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Effect of Climate Change on Water Availability of Bangga River, Central Sulawesi of Indonesia

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ABSTRACT

The objective of this study was to investigate the effects of climate change in evapotranspiration and rainfall for river water discharge of Bangga. Investigation has been carried out using daily data and analyzed on a daily, monthly and yearly. 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 were analyzed in a linear manner. The conclusion of this study is the climate changes in the Bangga watershed was characterized by slowly increasing temperature, decreasing rainfall, and increasing evapotranspiration.
KEYWORDS: climate change, Makesens, Bangga River

INTRODUCTION

Global Climate change has been discussed on the High Level Conference at Rio de Janeiro, Brazil in 1992 [1] and has given more impacts in the world. One of the global climate exchanges are the rising of intensity and frequency of climate extreme which included drought, flood, and hurricane [1]. Previous studies were presented many indicators climate exchange as the rising in sea level [2], drought, flood, and any kinds of problem in water resources development [3]. Drought has been increased in intensity and number on some parts of the world and it is as a natural hazard but with temporarily unbalanced water availability caused by high evapotranspiration and low precipitation, thus resulting in reduced water availability [4]. There was very possible to analyse water balance in many parts of watershed for making sure the impact of climate change in the watershed. As we all know that droughts inflicted economic and social damage worldwide [5]. Their irregular frequent and occurrence has been a special reason for the planning, management and development, and construction design of water resources. Droughts will influence the design and planning of water resources infrastructure. Therefore, hydrologists have to pay more attention to drought pattern of recurrence from the records of stream flow and precipitation [6]. Drought impacted the scarcity of natural water resources, so the understanding of drought recurrence and duration is an urgent importance. Hydrological models are a powerful utilization to know the future and current hydrological exchanges of a watershed [7][8]. Increasing in temperature however will rise the evaporation and it is possible to produce higher water vapour. Long-term changes in precipitation will give impact on socio-economic sectors as well as water such as irrigation, fresh water availability, hydro electrical power, etc.

Revolution of industry which is remarked by the usage of fosil gasoline mainly coal gasoline beginning from about 1840 in Eurape, has drastically increased gas of glass house in atmosphere because main result of the gasoline burning is as carbon-dioxide (CO_2). Reason of the glass house effect has globally and significantly increased annually the atmosphere temperature of land. The phenomenon is known as global climate change which will be faced beside increasing or drcreasing on rainfall of an area, the increasing of atmosphere temperature can also be related with the pattern changes of season, wind, humidity, and radiation. Decreasing of rainfall as the input variable of watershed is as the reason of global climate deviation and it will influence yearly as well as seasonal dynamic of river flow discharge.

This study was carried out to analyze the impact of climate change due to the river water availibility which related with the climate factors like temperature, humidity, radiation, wind velocity, and rainfall. The trend of climate change and water balance component will be analyzed and then being predicted.

MATERIALS AND METHODS

This study was conducted in Bangga watershed which was as the affluent of Palu River. The watershed administratively is located in Bangga Village, Dolo District, Sigi Regency, and Central Sulawesi Province of

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Indonesia. The study area was falls between south latitude 01^0 15'07" and $01^0$21'30"and east longitude 119^0 49'20" and 119^0 56'05". Location of study is as in Figure 1 below.

