Impact of climate change on rawa river water source in lake Lindu watershed, Central Sulawesi, Indonesia

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Abstract. Global Climate change has been discussed in the High-Level Conference in Rio de Janeiro, Brazil in 1992 and has given more impacts in the world. One of the global climate exchanges is the rising of intensity and frequency of climate extreme which included drought, flood, and hurricane. The objective of this study was to investigate the effects of climate change on evapotranspiration and rainfall for river water discharge of Rawa. The investigation has been carried out using daily data and analyzed on a daily, monthly and yearly. The rain stations that represent the location of this research are Palolo, Kulawi, and Wuasa. Climatological station nearest to the research station used Bora. Climate trends and projected changes in the method of Makesens analysis (Mann-Kendall, Sens) and the correlation of rainfall and evapotranspiration discharge used linear regression equation. Similarly, the correlation between changes in soil water storage with rainfall, evapotranspiration, and discharge was analyzed in a linear manner. The conclusion of this study is the climate changes in the River of Rawa watershed was characterized by slowly increasing temperature, increasing rainfall, and decreasing discharge.

1 Introduction

Global Climate change has been discussed in the High-Level Conference in Rio de Janeiro, Brazil in 1992 and has given more impacts in the world. One of the global climate exchanges is the rising intensity and frequency of climate extreme which included drought, flood, and hurricane. Global climate change that occurs in addition to impacting on the increase or decrease of rain in an area, rising temperatures, can also be associated with changes in season patterns, wind patterns, air humidity, and solar irradiance. Increased rainfall as a watershed input due to global climate aberration will affect river flow discharge, both on an annual and seasonal basis. The purpose of this research is to know the impact of climate change on river water discharge related to climate factors such as temperature, air humidity, solar irradiance, wind speed, evapotranspiration, solar radiation, and rain. Climate components and climate change trends will be analyzed and further projected in the next few years.

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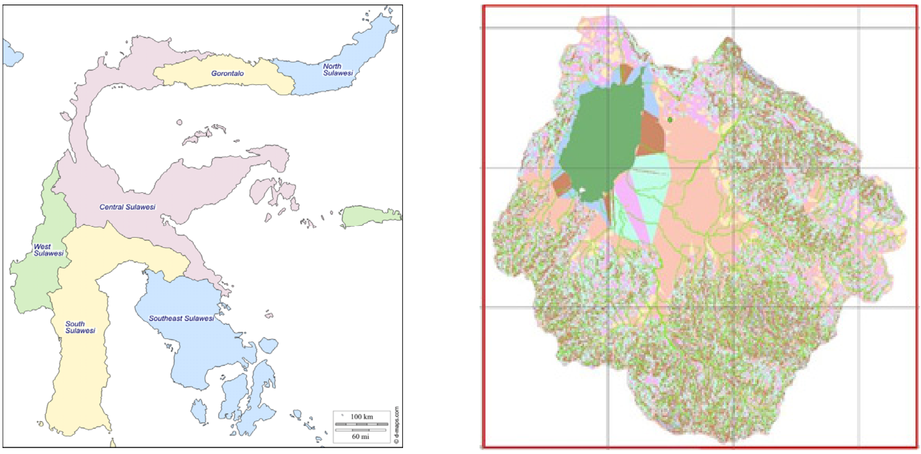
The research was conducted in River of Rawa which is an outlet of Lake Lindu watershed, which is administratively located in Lindu Sub-district, Sigi Regency, Central Sulawesi Province, Indonesia. Geographically situated at 1°3'-1°58' South Latitude and 119°57'-120°22' East Longitude. Lake Lindu's watershed area is 546.056 km^2. The location of the study is presented in Fig. 1.



(a) (b)

Fig 1. Location of research (a) Central Sulawesi Province, (b) Lake Windu Watershed.

2 Materials and methods

The data used in this research are primary data and secondary data. Primary data are field survey to know condition of Lake Lindu watershed, while secondary data are as follows: 1) monthly rainfall data Kulawi Station, Palolo and Wuasa (1993-2017), 2) climatology data of Bora Station (1993-2017), 3) daily Rawa River (2002-2014), 4) topographic map scale of 1:50,000. To determine the effect of climate change on Rawa River debit, it is necessary to 1) calculate region rainfall, 2) calculate evapotranspiration, 3) create discharge model, 4) calculate groundwater storage, and 5) detect climate change and its projection.

