Original Article

Application of Hydrological Method for Sustainable Water Management in the Upper-Middle Ciliwung (UMC) River Basin, Indonesia

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ABSTRACT

Water resources are under pressure due to population growth, economic development, and changes in land use. This study aims to develop a hydrological method for calculating the water availability and evaluating the water supply demand capacity using the Index of Water Supply-Demand (*IWSD*), based on a case study of the Upper-Middle Ciliwung river basin in Indonesia. The two hydrological models used in this study were the National Rural Electric Cooperative Association (NRECA) and “FJ. Mock” models. The NRECA model was selected based on a statistical evaluation of correlation coefficients and the volume of errors. Based on the evaluation of business as usual and a reduction in water availability scenarios, the *IWSD* shows a value > 0 , which means that the river can supply the necessary water for the economy, society, and environment. For other scenarios, with an increase in population growth and mix scenario, the *IWSD* shows values < 0 , which means that the river cannot supply water for the users. The applications of the hydrological methods were developed in order to understand and seek solutions for decision makers in sustainable water resource management.

Keywords: hydrological methods, FJ. Mock, National Rural Electric Cooperative Association, water supply demand

INTRODUCTION

The current and future challenges of water resources management vary widely because of the population growth, changes in land use, intensive socio-economic development, and warming climate [1]. Sustainable water resource management has become a very important issue because of the lack of good quality water resources due to environmental damage caused by the pressure of human activities.

This affects the balance between the supply and demand for water resources. The evaluation of the water supply capacity and water demand in a river basin can contribute to decision-making and strategy of sustainable water resources management. The evaluation of the water supply demand capacity aims to determine the balance between water supply and demand in a basin, in a certain period, using the Index of Water-Supply Demand (*IWSD*) method.

The water supply is calculated by a hydrological method

whereas the water requirement is calculated based on each sector's water needs and environmental water demand. There are several common hydrological models: Soil and Water Assessment Tool (SWAT) [2], Genie Rural four parameters Journal (GR4J) [3], Tank model [4], Rainrun [4], National Rural Electric Cooperative Association (NRECA) [5], and FJ. Mock [6,7]. The SWAT model uses parameters such as land use change, global change, and land conservation techniques [2]. The GR4J model uses daily input data of rainfall and evapotranspiration, the maximum capacity of the production store, the water exchange coefficient, the maximum capacity of the routing store, and the time base of a unit hydrograph [3]. The Tank model describes the several combination tanks for each soil layer in the catchment area [4]. The Rainrun model takes into account the average weighted runaway components of the forest and non-forest catchment fraction [4]. The NRECA uses an index of the soil moisture storage-capacity, the rate of discharge from groundwater storage to a

Fig. 1 Structure of the method.

stream, daily rainfall data, and potential evapotranspiration data [5]. The FJ. Mock model uses daily rainfall data, evapotranspiration, and hydrologic watershed characteristics. This model provides a good alternative tool for rapid watershed assessment using hydrological parameters as part of monitoring and evaluation, particularly in the regions with limited hydrological data [6,7]. The selection of a hydrological model is based on the watershed characteristics, data availability, and expected output.

In this study, two models were used: the FJ. Mock and NRECA. The model accuracy is evaluated by calibration and validation between the simulation results and observation data using two indicators: the r and the Volume of Errors (VE).

The objectives of this study are:

- (1) to select a hydrological model in order to estimate the water supply in a river basin based on limited data and an accuracy model.
- (2) to evaluate and analyze the water supply demand capacity with several scenarios for contributing to sustainable water resources management.

The methods were applied to the Upper-Middle Ciliwung (UMC) river basin in Indonesia with a coverage area of 264.35 km² [8]. This basin has a high population growth. The population served by piped water is still low. Known issues

in this river basin are the degradation of the water's quantity and quality and the high rate of land use change [2,8].