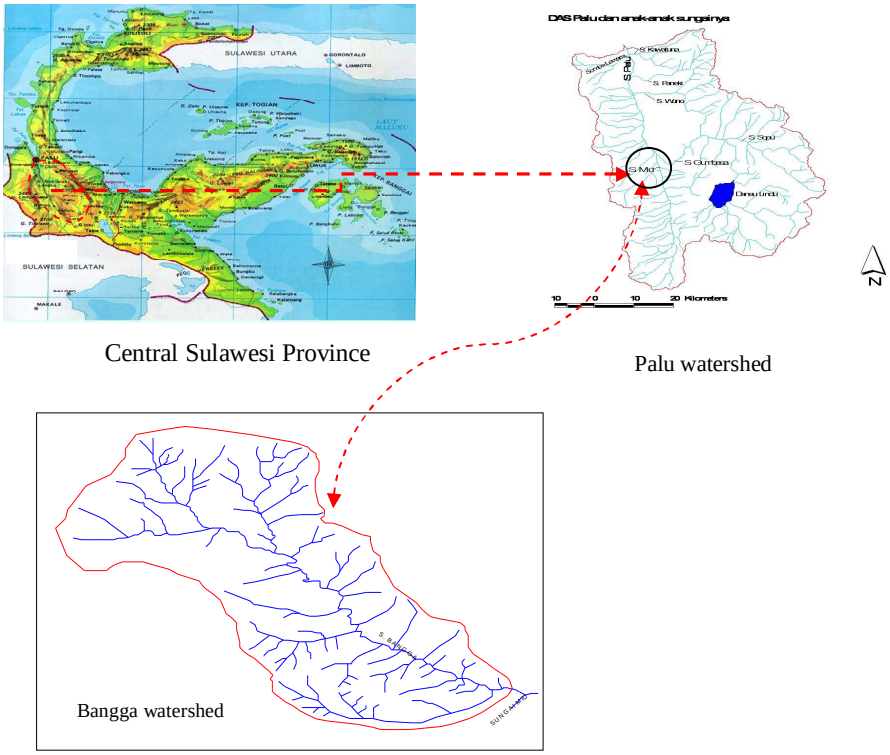


Figure 1 Map of location

Secondary data that was used in this study included: 1) daily rainfall data of Upper and Lower of Bangga Stasion in the year of 1993-2011; 2) climate data of Blora Stasiun in the tear of 1980-2011; 3) daily discharge data of Bangga River in the year of 1995-2011; and 4) topography map with the scale of 1:50,000.

To investigate the effect of climate exchange (evapotranspiration and rainfall) due to discharge of Bangga River, it was naccessary to carry out some steps of methodologies as follow: 1) analysis of area rainfall; 2) analysis of potential evapotranspiration; 3) to formulate model of discharge; 4) analysis of groundwater storage; 5) to detect climate exchange and prediction. Table 1 presented the summary of formula that was used in this study.

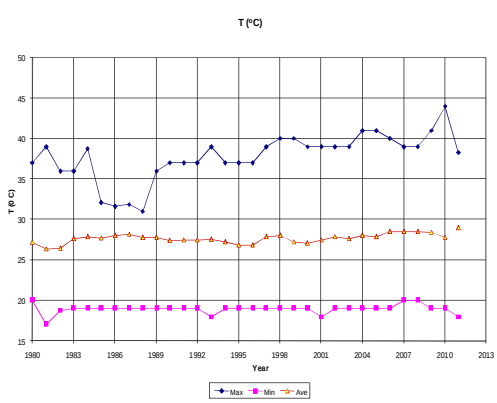
Table 1 Summary of research formula [9][10][11][12]

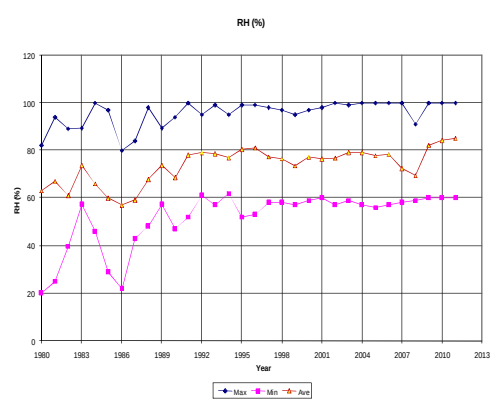
No.	Item	Model	Data	Method	Output
1	Watershed rainfall rate [8]	$\overline{R} = \frac{1}{n}(R1 + R2 + \ldots Rn)$	Daily rainfall	Aritmatic mean	Regional rainfall rate Jan to Dec
2	Potensial evapotranspiration [9]	$ETo = \frac{\Delta(Rn - G) + \rho a.cp\frac{(es - ea)}{ra}}{\Delta + \gamma(1 + \frac{rs}{ra})}$	- Temperature max, min, ave - Relatif humidity max, min, ave - Wind velocity max, min, ave - Time of sunshine max, min, ave	Penman Montieth	ETo Jan to Dec
3	Discharge model [10]	$Q' = a + b.R + c.ETo$	- Historical discharge - Daily rainfall - Potensial evapotranspiration	Linier regresion	Relation among discharge rainfall and potensial evapotranspiration
4	Soil water storage [10]	dS = R - ETo - Q'	- Yearly rainfall - Yearly potensial evapotranspiration - Yearly discharge	Linier regresion	Relation among soil storage rainfall, potensial evapotranspiration and discharge
5	Detect of climate change [11]	$S = \sum_{i=1}^{n-1}\sum_{j=i+1}^{n} \text{sign}(y_j - y_i)$ $\text{sign}(\vartheta) = \begin{cases} 1 & \text{if } \vartheta > 0 \\ 0 & \text{if } \vartheta = 0 \\ -1 & \text{if } \vartheta < 0 \end{cases}$ $\sigma^2 = \frac{n(n-1)(2n+5)}{18}$ $Z_S = \begin{cases} \frac{S-1}{\sigma} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sigma} & \text{if } S < 0 \end{cases}$ $\lvert Z_s \rvert \geq Z\alpha$	- Temperature max, min, ave - Relatif humidity max, min, ave - Wind velocity max, min, ave - Time of sunshine max, min, ave - Rainfall max, min, ave, monthly, yearly - Potensial evapo.max, min, ave - Soil water storage, max, min, ave - Discharge max, min, ave	Mann-Kendall method	Trend climate change - monthly - yearly
6	Trend slope [12]	f(t) = Qt + B $Q_i = \frac{X_j - X_k}{j - k}$	- Temperature max, min, ave - Relatif humidity max, min, ave - Wind velocity max, min, ave - Time of sunshine max, min, ave - Rainfall max, min, ave, monthly, yearly - Potensial evapo. max, min, ave - Soil water storage, max, min, ave - Discharge max, min, ave	Sens method	Trend slope climate change - Monthly - Yearly

