Effect of the climate change on groundwater recharging in Bangga watershed, Central Sulawesi, Indonesia

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ABSTRACT

This study was conducted to determine the effect of the climate change to the level of groundwater recharging. This research was conducted on the watershed of Bangga by using the Soil Water Balance of MockWyn-UB model. Input data compose of evapotranspiration, monthly rainfall, watershed area, canopy interception, heavy rain factor and the influence of climate change factors (rainfall and temperature). The conclusion of this study indicates that there is a decreasing trend in annual groundwater recharge observed from 1995 to 2011. The amount of groundwater recharge varied linearly with monthly rainfall and between 3% to 25% of the rainfall. This result implies that rain contributed more than groundwater recharge to runoff and evaporation and the groundwater recharge and Bangga River discharge depends largely on the rainfall. In order to increase the groundwater recharge in the study area, reforestation programmes should be intensified.

Keywords: Bangga watershed, Climate change, Groundwater recharge, MockWyn-UB model, Soil water balance

1. Introduction

Groundwater as set forth in the Indonesian Government Regulation number 43 of 2008 [1] was defined as the water contained in the soil or rock layers below the soil surface. Groundwater is one of the sources of water supply to the lives of human beings and animals on earth. Accumulation and spread of groundwater is determined by various factors, such as rainfall, morphology and geology [2]. The average height of rainfall in Indonesia is between 1,000 mm to 6,000 m per year. There are certain areas that have a rainfall of less than 1,000 mm but spread is very limited and only 0.9% of the total area of Indonesia. Areas with rainfall are 1,000-1,500 mm per year only covers an area of less than 4%.

Global climate change that will be encountered in addition to increase or reduce rainfall in some regions, the increasing in air temperature, can also be associated with changes in weather patterns, wind patterns, humidity, and solar radiation. The decline in rainfall as input variables watershed due to irregularities global climate will affect groundwater recharging and seasonal dynamics. In general, the impact is very simple: The higher rainfall will produce greater groundwater recharging and declining rainfall will reduce the recharging of groundwater.

The evidence on climate change has been reported systematically by official sources, including: The Intergovernmental Panel on Climate Change (IPCC), the United Nations Framework Convention on Climate Change (UNFCCC) and the World Wide Fund (WWF) Indonesia. IPCC in the 3rd report states that the global average temperature is projected to rise to 1.4-5.8˚C between 1990 and 2100. A scenario of climate change [3] predicted that the temperature would rise between 1.3˚C and 4.6˚C until 2100 with the trend of 0.1˚C - 0.4˚C per year.

According to Rao and Al-Wadany (1995): 1) Global climate change may occur because of the increase in CO2 and other gases in the atmosphere of active radiation. Temperature is expected to rise with the increase of CO2 and other gases. 2) Based on climate models, where rainfall and temperature shows significant changes in the future. Increased CO2 in the atmosphere and changes in forest cover is the main reason suggested for climate change. Changes in precipitation and temperature obviously affect the groundwater [4].

The result research from Tung and Haith (1995) states that the effect of global warming don’t happening only in the discharge flow in most watersheds but will vary from time and space. Because of seasonal changes in rainfall and temperature, river discharge may decline for several months and increases in others.
in different locations will see different patterns of climate change, and watersheds with different physical characteristics can respond in different ways. The flow of river flow is strongly influenced by the recharging of groundwater [5].

The study of Yates and Strzepek (1998) states that changes in rainfall and temperature could have serious consequences on regional water resources throughout the basin. Hydrological model showed a strong response among discharge as the dependent variable with rain and evapotranspiration as an independent factor. The flow of river flow is strongly influenced by the recharging of groundwater [6].

The research from Fu et al. (2007) states that 30% increase in precipitation causes a 50% increase in flow when normal temperatures compared to only 20-30% increase in the flow if the annual average temperature of 1.5°C higher than normal. In contrast, a decrease in rainfall of 20% produces about 25-30% less flow when the temperature is normal but 45% reduce in the flow if the temperature is 1.5°C higher than normal. Thus, the increase and decrease in rainfall affect groundwater recharge [7].