2.1 Region rainfall

Calculation of the rain of the region using the equation Polygon Thiessen [1-4]:

$$\overline{R} = \frac{1}{n}(R1 + R2 + \ldots Rn) \tag{1}$$

Based on the topographic map and the location of the rain station, the influence for each rain station Kulawi Station (0.37), Palolo (0.30) and Wuasa (0.33) will be calculated.

2.2 Evapotranspiration

Evapotranspiration is calculated by the Penman Monthiet equation [2-9]:

$$ETo = \frac{\Delta(Rn - G) + \rho a.cp \dfrac{(es - ea)}{ra}}{\Delta + \gamma\left(1 + \dfrac{rs}{ra}\right)} \tag{2}$$

Input climatology data was taken as an average of temperature, relative humidity, wind speed, and the duration of solar radiation.

2.3 Discharge model

The discharge model uses the equation [2, 10]

$$Q' = a + b.R + c.Eto \tag{3}$$

Data inputs are historical discharge, monthly rainfall, and evapotranspiration.

2.4 Soil water storage

The equations used [2, 10]

$$\mathrm{dS} = \mathrm{R} - \mathrm{ETo} - \mathrm{Q'} \tag{4}$$

Data inputs are monthly rainfall, monthly evapotranspiration, dan monthly discharge.

2.5 Detect of climate change

Using the Mann-Kendall equation [2-4, 6-7, 11-21]:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign(y_j - y_i) \tag{5}$$

$$sign(\vartheta) = \begin{cases} 1 & \text{if } \vartheta > 0 \\ 0 & \text{if } \vartheta = 0 \\ -1 & \text{if } \vartheta < 0 \end{cases} \tag{6}$$

$$\sigma^2 = \frac{n(n-1)(2n+5)}{18} \tag{7}$$

$$Zs = \begin{cases} \dfrac{S-1}{\sigma} if \rightarrow S > 0 \\ 0 if \rightarrow S = 0 \\ \dfrac{S+1}{\sigma} if \rightarrow S < 0 \end{cases} \tag{8}$$

$$|Z_s| \geq Z\alpha \tag{9}$$

Input data are temperature, relative humidity, wind velocity, time of sunshine, rainfall, evapotranspiration, soil water storage, and discharge, all of which are monthly data.

2.6 Trend Slope

Using the Sens equation [2-4, 6-7, 11-21]. The data is similar to climate change detection.

$$\mathrm{f(t)} = \mathrm{Qt} + \mathrm{B} \tag{10}$$

$$Q_i = \frac{X_j - X_k}{j - k} \tag{11}$$

3 Results and discussion

3.1 Climate and water balance changes

The time series curves of the Rawa River climate components are presented in Fig. 2, and the results of the calculation of climate change by the Mann-Kendall method are shown in Table 2.