RESULTS AND DISCUSSION

Climate and the exchange of water balance

Time series curve of climate components in Bangga River was presented as in Figure 2 and the result of climate change using Mann-Kendall Method was described as in Table 2 below.





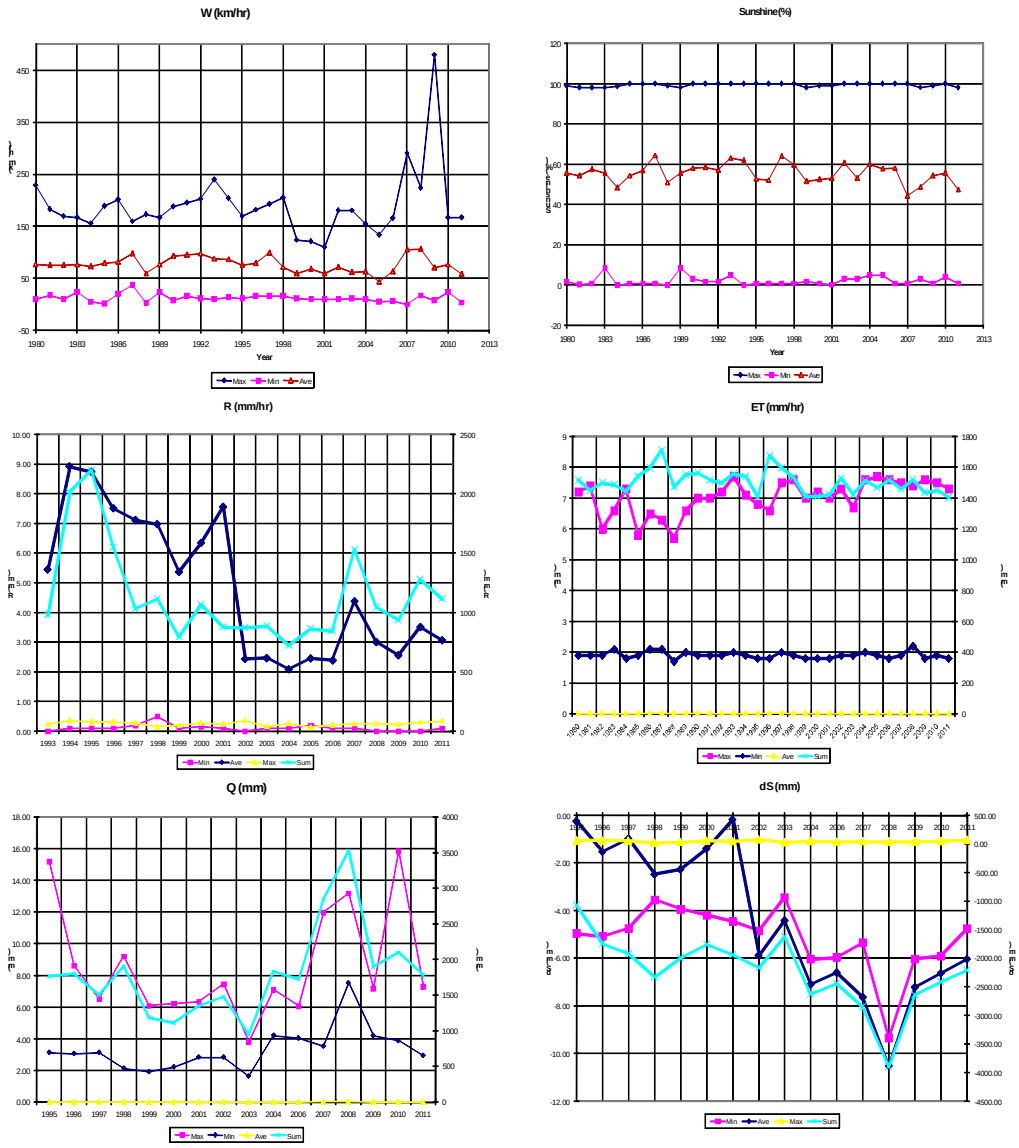


Figure 2 Time series curve of climate components

Figure 2 showed that during the period of 1980-2011, T_{min} and T_{ave} were relative unchanged due to the T_{max} but T_{max} indicated the tendency to increase. The relative humidity (RH_{max}, RH_{min}, RH_{ave}) is fluctuated in the period of 1980-1992 and then it was almost plain until the year of 2011. The wind velocity (V_{min}) did not almost have meaningfull increasing until 2011. V_{ave} occured the decreasing in the year of 1988 and the increasing in the year of 2007 and 2008, but V_{max} was fluctuative, even in the year of 2009 there was very high wind velocity. Duration of radiation (S_{min} and S_{max}) was not significantly changed duw to the time, but S_{ave} was fluctuated and had tendency to decrease. Rainfall (R_{min} and R_{max}) was fluktuated and it was significantly decreasing until the year of 2011. Evapotranspiration (ET_{min} and ET_{max}) was not meaningfull changed during the period of research, on the contrary ET_{min} and ET_{max} until the year of 1999, then it was plain until the year of 2011. Discharge of Q_{ave} was almost not changed during the observation, but on the contrary Q_{min}, Q_{max}, and Q_{sum} was fluctuated and the highest discharge was occured in the year of 2008. On the contrary of pattern was occured in the change of soil water storage) which dS_{ave} was not meaningfull change, but dS_{min}, dS_{max}, dS_{sum} was occured on the contrary pattern of discharge pattern.

Analysis result of Mann-Kendall was presented as in Table 2 which T_{min} did not indicate the significant change but T_{max} and T_{ave} indicated the positive and significant change. Relative humidity (RH_{max}, RH_{min}, RH_{ave}) had positive and significant change in all of the months and years, while wind velocity was occurred change but in general it was not significant. Duration of radiation (S_{min}) had positive and significant change, but S_{min} and

S_{ave} was occured change but it was not significant. The change of rainfall which was significant enough was only indicated by R_{ave} but R_{max}, R_{min}, and R_{sun} were occured change but it were not significant. Evapotranspiration (yearly of ET_{max}, ET_{min}, and ET_{ave}) had significant change, but monthly of ET_{ave} had less significant of change. Discharge indicated positive but less significant of change. This pattern was also occured in soil water storage but the trend of change was negative or in the opposite of discharge change.

Based on the analysis of Mann-Kendall, it could be concluded that the increasing of maximum temperature, decreasing of rainfall, increasing of relative humidity, and the consequences to the increasing of maximum evapotranspiration [9] were as the indicator of climate exchange in Bangga watershed, but this conclusion might be different if the period had been changed. It was similarly with if the whole data was limited by available data of river discharge (1995-2011), the result might indicate the different thing. So it was very necessary to remember that time period and number of time series data in the same quantity for all of climate data which would be analyzed. Level of significant also influenced the analysis result.

To know the effect of climate change and how the influence toward discharge (Q) and change of water storage (dS), it's needed graphic correlation between yearly rainfall with discharge, evapotranspiration and the change of water storage, as can be seen in figure 3.