River restoration activities are dredging sediment and garbage from the river and utilization of domestic and industrial wastewater treatment technologies will increase the quantity and quality of the river water. The application of the hydrological method to evaluate the water supply demand capacity is useful for consideration in the framework of future water resource development. By using various scenarios of water supply and demand, it can be found whether the river can supply water for economic, social, and environmental needs within a certain period.

CONCEPT AND METHOD

Concept of application of hydrological method for sustainable water resources management in the river basin

The method is composed of the supply and demand modules. The supply module is based on a regional rainfall, evapotranspiration, and hydrological model. The demand module based on water needs for each sector (domestic, industrial, and agricultural) and the environmental water demand. The structure of the method is shown in **Fig. 1**. The evaluation of the water supply and demand capacity

took place with scenarios of increasing water demand, due to population growth and economic development, and water supply reduction due to climate change. *IWSD*'s calculation results will recommend solutions towards the sustainability of water resources management. A value > 0 , means that the river can supply the water for the economy, society, and environment while a value < 0 , means that it is necessary to find a solution for a more sustainable water resources management.

Methodology

The methodology used in this study is comprised of the following:

- 1) Establishment of NRECA and FJ. Mock hydrological models with an analysis of rainfall and climate data into regional rainfall and evapotranspiration categories
- 2) Calibration and validation of the models
- 3) Method selection by comparing the method deviation values
- 4) Demand model analysis
- 5) Comparison between water supply and demand for several scenarios with the *IWSD* formula
- 6) Making recommendations regarding the water supply and demand in the catchment area.

The scenario used in this study was organized by consideration of parameters in the river's region: population growth, economic growth, land use change, and climate change. Based on population census from 1998 until 2008, the population growth rate in UMC river basin was 2.74%, the higher population growth rate from 2004 until 2006 was around 5.28% until 6.52% [3]. The economic growth rate from 1960 until 2010 showed varieties which tend to be stable between 5% and 6% a year so moderate economic growth scenario can be used with 5-6% economic growth rate [8]. Land use change in the UMC river basin is an average of 7.45% [8]. Climate change prepares for the worst condition (increasing and/or decreasing of rainfall ± 0.3 mm/day) [8].

In this study, the following scenarios were developed:

1. Reference or business as usual (BAU)
2. Scenario one: 5% population growth rate
3. Scenario two: 5% reduction of water availability
4. Mix scenario

The equation of the hydrological balance in the catchment area is as follows:

$$In = Out \pm \Delta S \quad (1)$$

In: inflow of water to the hydrological unit.

Out: outflow of the hydrological unit.

ΔS : change in storage within the selected hydrological unit

(e.g. catchment).

Regional rainfall and evapotranspiration analysis

The regional rainfall is transformed from monthly rainfall data. An algebraic method was used because the catchment area is between 250 and 50,000 ha. The formula of the algebraic method is as follows:

$$R_H = \frac{H_1 + \dots + H_n}{n} \quad (2)$$

R_H : average regional rainfall (mm),

H : monthly rainfall data from gauge station 1, 2, ..., n ,

N : number of gauge stations.

Evapotranspiration is the total volume of evaporation from the surface of the soil, ground surfaces, wetlands, natural water bodies, and transpiration of plants [9,10]. The Penman's equation is:

$$ETp = F_1 \cdot R(1-r) - F_2(0.1 + 0.9S) + F_3(k + 0.01w) \quad (3)$$

$$F_1 = A \frac{0.18 + 0.55S}{(A + 0.27)} \quad (4)$$

$$F_2 = AB \frac{0.56 - 0.092ed^{0.5}}{(A + 0.27)} \quad (5)$$

$$F_3 = \frac{(0.27)(0.35)(ea - ed)}{(A + 0.27)} \quad (6)$$

A : slope of the vapor pressure curve (Hg/°F),

B : black body radiation based on the value of temperature (Hg/°F),

ea : saturation vapor pressure for the measured air temperature (mm Hg),

ed : actual vapor pressure of the air (mm Hg) = $ea \times$ relative humidity (%),

S : average percentage of monthly of sun-shine,

R : solar radiation (mm/d),

r : reflection coefficient,

k : evaporation surface roughness coefficient = (1,0), and

w : wind velocity (mile/d).