According to research Lorena et al. (2010) states that in simulated river flow and evapotranspiration reflect different variations in rainfall. The positive trend of rainfall resulted in the increase of surface water and groundwater, whereas evapotranspiration only modestly affected. Comparison of the effects of rainfall trend towards surface water and groundwater shows that the increase in surface water is 3 times larger, implying ground water system has little effect on climate change [8].

Studies conducted in Indonesia on groundwater ranges in estimating the potential for groundwater, groundwater discharge capacity and utilization of groundwater. However, none of the above studies are trying to see the effects of climate change on groundwater recharge estimates. In this context, this study was conducted in order to determine the effect that may occur from climate change on the level of recharging of groundwater as an important parameter known to develop or to use groundwater without damaging the environment or negative effect. This study aims to answer the problems by investigating the effects of climate change on the groundwater recharge.

2. Material and Methods

2.1. Description of Study

This research was conducted in the catchment area of Bangga that is tributary Palu River. According to administrative located in village Bangga, Sigi District of Central Sulawesi of Indonesia. Catchment area of Bangga as geographically located between 01°15’07” - 01°21’30” south latitude and 119°49’20” - 119°56’05” east longitude. Area of catchment Bangga is 65.90 km² and the long of main river around 15.50 km. For more details, the location of the research is presented in the Fig. 1.

2.2. Model Description

2.2.1. Soil water balance model

The Soil Water Balance (SWB) model is part of the model MockWyn-UB [9] used to simulate groundwater recharging. This model considers the monthly hydro climatology components such as rainfall, evapotranspiration, infiltration coefficient and factors groundwater recession. Model of MockWyn-UB recommended using if the location of the study of climate changes. Detection of presence or absence of climate change can use the model Mann Kendall. Model inputs, parameters and outputs are presented in Table 1.

In this model, the rain that falls in the watershed is divided into three parts, namely in the forest, mixed farms and open land, using the equation:

\[ P_{RT} = (L_{RT}/L_{DAS}) \times P_{DAS} \]  
\[ P_{KC} = (L_{KC}/L_{DAS}) \times P_{DAS} \]
Penman Monteith method \([9, 11, 12, 14, 15, 17]\): the equation is equal to field capacity by using the results of research \([10]\).

Net rainfall based on land cover and vegetation canopy interception by using the results of research \([10]\).

\[
P_{NT} HT = 0.886P_{DAS} + 0.088 \quad (4)
\]

\[
P_{NT} KC = 0.925P_{DAS} + 0.333 \quad (5)
\]

\[
P_{NT} LT = P_{LT} \quad (6)
\]

\[
T_{PN} = P_{NT} HT + P_{NT} KC + P_{NT} LT \quad (7)
\]

Potential evapotranspiration for each month is calculated from Penman Monteith method \([9, 11, 12, 14, 15, 17]\):

\[
ETo = \frac{0.408\Delta RH + 900}{\Delta + \gamma (1 + 0.34 U_{2})} \quad (8)
\]

Actual evapotranspiration \((ETo)\) is divided into two parts:

1) If \(T_{PN} > ETo\) then the \(ETo = ETo\); \(9\)

2) If the \(T_{PN} < ETo\), then the \(ETo = T_{PN} + \Delta SM\) \(10\)

Difference between \(T_{PN}\) with the monthly evapotranspiration \(ETo\),

\[
S = T_{PN} - ETo \quad (11)
\]

Accumulated potential water loss \((APWL)\) is divided into two parts:

1) In the dry months or \(T_{PN} < ETo\), is done by adding up the value difference \((T_{PN} - ETo)\) each month with a value of \((T_{PN} - ETo)\) the previous month. \(12\)

2) In the wet months or \(T_{PN} > ETo\), then the value of \(APWL\) is equal to zero \(13\)

Soil Moisture \((SM)\) is divided into two parts:

In the wet months or \(T_{PN} > ETo\), \(SM\) value for each month is equal to field capacity,

In the dry months or \(T_{PN} < ETo\), \(SM\) value is calculated by the equation

\[
SM = SM_{C} e^{-\left(APWL/SM_{C}\right)} \quad (16)
\]

Changes in monthly soil moisture \((\Delta SM)\)

\[
\Delta SM = SM_{C} - SM_{C-1} \quad (15)
\]

Water surplus \((WS)\) occurs in wet months \((T_{PN} > ETo)\), obtained by If \(SM < SM_{C}\), then \(WS = 0\) and if not then \(WS = S\) \(16\)

**Table 1. Summary of SWB Model, Inputs, Parameters, Outputs**

| (a) Inputs Data | (b) Parameters | (c) Output |
|-----------------|----------------|------------|
| \(L_{DAS}\), \(L_{RT}\), \(L_{RC}\), \(L_{LT}\) | \(\alpha P\) | \(V_{b}\) Monthly groundwater volume (mm) |
| \(P_{DAS}\) | Precipitation correction factor | Total area, forest area, area mix farm and open land area respectively (km²) |
| \(ETo\) | Temperature correction factor | Total monthly precipitation (mm) |
| \(\alpha T\) | Coefficient of infiltration | Monthly evapotranspiration (mm) |
| \(k\) | Groundwater flow recession factor | |

Groundwater \((V_{b})\) depends on the amount of water balance and soil conditions. The data required are:
1) The coefficient of infiltration \((k)\), the value 0.2 to 0.5
2) Groundwater flow recession factor \((\alpha T)\), the value from 0.4 to 0.7

\[
Infiltration(I) = WS \times I_{n} \quad (17)
\]

\[
V_{b} = k \times V_{n-1} + 0.5(1+k).I \quad (18)
\]

A flowchart gives the structure of the model is shown in Fig. 2 \([9]\). The flowchart shows the step of the model operation which is follows:
1) Watershed area \((L_{DAS})\), forest area \((L_{RT})\), area mixed farms \((L_{RC})\) and area open land \((L_{LT})\) calculated from topographic maps (km²).
2) Input factor rain correction \((\alpha P) = 1.2 \quad [9]\).
3) Rain in the forest \((P_{RT})\), rain the mix farm \((P_{RC})\) and rain in open land \((P_{LT})\) calculated by Eq. (1)-(3).
4) Net of rain forest \((P_{NT} HT)\), net of mix farm \((P_{NT} KC)\) and net of open land \((P_{NT} LT)\) calculated by Eq. (4)-(6).
5) Total rain net \((T_{PN})\) calculated by Eq. (7).
6) Input factor temperature correction \((\alpha T) = -1.0^\circ C \quad [9]\) into the Eq. (8).
7) Potential evapotranspiration \((ETo)\) calculated by Eq. (8) with program computer Cropwat 8 for windows.
8) Actual evapotranspiration \((ETo)\) calculated by Eq. (9)-(10).
9) Difference between \(T_{PN}\) with the monthly potential evapotranspiration calculated by Eq. (11).
10) Accumulated potential water loss \((APWL)\) calculated by Eq. (12)-(13).
11) \(SM\) calculated by Eq. (14).
12) Change in soil moisture \((\Delta SM)\) calculated by Eq. (15).
13) \(WS\) calculated by Eq. (16).
14) Infiltration \((I)\) calculated by Eq. (17).
15) The volume of groundwater is calculated by the Eq. (18).