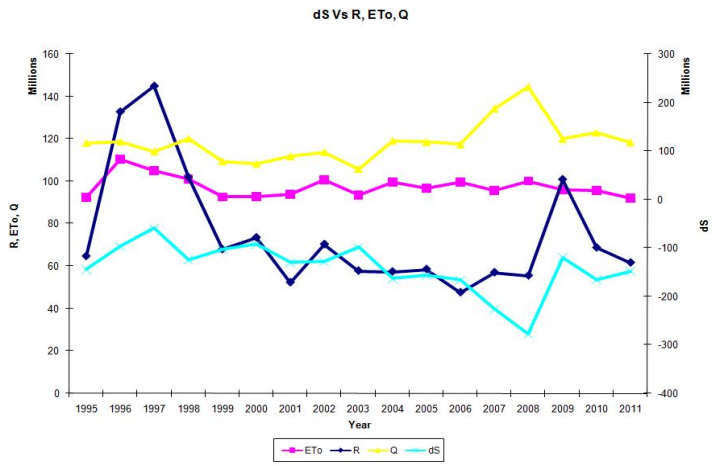


Figure 3 The correlation between the change of water storage with yearly rainfall, discharge and evapotranspiration

As can be seen that the possibility of the climate change was occurred after 1998 with anomaly rainfall at year 1995 and year 2009 but this situation do not influence the change of water storage significantly.