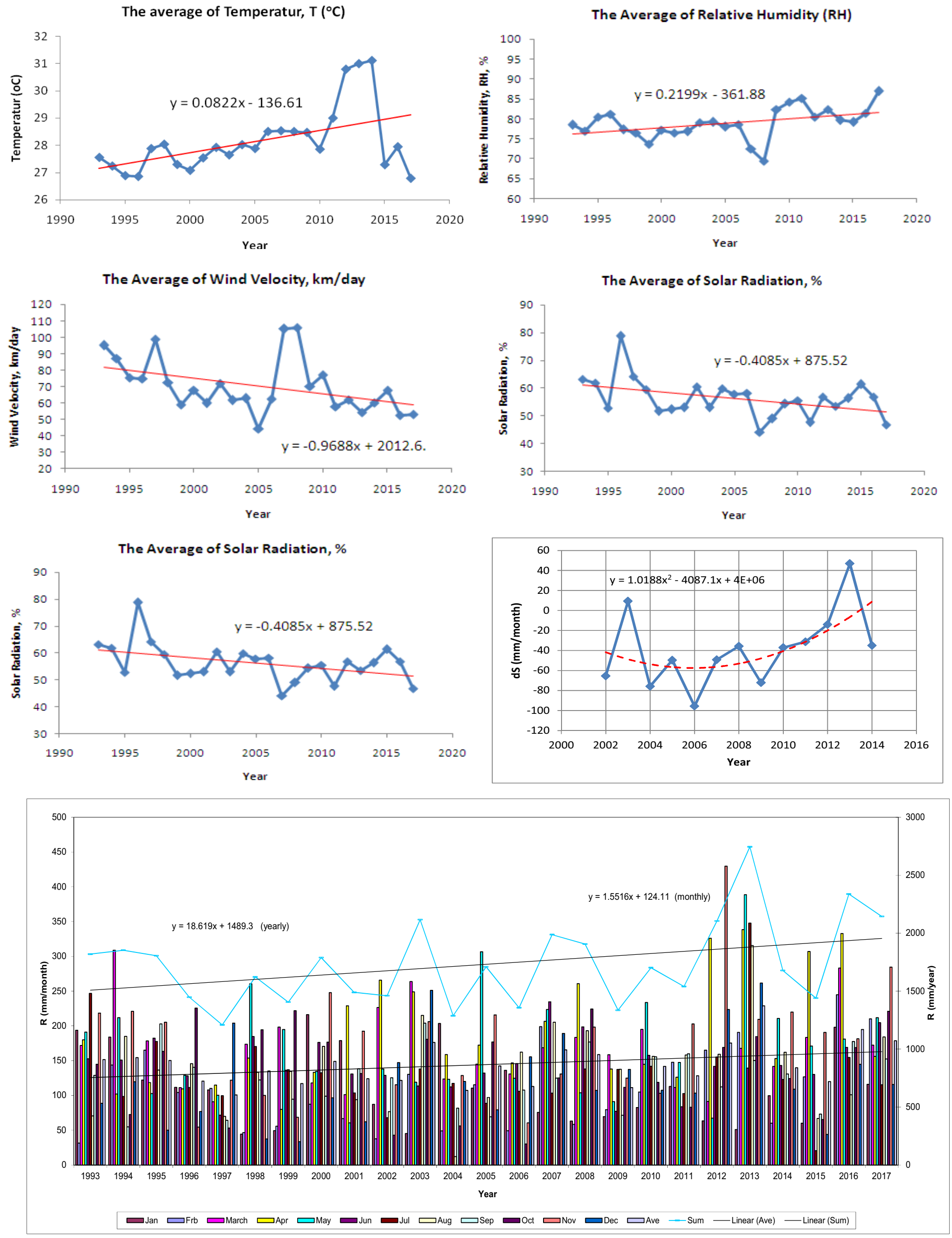


Fig 2. Time series charts of climate components.

Fig. 2 shows the time series curve of climate components. It can be seen that the average temperature fluctuated from 1993 to 2010 with the trend of rising slowly, while in 2011 until 2017 there was a sharp increase and decrease. The lowest temperature occurred in June 2017 (23.600°C), and the highest occurred in September 2014 (31.990°C). The average temperature is a slow increasing trend with the linear equation y = 0.08222X - 136.61.

Applied average air humidity fluctuates from 1993 to 2006, a sharp decline occurred in 2008, increasing and decreasing from 2009 to 2017. Lowest air humidity occurred in January 2008 (66%) and highest in September 2017 (96%). In general, air humidity there is a slowly increasing trend with the linear equation of y = 0.2199X-361.88. The wind speed fluctuated slowly from 1993 until 2017 except for the years 2007 and 2009 there was a very significant increase. Average wind velocity occurred in June 2002 (21 km/day), and the highest occurred in April 2009 (194 km/day). In general, the average wind speed decrease trend slowly with linear line equation y = -0.99688X + 2012.60.

The average solar radiation from 1993 to 2017 fluctuated significantly for each month. The lowest average sun exposure occurred in January 2017 (16%) and highest in August 1997 (92%). In general, the average of sun exposure occurs slowly decreasing trend with linear line equation y = -0.4085x + 87.552. The average solar radiation from 1993 to 2017 fluctuates significantly every month. The lowest solar radiation occurred in January 2017 (12.10 MJ/m^2/day) and the highest in March 1996 (26.70 MJ/m^2/day). In general, the average of solar radiation occurs slowly decreasing trend with the linear line equation y = -0.0803x + 180.1.

The monthly rainfall rate from 1993 to 2017 fluctuates significantly every month with rising trends, while annual rain fluctuates slowly with rising trends. The linear equation for the mean monthly rainfall is y = 1.5516x + 124.11 and the annual rain linear equation y = 18.619x+1489.3. Soil water storage fluctuates slowly from 2002 to 2014 with an upward trend. Lowest water storage occurred in 2006 (-95.66 mm/month) and highest in 2013 (46.90 mm/month). Polynomial soil water storage equation: $y = 1.0188x^2 - 4087.1x + 4E + 06$ with rising trend.