The actual evapotranspiration is described as follows:

$$\Delta E = ETp \times \left(\frac{m}{20} \right) \times (18 - h) \quad (7)$$

Fig. 2 Schematic of monthly runoff calculations from rainfall and potential evapotranspiration data [5].

$$ETa = ETp - \Delta E \quad (8)$$

ET_p : potential evapotranspiration (mm/day),

ΔE : difference between potential evapotranspiration and limited evapotranspiration,

ET_p : potential evapotranspiration,

ETa : actual evapotranspiration,

h : number of rainy days in a month, and

m : percentage of land covered vegetation ($m = 0\%$ dense forest, $m = (10 - 40\%)$ eroded land, and $m = (30 - 50\%)$ agricultural land).

Description of NRECA model

The NRECA model was developed by Norman H. Crawford (USA) in 1985. This model is a simplification of the Standard Watershed Model IV (SWM).

NRECA model is developed in the USA which is a sub-tropical country while Indonesia has a tropical climate so the rainfall conditions are different. Besides, the kind of soil and land covering vegetation are also different.

NRECA model has five parameters to count the water debit in a river basin where each parameter has its own certain value regarding the rainfall condition, kind of soil, and the land covering vegetation. To count the water discharge, trials and errors are done towards the value of the parameter mentioned so the water discharge result is counted with the tolerance limit at $\leq 10\%$ if validated towards the measure-

ment result. Those five parameters of the NRECA model are:

- NOM or Nominal: an index of the soil moisture storage capacity in the watershed, with values $NOM = 100 + C \times$ average annual rainfall, where C is approximately 0.2 in watersheds with precipitation throughout the year and 0.25 in watersheds with seasonal rainfall;
- GWF: an index to the rate of discharge from the groundwater storage to the stream, with values ranging from 0.2 – 0.9;
- PSUB: the fraction of runoff that moves out of the watershed as base flow or groundwater flow, with values ranging from 0.3 – 0.8;
- SMSSTOR: the initial moisture storage, with values ranging from 500 – 760;
- GWSTOR: the initial groundwater storage, with values ranging from 200 – 330.

A diagram of the calculations is shown in **Fig. 2**. The water balance equation is:

$$\text{run off} = \text{precipitation} - \text{actual evapotranspiration} + \text{storage} \quad (9)$$

The total river discharge was analyzed with the following formula [5,11]:

$$Q = (\text{direct flow} + \text{groundwater flow}) \times A \quad (10)$$

A : number area (km^2),

direct flow : $\text{excess moist} - \text{recharge to groundwater}$,

excess moist : $\text{excess moist ratio} \times \text{water balance}$,

water balance : $\text{precipitation} - \text{AET}$,

AET : $PET \times (AET/PET)$ ratio from **Fig. 3**,

Fig. 3 AET/PET ratio as a function of PRECIPITATION/PET and soil moisture ratio.

The *excess moist ratio* = 0 if the *water balance* is negative. If the *water balance* is positive, the *moist ratio* is obtained by the *soil moisture storage ratio*, Fig. 4.

storage ratio: moisture storage/Nominal,

NOM: given by $100 + 0.2 \times \text{average annual rainfall}$,

Nominal: an index of the soil moisture storage capacity in the watershed,

recharge to groundwater: given by $\text{PSUB} \times \text{excess moist}$,

Groundwater flow: given by $\text{GWF} \times (\text{recharge to groundwater} + \text{BEGIN STOR GW})$,

PET: potential evapotranspiration,

agreement. A validation test was conducted by applying the calibrated model to a second period of data not used in the calibration [12].