Table 2 Recapitulation of climate change based on Mann-Kendall Method

Uraian	From	To	n	Trend											
				Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nop	Dec
T (°C)															
Test Z, max	1980	2011	32	3.16	3.83	3.53	3.84	3.88	3.99	3.78	3	4.08	3.58	4.46	4.28
				Pos and YS	Pos and YS	Pos and YS	Pos and YS	Pos and YS	Pos and YS	Pos and YS	Pos and YS	Pos and YS	Pos and YS	Pos and YS	Pos and YS
Test Z, min	1980	2011	32	-0.8	-1.7	-2.66	-1.28	0.68	1.26	-0.3	-0.55	-0.49			
				Neg but NS	Neg and YS	Neg and YS	Neg but NS	Pos but NS	Pos but NS	Neg but NS	Neg but NS	Neg but NS			
Test Z, ave daily-1	1980	2011	32	1.67	0.15	1.07	1.79	2.26	1.77	2.21	1.66	2.74	0.6	1.12	2.13
				Pos and YS	Pos but NS	Pos but NS	Pos and YS	Pos and YS	Pos and YS	Pos and YS	Pos and YS	Pos and YS	Pos but NS	Pos but NS	Pos and YS
Test Z, ave daily-2	1980	2011	32	2.84											
				Pos and YS											
RH (%)															
Test Z, max				2.83	3.18	3.95	2.92	3.09	2.75	3.46	4.33	2.48	4.6	3.32	3.51
	1980	2011	32	Pos and YS	Pos and YS	Pos and YS	Pos and YS	Pos and YS	Pos and YS	Pos and YS	Pos and YS	Pos and YS	Pos and YS	Pos and YS	Pos and YS
Test Z, min				3.85	3.58	4.01	3.53	3.45	2.07	4.39	3.92	2.85	3.16	2.98	2.42
	1980	2011	32	Pos and YS	Pos and YS	Pos and YS	Pos and YS	Pos and YS	Pos and YS	Pos and YS	Pos and YS	Pos and YS	Pos and YS	Pos and YS	Pos and YS
Test Z, ave daily-1				3.75	3.8	3.81	4.04	3.31	2.63	3.94	3.62	2.82	4.58	3.54	3.76
	1980	2011	32	Pos and YS	Pos and YS	Pos and YS	Pos and YS	Pos and YS	Pos and YS	Pos and YS	Pos and YS	Pos and YS	Pos and YS	Pos and YS	Pos and YS
Test Z, ave daily-2				3.81											
	1980	2011	32	Pos and YS											
W (km/d)															
Test Z, max				0.18	-0.1	0.57	1.9	1.9	0.32	-0.29	-0.67	-0.6	-0.92	0.31	-1.23
	1980	2011	32	Pos but NS	Neg but NS	Pos but NS	Pos and YS	Pos and YS	Pos but NS	Neg but NS	Neg but NS	Neg but NS	Neg but NS	Pos but NS	Neg but NS
Test Z, min				-2.73	-0.89	-1.02	-2.47	-0.54	-1.43	-0.99	-2.53	-2.5	-1.38	-2.13	-2.21
	1980	2011	32	Neg and YS	Neg but NS	Neg but NS	Neg and YS	Neg but NS	Neg but NS	Neg but NS	Neg and YS	Neg and YS	Neg but NS	Neg and YS	Neg and YS
Test Z, ave daily-1				-1.1	-0.93	-0.47	0.31	0.18	-1.48	-2.08	-0.99	-1.83	-0.68	-1.36	-0.96
	1980	2011	32	Neg but NS	Neg but NS	Neg but NS	Pos but NS	Pos but NS	Neg but NS	Neg and YS	Neg but NS	Neg and YS	Neg but NS	Neg but NS	Neg but NS
Test Z, ave daily-2				-1.49											
	1980	2011	32	Neg but NS											
SH (%)															
Test Z, max				1.78	0.34	0.72	0.05	-0.1	-0.6	-0.95	1.42	0.83	2.16	3.1	2.49
	1980	2011	32	Pos and YS	Pos but NS	Pos but NS	Pos but NS	Neg but NS	Neg but NS	Neg but NS	Pos but NS	Pos but NS	Pos and YS	Pos and YS	Pos and YS
Test Z, min				0.85	-0.31	-1.15	-1.01	0.23	-1.16	-0.44	-1.62	-0.24	-2.28	-1.04	0.26
	1980	2011	32	Pos but NS	Neg but NS	Neg but NS	Neg but NS	Pos but NS	Neg but NS	Neg but NS	Neg but NS	Neg but NS	Neg and YS	Neg but NS	Pos but NS
Test Z, ave daily-1				1.05	0.36	-1.1	-0.94	0.57	-0.36	-1.8	-1.49	-1.43	-1.25	0.75	0.02
	1980	2011	32	Pos but NS	Pos but NS	Neg but NS	Neg but NS	Pos but NS	Neg but NS	Neg and YS	Neg but NS	Neg but NS	Neg but NS	Pos but NS	Pos but NS
