Recharge Potential Calculation

The groundwater recharge potential was calculated based only on the yearly average rainfall, land use map, evapotranspiration, and population density. The land use map was employed to calculate the Kimpv and Kdsro values, which were subsequently utilized. The values of Kdsro and Kimpv are 0.1 and 0.4, respectively. The population density data were used to calculate the Fimpv value (Table 4). The population density is directly correlated with the Fimpv value. Higher population density leads to a higher Fimpv value.

Table 4 Population in the Mesuji-Tulang Bawang River Basin, divided by district (Own study)

No.	District	Area (km^2)	Population (people)	Population Density (people/km^2)	F_{impv}	
					%	Value
1	Lampung Barat	2118.76	302750	143	40%	0.40
2	Lampung Utara	2529.54	634120	251	65%	0.65
3	Lampung Tengah	4544	1477400	325	70%	0.70
4	Way Kanan	3657.49	476870	130	40%	0.40

No.	District	Area (km²)	Population (people)	Population Density (people/km²)	F_{impv}	
					%	Value
5	Tulang Bawang	3091.08	430630	139	40%	0.40
6	Mesuji	2205.27	229770	104	40%	0.40
7	Tulang Bawang Barat	1285.74	287710	224	57%	0.57
8	Tanggamus	2900.29	645810	223	157%	1.57
9	Ogan Komering Ilir	18359.04	772742	42	10%	0.10
10	Ogan Komering Ulu	4797.06	367603	77	25%	0.25
11	OKU Selatan	5493.94	416616	76	25%	0.25
12	OKU Timur	3370	653062	194	50%	0.50

Using the above data, the groundwater recharge is estimated to have a maximum value of 836 mm/y (Fig. 12), approximately 25% of the maximum rainfall value of 3357 mm/y in the Mesuji-Tulang Bawang River Basin.

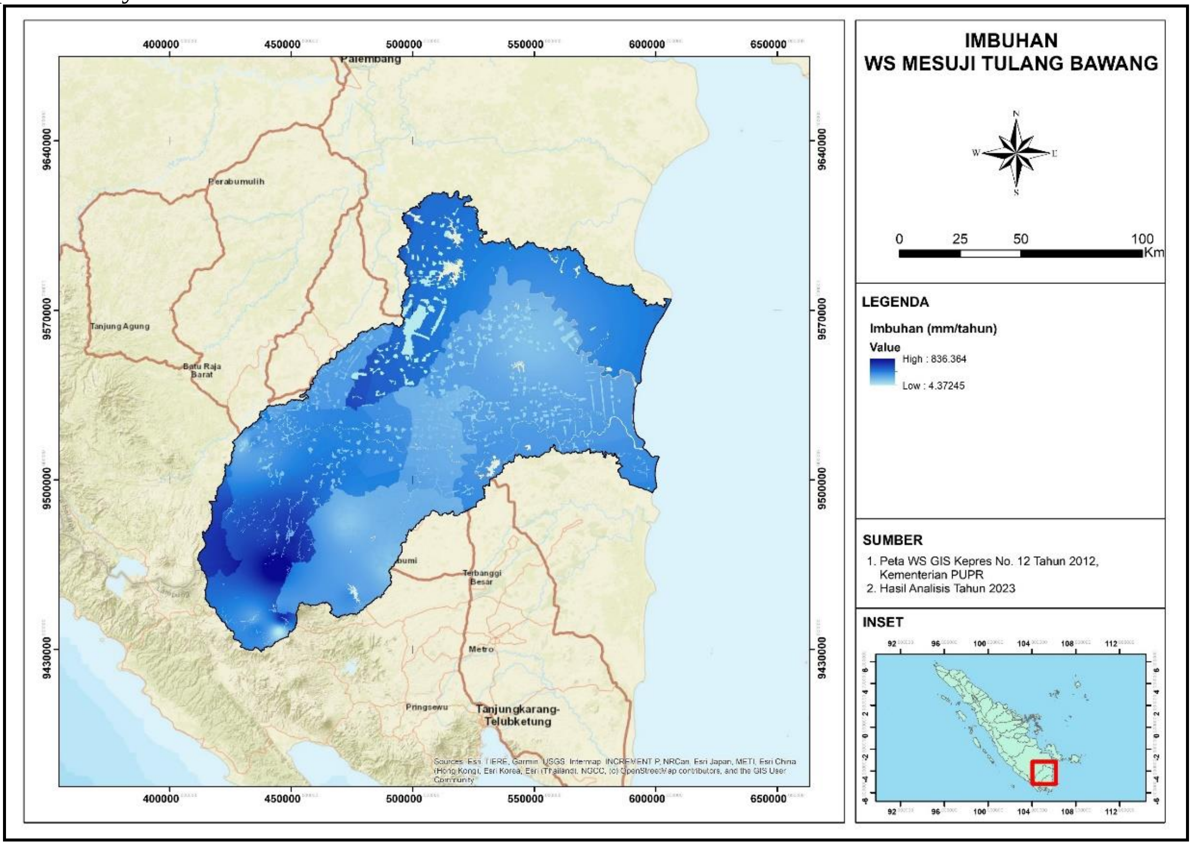

Fig. 12 Groundwater recharge value for the Mesuji-Tulang Bawang River Basin (Own study)

4. Conclusions

IWRM has been implemented in numerous regions globally. However, the comprehensive application of IWRM research has not yet been realized in Indonesia. Indonesia has many transboundary WSs with specific conditions and problems. One important step in implementing the IWRM is investigating water availability in the desired area.

The initial research focused on analyzing hydrological data and assessing the potential for groundwater recharge in a specific river basin, with the aim of gaining preliminary insights into water resource management that integrate surface water and groundwater.

The Isohyet method was applied to calculate the yearly average rainfall value for the Mesuji-Tulang Bawang River Basin. The maximum rainfall over the research area was 3357 mm/y; the lowest rainfall was 1812 mm/y. Additionally, the evapotranspiration potential was calculated using the Thorn-White method with the temperature data from Rantau Nipis climatological station.

Groundwater recharge potential is highly dependent on population density, land use, evapotranspiration, and rainfall. The investigation in the Mesuji-Tulang Bawang River Basin shows that the groundwater recharge potential highly varied, ranging from 4.3 to 836 mm/y, which is approximately 25% of the maximum rainfall value in the Mesuji-Tulang Bawang River Basin (3357 mm/y).

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