$$r = \frac{n \sum X_i Y_i - (\sum X_i)(\sum Y_i)}{\sqrt{\{n \sum X_i^2 - (\sum X_i)^2\} \{n \sum Y_i^2 - (\sum Y_i)^2\}}} \quad (11)$$

$$VE = \frac{\sum_i^n X_i - \sum_i^n Y_i}{\sum_i^n X_i} \times 100\% \quad (12)$$

r : correlation coefficient,

VE : volume error,

x_i : simulated daily discharge (m^3/sec),

y_i : observed daily discharge (m^3/sec),

n : total step calibration.

Description of FJ. Mock model

A flowchart of the calculations is shown in Fig. 5.

Method performance evaluation

The model accuracy was evaluated by calibration and validation using the r and VE indicators. The formula can be seen in equations (11) and (12). The model is rated as having a high associate degree if the value of r is $0.7 < r < 1$. Calibration refers to the adjustment of model parameters to reproduce observations within acceptable levels of

Water demand model

The water demand model consists of the domestic, industrial, agricultural, and environmental water demand [13]. The formula for calculating water requirements is as follows:

Excess Moisture Ratio **Fig. 4** Soil moisture storage ratio. **Fig. 5** Flowchart of Mock calculation [13].

Table 1 Standard water demand for unit water demand.

No.	Unit water demand	Standard
1	Domestic	160 L/people/day
2	Big Industrial process	65000 L/day/unit
3	Small Industrial process	1000 L/day/unit
4	Industrial worker	60 L/people/day
5	Agriculture	1.2 L/ha/sec
6	Environmental	300 L/people/day

$$\text{water requirement} = \text{water demand unit} \times \text{standard} \quad (13)$$

The standard can be seen in **Table 1** [14]. Domestic water requirements are calculated based on the projected population according to the geometric method:

$$P_n = P_o (1+r)^n \quad (14)$$

P_n : projected population in the future,

P_o : initial population,

r : annual population growth rate, and

n : time or period.

Dependable flow

The dependable flow is the amount of available discharge to meet water needs, taking into account the risk of failure (**Table 2**). The level of reliability of discharge may occur under probability of occurrence, following the Weibull formula [15]:

$$P \% = \frac{m_2}{(n_2 + 1)} \times 100\% \quad (15)$$

P %: probability percentage (%),

m_2 : serial number of the data, and

n_2 : amount of data.

Water supply and demand capacity evaluation method

The formula of water supply and demand capacity evaluation is as follows:

$$IWSD = 1 - \text{water demand/water supply} \quad (16)$$

If $IWSD < 0$, the volume of usable water is not sufficient to support the economy, society, and environment [16].

DESCRIPTION OF FIELD AND DATA

The UMC river basin is located between 106°50'20" to 106°50'50" East Longitude and 6°22'30" to 6°28'35" South

Table 2 Dependable flow for water planning.

Planning water demand	Probability
Drinking water	P 90%
Hydropower	P (85 – 90)%
Irrigation	P (70 – 85)%

Latitude, comprising a total area of 264.35 km² (**Fig. 6**). Two main urban centers (the cities of Bogor and Depok) and Bogor regency are within the basin with a total permanent population of 3.79 million people (2014 census). The main river in this basin is Ciliwung with a length of 119 km, an average rainfall of 1586 to 2486 mm/year, a maximum temperature of 30°C, and a humidity of between 65% and 70% [17].

The data collected for this study can be classified into five different categories, i.e., hydrology data (daily rainfall data and discharge river actual data), land use and soil characteristics, meteorological data (precipitation, relative humidity, sunshine hours, average temperature, and wind speed), population data, and water usage data (irrigation and industry). The data were collected from the Statistical District Data and Ciliwung-Cisadane River Basin Agency. Daily rainfall data were used from Gandog, Cibinong, UI-Depok, and Gunung Mas stations for the years between 2008 and 2012. The observed data were taken from Katulampa weir.