Test Z, ave daily-2				-0.78											
	1980	2011	32	Neg but NS											
R (mm/d)															
Test Z, max				0.21	0.04	0.07	-0.67	-1.12	-0.98	-0.14	0.91	-1.54	-1.82	-0.21	0.63
	1993	2011	19	Pos but NS	Pos but NS	Pos but NS	Neg but NS	Neg but NS	Neg but NS	Neg but NS	Pos but NS	Neg but NS	Neg and YS	Neg but NS	Pos but NS
Test Z, min				0.81	1.98	0.07	0.32	-1.2	0.11	0.25	0	-0.32	-1.31	-0.04	-0.07
	1993	2011	19	Pos but NS	Pos and YS	Pos but NS	Pos but NS	Neg but NS	Pos but NS	Pos but NS	NT	Neg but NS	Neg but NS	Neg but NS	Neg but NS
Test Z, ave daily-1				-1.26	-2.03	-1.58	-2.14	-2.56	-1.68	-2.66	-1.58	-3.08	-3.19	-2.98	-1.61
	1993	2011	19	Neg but NS	Neg and YS	Neg but NS	Neg and YS	Neg and YS	Neg and YS	Neg and YS	Neg but NS	Neg and YS	Neg and YS	Neg and YS	Neg but NS
Test Z, ave daily-2				-2.73											
	1993	2011	19	Neg and YS											
Test Z, monthly				0	-0.46	-0.14	-0.81	-0.77	-0.98	-0.42	0.14	-0.98	-2.38	-0.56	0.91
	1993	2011	19	NT	Neg but NS	Neg but NS	Neg but NS	Neg but NS	Neg but NS	Neg but NS	Pos but NS	Neg but NS	Neg and YS	Neg but NS	Pos but NS
Test Z, ave monthly				-0.95											
	1993	2011	19	Neg but NS											
Test Z, yearly				-0.95											
	1993	2011	19	Neg but NS											
Potensial Evapotranspiration (ET, mm/d)															
Test Z, max				3.11	2.68	1.93	3.49	2.98	3.26	2.24	2.48	3.78	2.69	3.07	3.81
	1980	2011	32	Pos and YS	Pos and YS	Pos and YS	Pos and YS	Pos and YS	Pos and YS	Pos and YS	Pos and YS	Pos and YS	Pos and YS	Pos and YS	Pos and YS
Test Z, min				-2.31	-1.23	-1.59	-2.59	-0.84	-2.08	-1.01	-2.76	-1.85	-3.16	-2.19	-1.87
	1980	2011	32	Neg and YS	Neg but NS	Neg but NS	Neg and YS	Neg but NS	Neg and YS	Neg but NS	Neg and YS	Neg and YS	Neg and YS	Neg and YS	Neg and YS
Test Z, ave daily-1 / monthly				0.55	-0.13	-1.27	-2.22	-0.19	-0.26	-2.29	-1.41	-1.3	-1.4	-0.23	0.37
	1980	2011	32	Pos but NS	Neg but NS	Neg but NS	Neg and YS	Neg but NS	Neg but NS	Neg and YS	Neg but NS	Neg but NS	Neg but NS	Neg but NS	Pos but NS
Test Z, ave daily-2 / monthly				-1.31											
	1980	2011	32	Neg and YS											
Dischage (Q, m^3/s)															
Test Z, max				2.03	0.81	0.32	1.67	0.18	0.9	0.99	0.72	0.59	0.5	0.63	1.22
	1995	2011	16	Pos and YS	Pos but NS	Pos but NS	Pos and YS	Pos but NS	Pos but NS	Pos but NS	Pos but NS	Pos but NS	Pos but NS	Pos but NS	Pos but NS
Test Z, min				2.31	2.08	2.04	1.36	1.31	1.31	1.22	1.49	1.72	1.08	1.23	2.34
	1995	2011	16	Pos and YS	Pos and YS	Pos and YS	Pos but NS	Pos but NS	Pos but NS	Pos but NS	Pos but NS	Pos and YS	Pos but NS	Pos but NS	Pos and YS
Test Z, rerata harian-1				2.64	2.03	1.46	1.66	0.74	1.19	1.57	1.9	1.16	1.07	1.25	2.15
	1995	2011	16	Pos and YS	Pos and YS	Pos but NS	Pos and YS	Pos but NS	Pos but NS	Pos but NS	Pos and YS	Pos but NS	Pos but NS	Pos but NS	Pos and YS
Test Z, rerata harian-2				1.52											
	1995	2011	16	Pos but NS											
Water storage (dS)															
Test Z, max				-0.23											
	1995	2011	16	Neg but NS											
Test Z, min				-1.58											
	1995	2011	16	Neg but NS											
Test Z, average				-3.11											
	1995	2011	16	Neg and YS											
Test Z, sum				-2.75											
	1995	2011	16	Neg and YS											