From the calculation results with the Mann-Kendall method in Table 2 it can be seen that the temperature shows a change in climate with a significant upward trend except in October. Wind speeds are changing climate with significant downward trend except in March and October. Long sun radiation shows climate change with the downward trend but not significant except in January. Solar radiation shows climate change towards positive and negative but not significant except in January, June, August, and December. The average monthly rainfall indicates climate change is positive and negative but not significant except in July there is no climate change. Evapotranspiration shows climate change with significant downward trend except in February, March, September, November, and December. Average discharge indicates climate change is positive and negative but insignificant, except in December there is no trend. Soil water storage shows a significant climate change with a positive trend. Based on these climatic components it can be said that in the Lake Lindu watershed there is a significant climate change.

3.2 Estimated water discharge of Rawa River

This study aims to find whether or not there will be changes in river water discharge due to local climate change. For that, we need to know the relationship between river flow with rainfall and evapotranspiration. From monthly data (2002-2014) for rainfall, evapotranspiration and discharge obtained linear relationship Q' = 0,197R + 1,865E - 191.57. With this equation, we can estimate the amount of river water discharge based on

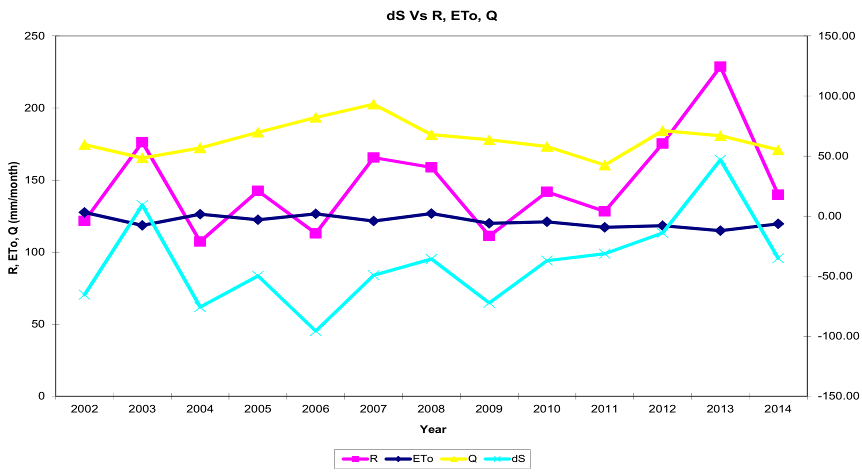
Table 2. Climate change calculation result with Mann-Kendall Model.

Hydroclimate	From	To	n	Trend											
				Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
T(C) Temperature															
Average	1993	2017	25	2.979 Pos and YS	2.156 Pos and YS	2.198 Pos and YS	1.593 Pos and YS	2.178 Pos and YS	1.731 Pos and YS	3.529 Pos and YS	2.971 Pos and YS	2.694 Pos and YS	1.406 Pos and YS	2.550 Pos and YS	2.312 Pos and YS
Average	Jan	Dec	25	2.757 Pos and YS											
W (km/day) Wind Velocity															
Average	1993	2017	25	-2.548 Neg and YS	-1.659 Neg and YS	-1.402 Neg and YS	-2.057 Neg and YS	-2.199 Neg and YS	-2.220 Neg and YS	-1.123 Neg and YS	-1.285 Neg and YS	-1.706 Neg and YS	-1.098 Neg and YS	-1.730 Neg and YS	-2.034 Neg and YS
Average	Jan	Dec	25	-2.686 Neg and YS											
SH (%) Time Length of Sunshine															
Average	1993	2017	25	-2.502 Neg and YS	-1.006 Neg and YS	-0.093 Neg and YS	-0.749 Neg and YS	-0.914 Neg and YS	-1.496 Neg and YS	-1.332 Neg and YS	-2.034 Neg and YS	-0.094 Neg and YS	-1.380 Neg and YS	-0.211 Neg and YS	-1.309 Neg and YS
Average	Jan	Dec	25	-1.682 Neg and YS											
Rad (MJ/m^2/day) Radiation															
Average	1993	2017	25	-2.526 Neg and YS	-1.403 Neg and YS	-0.234 Neg and YS	-0.446 Neg and YS	-1.363 Neg and YS	-1.871 Neg and YS	-1.427 Neg and YS	-2.643 Neg and YS	-0.211 Neg and YS	-0.983 Neg and YS	-0.492 Neg and YS	-1.661 Neg and YS
Average	Jan	Dec	25	-1.962 Neg and YS											
R (mm/month) Rainfall															
Average	1993	2017	25	-1.191 Neg and	2.265 Pos and	0.304 Pos and	2.592 Pos and	0.724 Pos and	0.304 Pos and	0.000 NT	1.191 Pos and	1.144 Pos and	-0.117 Pos and	1.051 Pos and	1.565 Pos and