RESULTS AND DISCUSSION

Regional rainfall and evapotranspiration

The hydrology method built for this study is a rainfall-runoff model that uses daily rainfall and climate data. The result of the average rainfall regional analysis, using algebraic methods, shows the highest rainfall value of 457.9 mm and the lowest of 21.09 mm. The average monthly rainfall ranges from 91.36 mm to 369.34 mm. The results can be seen in **Figs. 7 and 8**. The evapotranspiration results obtained by the Penman's method can be seen in **Fig. 9**.

Model calibration and validation

The model calibration is a process of obtaining the best fit between the observed and simulated results by adjusting the input parameter values, whereas model validation is the process of comparing a set of observed data with the simulation results without adjusting any input parameter values [18]. A 12-month test run from January to December 2011 was carried out in order to calibrate the model parameters. The model validation was carried out from January to December 2012.

Fig. 6 Research location.

Fig. 7 Monthly regional rainfall from 2008 to 2012.

Table 3 shows the parameters and values of the calibration results for the NRECA model. The NRECA model performance for the calibration and validation periods can be seen in **Table 4**. Based on the calibration and validation values obtained, model NRECA is chosen to count the water discharge in UMC river basin with the most optimal parameters used:

NOM 400 mm, PSUB 0.5 mm, GWF 0.27 mm, SMSSTOR 700 mm, and GWSTOR 330 mm.

Table 5 shows the parameters and values of the calibration results for the FJ. Mock model.

The FJ. Mock model performance for the calibration and validation periods can be seen in **Table 6**.

Fig. 8 Monthly average regional rainfall in the UMC river basin.

Fig. 9 Monthly evapotranspiration using Penman's method from 2008 to 2012.

The hydrological method used to estimate the water availability in the UMC river basin was the NRECA model because the calibrated values of r and V/E were 0.90 and 0.25, respectively, while the values obtained from the FJ. Mock model were 0.81 and 0.24, respectively. **Figures 10 and 11** show a comparison between the simulated and observed monthly discharges and **Fig. 12** shows the comparison graph between the NRECA and FJ. Mock.

Application of the hydrologic method for estimating water availability in the UMC river basin

Water availability at the UMC river basin was estimated using the NRECA hydrology model. The model input data is the catchment area of 264.4 km², the rainfall and evapotranspiration of the calculation results (**Figs. 7 to 9**), and the optimal model parameters of the calibration process: NOM 400, PSUB 0.5, GWF 0.27, SMSTOR 700, and GWSTOR

330.

The results of water availability and dependable discharge calculations can be seen in **Table 7**.

Based on the calculations of water availability in **Table 8**, the calculated dependable flow for each water planning is 90% probability for drinking water, 85% probability for hydropower, and 80% probability for irrigation, **Fig. 13**.

Water demand in the UMC river basin

The total water requirement in the UMC river basin was calculated based on the water users in **Table 8** [17,19–21].

Future water requirements are estimated by projections according to the planning time. Based on the existing data on the population number, from 2005 to 2014, **Table 9**, the population growth is 3.34%.

The value of r is calculated as follows:

$$r = (P_n/P_o)^{(1/n)} - 1$$

Table 3 Final calibrated flow parameter values for NRECA model.

Discharge parameters	Units	Symbol	Low and upper bounds	Fitted values
Initial nominal	mm	Nom	200–400	400
The fraction of runoff that moves out of the watershed as base flow or groundwater flow	mm	PSUB	0.3–0.8	0.50
An index to the rate of discharge from the groundwater storage to the stream	mm	GWF	0.2–0.9	0.27
Initial moisture storage	mm	SMSSTOR	500–760	700
Initial groundwater storage	mm	GWSTOR	200–330	330

Table 4 Summary of model performance for calibration and validation periods for NRECA model.