where:

Pos	=	Positif atau increasing trend	$Z_{cal} > Z\alpha$ ..... Yes significant (YS)	
Neg	=	Negatif atau decreasing trend		
YS	=	Yes significant	$Z_{cal} < Z\alpha$ ..... No significant (NS)	
NS	=	No significant		
NT	=	No trend	$Z = 0$ ..... No trend (NT)	

Table Z of normal standard

$Z_{0.001} = 3{,}292$ ..... $\alpha = 0{,}1\%$

$Z_{0.01} = 2{,}576$ ..... $\alpha = 1\ \%$

$Z_{0.05} = 1{,}96$ ..... $\alpha = 5\%$

$Z_{0.1} = 1{,}645$ ..... $\alpha = 10\%$

Estimation of water discharge

This study intended to find there was or would be the discharge change caused by local climate change. Therefore, it was nacessary to be found the relation among discharge by considering rainfall and evapotranspiration. Based on the yearly data (1995-2011) of rainfall, evapotranspiration, and discharge, it was obtained the linear relation of Q' = 0,449 R + 1,72 E – 1254,666. This formula could be used as model predictor of discharge due to rainfall and evapotranspiration. The correlation between observed data (Q) and estimation data (Q') was presented as in Figure 4. The left of Figure 4 showed that evapotranspiration was almost not changed due to the time, rainfall was fluctuated and had the decreasing trend, but discharge was fluctuated and had the trend of significant enough increasing, and the peak was occured in the year of 2008. It indicated that though the increasing of rainfall and evapotranspiration was not significant increasing, but the discharge had significant enough of increasing, it meaned that there was the other factor as the cause. The right of Figure 4 indicated that the relation between historical data (Q) and prediction data (Q') with relative small of R^2 indicated the less good of correlation. It might be caused by the other factors as well as rainfall and evapotranspiration which influenced discharge [10].