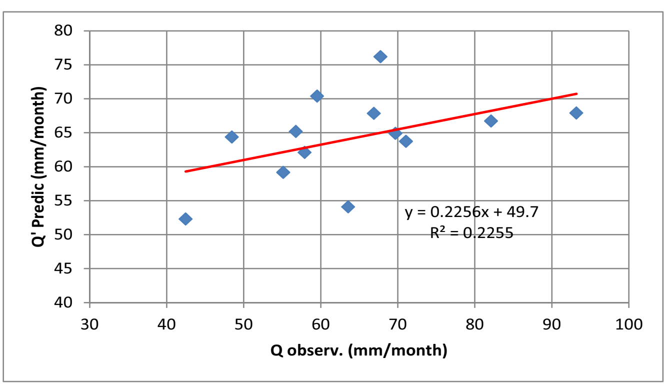
Hydroclimate	**From**	**To**	**n**	**Trend**											
				Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
				NS	YS	NS	NS	NS	NS		NS	NS	NS	NS	NS
Average	Jan	Dec	25	1.191 Pos and NS											
Eto (mm/day) Evapotranspiration															
Average	1993	2017	25	-2.465 Neg and YS	-0.516 Neg but NS	-0.679 Neg but NS	-2.548 Neg and YS	-1.998 Neg and YS	-2.482 Neg and YS	-1.911 Neg and YS	-2.226 Neg and Ys	-0.589 neg but NS	-1.805 Neg and YS	-0.633 Neg but NS	-1.476 Neg but NS
Average	Jan	Dec	25	-2.919 Neg and YS											
Q (m^3/sec) Discharge															
Average	2002	2014	13	-0.183 Neg but NS	0.793 Pos but NS	-0.671 Neg but NS	-0.183 Neg but NS	0.793 Pos but NS	0.183 Pos but NS	0.671 Pos but NS	0.915 Pos but NS	1.159 Pos but NS	0.305 Pos but NS	0.427 Pos but NS	0.000 NT
Average	Jan	Dec	13	0.671 Pos but NS											
dS (mm/year) Soil water storage															
Average	2002	2014	13	2.013 Pos and YS											
Pos	=	Positif or increasing trend			$Z_{hit} > Z\alpha$ .... Yes Significant (YS) $Z_{hit} < Z\alpha$ .... No Significant (NS) $Z = 0$ .... No Trend (NT)										
Neg	=	Negatif or decreasing trend													
YS	=	Tes Significant													
NS	=	No Significant													
NT	=	No Trend													

rain and evapotranspiration data. The relationship between the discharge observation data (Q) and the discharge forecast (Q') is shown in Fig. 3.

From Fig. 3 left, it can be seen that the evapotranspiration is almost no change in time, rainfall fluctuates and tends to experience a rising trend, the river flow is relatively stable there is a significant change, while soil water storage fluctuates in tandem with the ups and downs of rain. This shows that although the rain fluctuates, evapotranspiration is relatively stable and soil water storage fluctuates, but the water flow is relatively unchanged, which means there are other factors as the cause. While the right three image shows the relationship between the observed discharge data Q and the predicted Q data whose R2 value is relatively small, indicating the correlation is not good. This may be caused by factors other than rain and evapotranspiration affecting the discharge.