Period	Mean annual water yield (mm)		Monthly method efficiency	
	Observed	Simulated	<i>r</i>	<i>VE</i>
Calibration	157.58	118.2	0.90	0.25
Validation	172.83	166.2	0.97	0.03

Table 5 Final calibrated flow parameter values for FJ. Mock model.

Discharge parameters	Units	Symbol	Low and upper bounds	Fitted values
Reflection coefficient	-	<i>r</i>	0.4	0.4
Exposed surface	mm	m	(30–50) %	40
Coefficient of infiltration	mm	if	0.3–0.35	0.35
Groundwater recession constant	-	K	0.5–0.95	0.8
Percentage of rainfall into runoff	mm	Pf	0.05–0.1	0.1

Table 6 Summary of model performance for calibration and validation periods for FJ. Mock model.

Period	Mean annual water yield (mm)		Monthly method efficiency	
	Observed	Simulated	<i>r</i>	<i>VE</i>
Calibration	157.58	119.4	0.81	0.24
Validation	172.83	178.22	0.95	0.03

$$= (3.79/2.82)^{(1/9)} - 1$$

$$= 0.0334 \text{ or } 3.34\%$$

The projected population for the next 50 years based on BAU with a population growth rate of 3.34%, and scenario 1 with a population growth rate of 5%, can be seen in **Table 10**.

The results of the calculations for the water requirements for each scenario can be seen in **Tables 11 and 12**. Volume of WS and WD for evaluation of two scenarios can be seen in **Table 13**.

Evaluation of water supply demand capacity of the UMC river basin

The development and the application of hydrological methods have been a cornerstone of hydrological research

for many decades. The purpose of the development of these methods is to improve the understanding of hydrological processes involved in the rainfall and runoff transformations and to provide practical solutions for water resources management problems [22].

In this study, a hydrological method is used to evaluate whether the availability of water in the river basin can still meet the needs of its users. The evaluation was done with two scenarios. The first scenario assumed an economic growth of 5% and a population growth of 5%. The second scenario assumed a 5% reduction in water availability due to changes in the forest area, which decreases every year by an average of 7.45% and the existence of global climate change.

Based on the *IWSD* formula, an evaluation of the water

Fig. 10 Comparison of simulated NRECA method and observed monthly river discharge for the calibration period Jan-Dec 2011 and validation period Jan-Dec 2012.

Fig. 11 Comparison of simulated FJ. Mock method and observed monthly river discharge for the calibration period Jan-Dec 2011 and validation period Jan-Dec 2012.

Fig. 12 Comparison between simulated and observed discharge in the UMC river basin.

Table 7 Water availability in the UMC river basin.

Year	Jan	Feb	March	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
2008	19.76	34.85	31.41	26.08	15.05	9.42	6.04	6.92	8.57	8.84	28.12	17.38
2009	29.18	32.11	29.39	24.93	25.04	16.21	8.58	5.80	4.37	11.27	11.87	10.15
2010	21.00	30.51	25.40	9.88	20.04	17.88	13.19	18.71	25.62	20.92	22.84	16.87
2011	17.50	11.22	9.43	13.87	18.91	10.04	5.92	3.66	2.76	9.30	16.34	20.06
2012	20.41	29.20	16.76	19.84	18.25	9.38	5.35	3.91	3.68	11.29	26.38	27.50
Average	21.57	27.58	22.48	18.92	19.46	12.58	7.82	7.80	9.00	12.32	21.11	18.39

Table 8 Water users in the UMC river basin year of 2014.

No.	Water use	Unit	Amount
1	Population	million people	3.79
2	Big industry	unit	1,158
3	Small industry	unit	4,416
4	Industry worker	people	144,679
5	Irrigation area	ha	1,199
6	Environmental	million people	3.79

Fig. 13 Comparison of monthly dependable discharge in the UMC river basin.**Table 9** Existing number of residents of UMC river basin (million people).