### 2.2.2. Climate change

Detection of climate change using a model Mann - Kendall \([9, 11-13, 17-20]\):
\[ S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \text{sgn}(X_j - X_k) \]  

(19)

\[ \Sigma_s = \sqrt{n(n-1)(2n+5)/18} \]  

(20)

\[ Z = \begin{cases} 
(S-1)/\sigma_s & \text{if } j > k; \\
0 & \text{if } j = k; \\
(S+1)/\sigma_s & \text{if } j < k \end{cases} \]  

(21)

Where \( X_j \) and \( X_k \) are the data value of the data "j" and "k", 

\[ j > k. \]

After the detection of whether there is a trend of improvement or deterioration in the rain with the Mann-Kendall, so to determine the amount the trend to use methods of non-parametric Sen’s [21, 22] assuming the trend linear, the procedure is started Eq. (19)-(21). Both methods are combined so-called Makesens method

\[ f(t) = Qt + B \]  

(22)

Where: \( Q \) is the slope and \( B \) is a constant.

To obtain a slope estimates \( Q \) in Eq. (22), it first needs to be calculated slope for all data with the equation:

\[ Q = \frac{X_j - X_k}{j-k} \]  

(23)

where \( j > k \).

If there is "n" value "\( X_j \)" in a time series, it is obtained as \( N = n(n-1)/2 \) slope estimation \( Q \). Sens slope estimate is the median of \( N \) values \( Q \). \( N \) value of \( Q \) is ranked from small to large, with an estimated Sens is:

\[ Q = Q_{(N+1)/2} \]  

if \( N \) is odd or

\[ Q = 0.5(Q_{(N/2)} + Q_{(N+2)/2}) \]  

if \( N \) is even

(24)

To obtain estimates of "B" in Eq. (22), the value of "n" data from the difference \( (X_i - Qt_i) \) is calculated. The median value is the estimated of "B".

2.3. Data Collection and Analysis

2.3.1. Data collection and analysis for climate change

The data required to analyze climate change in the form of secondary data: 1) Data daily rain of station Up Bangga and Down Bangga available from 1980 to 2011; 2) Data climatology of Bora station available from 1980 to 2011; 3) Potential Evapotranspiration data available from 1980 to 2011 [9].

Fig. 3 presents the monthly rainfall in Bangga watershed for the observation period 1995 to 2011. During this period the average rain is 110 mm, the largest rainfall occurred in September 1995 of 345 mm and the smallest occurred in April 2002 amounted to 0.00 mm. It can be seen that a decline in the monthly rainfall trends over the period.

Fig. 4 presents the potential evapotranspiration for the observation period from 1995 to 2011. During this period the average...
rain is 120 mm/mon, the largest rainfall occurred in March 1996 of 160 mm/mon and the smallest occurred in February 2009 amounted to 92 mm/mon. It can be seen that a decline in the monthly rainfall trends over the period.

2.3.2. Data collection and analysis for model
The data required to analyze the model in the form of secondary data and primary data. For secondary data are required: 1) Data monthly rain of station Up Bangga and Down Bangga available from 1995 to 2011; 2) Data temperature of Bora station available from 1995 to 2011; 3) Data Potential Evapotranspiration available from 1995 to 2011; 4) Maps satellite imagery; 5) Maps the earth in such a scale of 1:50,000 and 6) Soil type maps, scale 1:50,000.

7) The primary data obtained by directly sampling the soil in the research site to obtain the percentage fraction of land, SM content, soil bulk density and soil type conducted in accordance with vegetation land cover (mixed garden and forest) to make a hole in the soil profile depth of the surface soil, topsoil and subsoil below (SM storage) [9].

3. Results and Discussion
The SWB model is part of the model MockWyn-UB which considers climate change in the form of rain correction factor ($\alpha$) and temperature correction factor ($\beta$) as input. Thus, before using this model needs to be analyzed in advance whether there is a climate change study site by using Mann-Kendall models. Furthermore, the projected changes are analyzed by the method of non-parametric Sen's by Sutapa (2015) [9] there has been a climate change in Bangga watershed as mention in Table 2. Thus this model can be used SWB model calculation results are presented in Table 3.