(a)



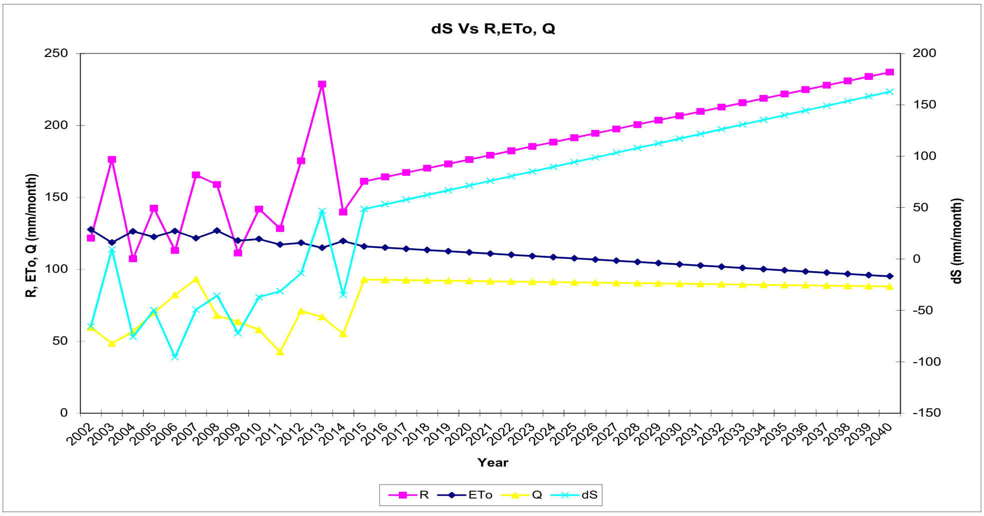
(b)

Fig. 3. (a) The correlation of discharge with rain and evapotranspiration, (b) The correlation between discharge observation and discharge calculation.

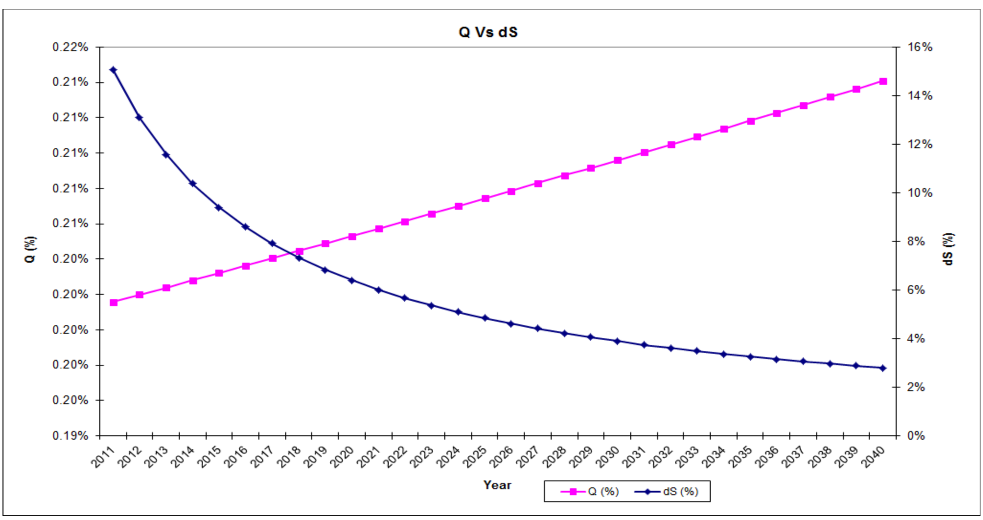
3.3 River discharge trend and soil water storage

Fig. 4 shows the rainfall, rainfall, evapotranspiration and soil water storage period (2002-2014) and its projection until 2040. The change in soil water storage (dS) is directly proportional to rain (R) and inversely proportional to evapotranspiration (ET) and discharge

(Q). The same thing also happens in Fig. 4 right, where the change of soil water storage (dS) is inversely proportional to the flow of water (Q), that is, the greater the discharge and evapotranspiration, the soil water storage change will be smaller. There is an interesting thing that happened from the Fig. 4 left that is the relationship between the discharge and rain, where the more rain, the smaller the discharge. This indicates that discharge can not only be affected by rain and evapotranspiration factors but also other influencing factors, such as land cover.



(a)



(b)

Fig. 4. (a) Rain forecast, evapotranspiration, (b) Discharge, and changes in soil water storage.

3 Conclusions

Based on monthly hydro climatology data from 1993 to 2017 period, then analyzed by Mann-Kendall method, it can be concluded that there have been significant changes in climate in Lake Lindu watershed by considering the Z value is bigger or smaller than zero. Also, the change can also be seen in the increase in temperature and rainfall and the decrease in river flow gradually. This indicates the occurrence of climate change that affects the river discharge and soil water storage changes.

The authors would like to thank the Regional Office of the Sulawesi River Region III in Palu, Central Sulawesi, Indonesia which has provided hydro climatological data to support this research.

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