Year	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
	2.82	3.07	3.15	3.21	3.13	3.15	3.20	3.59	3.65	3.79

Table 10 Number of residents of UMC river basin (million people).

Scenario	Year			
	2014	2024	2034	2064
BAU	3.79	5.26	7.31	19.59
One	3.79	6.17	10.06	43.46

Table 11 Water demand projection based on BAU scenario.

No.	Water Use	Water Demand (10^6 m ³ /year)			
		2014	2024	2034	2064
1	Domestic	221.34	307.71	426.99	1,144.13
2	Industrial	32.25	44.80	62.22	166.73
3	Agriculture	45.37	63.02	87.53	234.55
4	Environmental	415.01	576.42	800.61	2,145.24
	Total	713.97	991.66	1,377.36	3,690.64

Table 12 Water demand projection based on scenario 1.

No.	Water Use	Water Demand (10^6 m ³ /year)			
		2014	2024	2034	2064
1	Domestic	221.34	360.53	587.27	2,538.15
2	Industrial	32.25	52.54	85.58	369.87
3	Agriculture	45.37	73.91	120.39	520.32
4	Environmental	415.01	676.00	1,101.13	4,759.03
	Total	713.97	1,162.98	1,894.37	8,187.37

Table 13 Volume of WS and WD for evaluation of different scenarios.

Year	BAU		Scenario 1	Scenario 2
	Volume WS 10^6 m ³	Volume WD 10^6 m ³	Volume WD 10^6 m ³	Volume WS 10^6 m ³
2014	6276.42	713.97	713.97	5962.60
2024	6276.42	991.66	1162.98	5962.60
2034	6276.42	1377.36	1894.37	5962.60
2064	6276.42	3690.64	8187.37	5962.60

Table 14 IWSD values for evaluation of water supply demand capacity of different scenarios.

<i>IWSD</i>				
Year	BAU	Scenario 1	Scenario 2	Mix scenario
2014	0.89	0.89	0.88	0.88
2024	0.84	0.81	0.83	0.80
2034	0.78	0.70	0.77	0.68
2064	0.41	-0.30	0.38	-0.37

supply demand capacity for each scenario can be seen in **Table 14**.

Based on *IWSD* analysis, the river can carry and support the economy, society, and environment from the year 2014 until the year 2064, as the *IWSD* values were all greater than zero for the BAU and scenario 2. In scenario 1 and the mix scenario, the *IWSD* value is smaller than zero. The utilization of water resources for the planning year 2064 needs to consider other aspects such as recycling of water, water use efficiency, and search for new water sources.

CONCLUSIONS

Hydrological method was used to calculate the availability of water in a watershed based on the results of a comparison between simulated and measured discharge. In this study, we used the FJ. Mock and NRECA models because of the availability of data and the ease of calculation methods. Data included daily rainfall data, potential evapotranspiration data, and hydrologic watershed characteristics. The model accuracy was evaluated by calibration and validation between the simulation results and observation data using two

indicators: the r and the VE . The model used was the model that has the greatest r and the smallest VE .

The NRECA model gave an r of 0.90 and VE of 0.25. The FJ. Mock model had an r of 0.81 and VE of 0.24. Based on these calibrated results, the hydrological model used in this study was the NRECA model. This model can be used to calculate the water availability and analyze the dependable flow for multiple water needs (P90% for drinking water, P85% hydropower, and P80% for irrigation).

Based on the $IWSD$, the river can carry and support the economy, society, and environment from the year 2014 until the year 2064, as the $IWSD$ values were all greater than zero for BAU scenarios and scenario 2.

This hydrological method application can be used to evaluate the water supply demand capacity with the assumption value approach adapted to current conditions and future predictions for the water resources development plan along with the development strategy that needs to be done. Future research should further improve the accuracy of the results using more detailed data and refined assumptions. For example, time series data used for calculations and debit data for river measurements are more than or equal to 10 years.

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