Table 2. Results of Mankendall Model

| Temperature, T (ºC) | From | To  | n  | Trend       | Test Z, average daily |
|-------------------|------|-----|----|-------------|-----------------------|
|                   | 1980 | 2011| 32 | 2.84        |
|                   |      |     |    | Pos and YS  |
| Rainfall, R (mm/d)| Test Z, average daily | 1993 | 2011 | 19 | -2.73       |
|                   |      |     |    | Neg and YS  |
| Potential Evapotranspiration (ET, mm/d) | Test Z, average monthly | 1980 | 2011 | 32 | -1.31       |
|                   |      |     |    | Neg and YS  |

Table 3. Estimates of Monthly Groundwater (mm)

| No. | Year | Jan  | Feb  | Mar  | Apr  | May  | Jun  | Jul  | Aug  | Sep  | Oct  | Nov  | Dec  | Sum  | Average |
|-----|------|------|------|------|------|------|------|------|------|------|------|------|------|-------|---------|
| 1   | 1995 | 32.82| 66.17| 83.72| 41.69| 28.67| 43.47| 45.29| 66.14| 91.54| 75.59| 67.18| 33.45| 675.74| 56.31   |
| 2   | 1996 | 16.06| 19.24| 7.70 | 6.13 | 6.10 | 10.59| 4.24 | 8.82 | 6.37 | 2.55 | 1.02 | 0.41 | 88.22 | 7.35    |
| 3   | 1997 | 16.06| 7.30 | 2.92 | 8.26 | 3.31 | 1.32 | 8.33 | 3.33 | 1.33 | 0.53 | 21.87 | 8.75 | 82.31 | 6.66    |
| 4   | 1998 | 15.06| 6.02 | 2.41 | 15.75| 6.30 | 13.59| 56.67| 22.67| 17.53| 7.01 | 2.80 | 1.12 | 166.92| 13.91   |
| 5   | 1999 | 26.31| 19.39| 12.86| 21.96| 16.20| 11.32| 7.91 | 5.53 | 3.87 | 16.52| 11.55| 8.07 | 160.48| 13.37   |
| 6   | 2000 | 54.18| 21.67| 8.67 | 3.47 | 1.39 | 31.39| 12.55| 5.02 | 2.01 | 0.80 | 0.32 | 0.13 | 141.00| 11.80   |
| 7   | 2001 | 17.18| 6.87 | 2.75 | 17.65| 17.33| 13.13| 5.25 | 2.10 | 0.84 | 0.34 | 0.13 | 0.05 | 83.63 | 6.97    |
| 8   | 2002 | 15.06| 6.02 | 2.41 | 0.96 | 0.39 | 17.12| 6.85 | 2.74 | 1.10 | 0.44 | 10.42| 4.17 | 67.67 | 5.64    |
| 9   | 2003 | 15.06| 6.02 | 2.41 | 7.01 | 2.81 | 1.12 | 0.45 | 0.18 | 0.07 | 0.03 | 0.17 | 0.24 | 36.74 | 3.06    |
| 10  | 2004 | 15.06| 6.02 | 2.41 | 2.40 | 8.76 | 3.50 | 1.40 | 0.56 | 0.22 | 0.09 | 0.04 | 0.01 | 40.47 | 3.37    |
| 11  | 2005 | 15.06| 6.02 | 2.41 | 0.96 | 2.03 | 0.81 | 0.33 | 0.13 | 2.99 | 1.85 | 0.74 | 0.30 | 33.62 | 2.80    |
| 12  | 2006 | 15.06| 6.02 | 2.41 | 5.58 | 2.23 | 0.89 | 0.36 | 0.14 | 0.06 | 0.02 | 0.01 | 0.00 | 32.79 | 2.73    |
| 13  | 2007 | 15.06| 22.59| 9.04 | 16.30| 39.96| 20.58| 8.23 | 39.03| 15.61| 6.70 | 2.68 | 1.50 | 197.27| 16.44   |
| 14  | 2008 | 15.06| 6.02 | 10.23| 20.97| 17.63| 17.44| 44.34| 17.74| 7.09 | 2.84 | 1.14 | 0.45 | 160.94| 13.41   |
| 15  | 2009 | 26.35| 18.44| 12.91| 9.04 | 6.33 | 4.43 | 3.10 | 2.17 | 1.52 | 1.06 | 0.74 | 6.74 | 92.83 | 7.74    |
| 16  | 2010 | 15.06| 6.02 | 2.41 | 0.96 | 0.39 | 53.11| 65.35| 76.29| 30.52| 12.21| 4.88 | 1.95 | 9.15  | 22.43   |
| 17  | 2011 | 18.29| 8.89 | 4.32 | 2.10 | 1.02 | 0.50 | 0.24 | 32.89| 22.24| 10.81| 44.61| 21.68| 167.59| 13.97   |