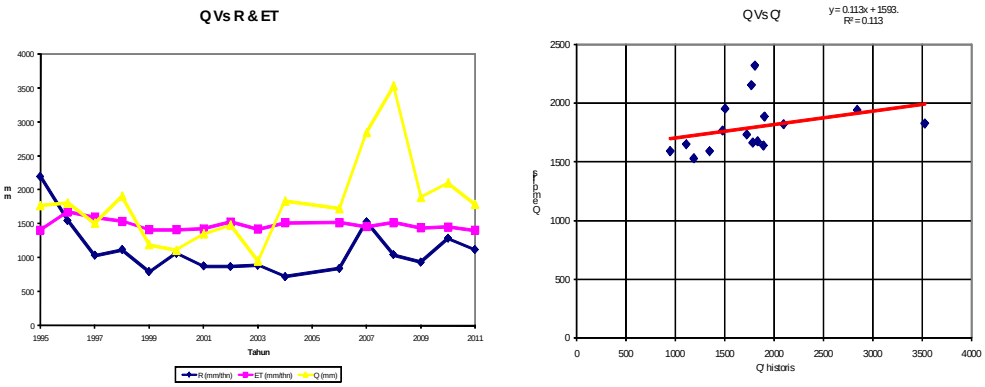


Figure 4 The correlation between discharge and rainfall & evapotranspiration and between historical and empirical data

Trend of water discharge and soil water storage

The left of Figure 4 showed historical discharge data (1995-2011) and the projection of change until 2030. Soil water storage change (dS) was straight comparated with rainfall (R) and contrary compared with evapotranspiration (ET) and discharge (Q). The similar condition was also occured in the right of Figure 5, which soil water change (dS) was contrary comparated with discharge (Q), it meaned that the bigger discharge and evapotransporation would cause the smaller soil water storage change [11]. There was interesting occurrance in the left of Figure 5 that was the relation between discharge and rainfall which the more decreasing of rainfall would cause the bigger discharge. It indicated that discharge could not only be influenced by the factors of rainfall and evapotranspiration but there was also influenced by the other factor such as land cover [11][12].

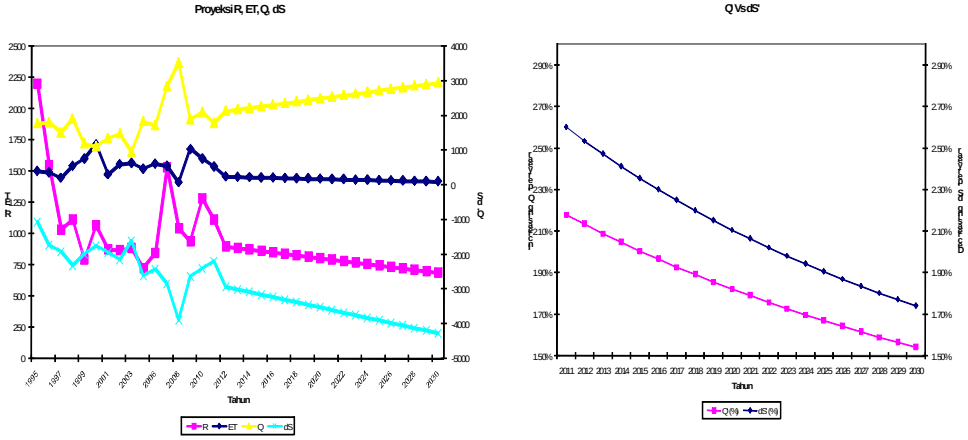


Figure 5 Prediction of rainfall, evapotranspiration, discharge, and soil water storage

CONCLUSION

Based on the daily, monthly, and yearly measurement and analysis in the period of 1980 until 2011 using Mann-Kendall Method, it could be concluded that there was climate exchange in Bangga watershed. The changes could be seen from the slowly increasing of temperature, decreasing of rainfall, and increasing of evapotranspiration. The phenomenon of climate exchange was very clear in the decreasing of average rainfall and increasing of daily maximum evapotranspiration which indicated dry season occured in the watershed and gave impact in river discharge and soil water storage.

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