Average 20.04 13.99 10.12 10.66 9.46 14.37 15.94 16.79 12.05 8.26 10.03 5.23 146.94 12.24
Climate change is occurred if the values of Z test more or less than zero. Otherwise, if the value of Z test is equal to zero is not occurred climate change. A confidence value ($\alpha$) used in the calculation of Mann-Kendall is 0.001; 0.01; 0.05 and 0.1. According to the table of normal standard “Z” the values are: $Z_{0.001} = 3.292$; $Z_{0.01} = 2.576$; $Z_{0.05} = 1.96$; $Z_{0.1} = 1.645$.

Signs of significance in the calculation of the Mann-Kendall categorized into five categories, namely: three star (***) , two (**), one (*), the (+) and empty (..) which indicates the level of confidence ($\alpha$) = 0.001; 0.01; 0.05 and 0.1 respectively. If there is no sign (blank) means a significant level ($\alpha$) of more than 0.1 or can be said to be insignificant [9].

Fig. 5 presents the relationship between monthly rainfall (R) and potential evapotranspiration (ETo) with groundwater (GW) as a result of modeling taking into account climate change in year 1995. It can be seen that the potential evapotranspiration almost the same throughout the month, then the amount of groundwater is only affected by the amount of monthly rainfall. This model may give good performances because of the variation of the groundwater or linear follow the up and down of monthly rainfall. The mean effect of evapotranspiration (ETo) and rainfall (R) to be groundwater is 58% and 42%, where the influence of evapotranspiration ranged from 37% to 68%, while rainfall ranges between 32% to 54%.

Fig. 6 presents the results of the calculation model of groundwater in the period 1995 to 2011. At the beginning of the simulation in 1995 resulted in ground water is high enough then dropped dramatically in all months. In January (year 1995 to 2011) the value of the largest groundwater occurred in 2000, while in others nearly flat. In February and March the value of groundwater fluctuation but not too big. Period May-August (year 1995 to 2011) the largest fluctuation occurred in 2010. Finally, for the period September-December (year 1995 to 2011) the value of groundwater occurred in 1995, while for the others there is a fluctuation but not too big.

Fig. 7 presents variation of monthly groundwater January-December. During this period the average groundwater is 147 mm/y, the largest groundwater is 676 mm/y in year 1995 and the smallest occurred in year 2006 amounted to 33 mm/y. It can be seen that there is a downward trend in groundwater from the beginning to the end of the simulation.

Fig. 8 and Fig. 9 present variation of yearly rainfall (R), evapotranspiration (ETo), groundwater (GW) and percentage of rainfall to be groundwater for period 1995 to 2011. During this period the average rainfall to be groundwater is 9.9%, the largest rainfall to be groundwater is 25.60% in year 1995 and the smallest occurred in year 2005 amounted to 3.24%. It can be seen that the fluctuation of the rain changes into groundwater.
Fig. 9. Variation of percentage rainfall (R) to be groundwater (GW).

Fig. 10. Relationship between groundwater (GW) versus rainfall (R) and potential evapotranspiration (ET0) base line 1995-2011 and projection to 2031.

From the results that have been presented can be seen that groundwater recharging period 1995 to 2011, in January decline of simulation start in 1995 until 1998, raised significantly in 2000 before finally almost the same until 2011. In February decreased very sharply from the beginning of the simulation until 1998, then slightly increased in 2000, 2007, 2009 and other years is almost the same. In March a very sharp decline from the beginning of the simulation until 1998 and then fluctuated until the end of the simulation (2011). In April there is a decrease until 1996, there is an increase in 1999, 2001, 2007, 2008 and 2009, while in others fluctuate. In May decline began early simulation and an increase in 1999, 2001 and 2007. In June decline began early simulation and an increase in 2000, 2007 and 2010. In July a decline from early simulation until 1997 and increase in 1998, 2008 and 2010. In August a decline from early simulation to 1997 and increased in 1998, 2007 and 2010. In September, October, November and December, there was a very sharp decline from the beginning of the simulation until 1996 and fluctuate for other years.

The annual simulation results indicate a trend decline in groundwater recharge from early 1995 until the end of the simulation in 2011. From 1998 to 2000, 2007, 2008, 2010 and 2011 recharging groundwater is above the average annual groundwater for the simulation period (1995 to 2011). The amount of groundwater recharging linearly with the mount of monthly rainfall is happening. It means that the higher the rainfall that occurred then recharging groundwater will be even greater, and vice versa.

Percentage rain to fill ground water is very small, ranging from 3% till 25%. This indicates that the rain that falls on the watershed Bangga to be a lot more runoff and evaporation. If observed Fig. 8, it is clear that in general the amount of annual rainfall is less than evaporation and no recharging groundwater. This is unlikely to happen. That is the amount of annual rainfall, evaporation annual and annual groundwater cannot be compared. What can be done is to compare a monthly basis in accordance with this simulation. It can be seen from Fig. 5 where the value is greater than the monthly rainfall evaporation and groundwater recharge occurs. This occurs and goes for the other years during the period 1995 to 2011.

4. Conclusions

The conclusion from this study is going on a downward trend in the annual groundwater recharge from early 1995 until the end of the simulation in 2011. For 1998 till 2000, 2007, 2008, 2010 and 2011 recharging groundwater is above the average annual groundwater for the simulation period (1995 to 2011). The amount of groundwater recharging linearly with the mount of monthly rainfall is happening. It means that the higher the rainfall that occurred then recharging groundwater will be even greater, and vice versa. Percentage of rain to fill ground water is very small, ranging from 3% to 25%. This indicates that the rain that falls on the Bangga watershed to be a lot more runoff and evaporation.

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Nomenclature

| Symbol | Definition                        |
|--------|-----------------------------------|
| B      | Constant                          |
| ET0    | Potential evapotranspiration, mm/d|
| ETa    | Actual evapotranspiration, mm/d   |
| es     | Saturated water vapor pressure, kPa|
| ea     | Actual water vapor pressure, kPa   |
| I      | Infiltration                      |
| In     | Coefficient of infiltration       |
| k      | Groundwater flow recession factor |
| LDAW   | Total area in watershed, km²      |
| LFT    | Forest area, km²                  |
| LMC    | Mix farm area, km²                |
| LA     | Open land area, km²               |
The amount of observational data

$P_{DAS}$: Total rain in watershed, mm

$P_{HT}$: Rain in forest, mm

$P_{KC}$: Rain in mixed farm, mm

$P_{LT}$: Rain in open land, mm

$P_{NT\ HT}$: Net rain forest, mm

$P_{NT\ KC}$: Net rain mixed farm, mm

$P_{NT\ LT}$: Net rain open land, mm

$Q$: Slope

$R_0$: Net radiation, cal/cm²/d

$S$: Variants

$T_{PN}$: Total net rain, mm

$U_2$: Wind velocity at a height of 2 m above the ground, m/s

$V_0$: Volume of groundwater, mm/month

$Z$: Statistical value

$\alpha_P$: Precipitation correction factor

$\alpha_T$: Temperature correction factor

$\sigma$: Root of Variants

$\Delta$: The slope of the vapor pressure of water against temperature, kPa/°C

$\gamma$: Psychrometric constant, kPa/°C

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