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EFFECTS OF CLIMATE CHANGE ON THE HAZARDS OF FLOODS, DROUGHT AND DECLINING WATER SUPPLY IN THE DOLAGO WATERSHED, PARIGI MOUTONG DISTRICT, CENTRAL SULAWESI, INDONESIA

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ABSTRACT

The utilization of water for various purposes continues to increase from year to year as a result of the rapid rate of population growth and the development of human activities. The availability of water decreases and even tends to be increasingly scarce, mainly due to the decrease in environmental quality and quality due to pollution as a result of climate change. This research was conducted to determine and identify the dangers of climate change to the water sector that occurs in the Dolago Watershed. The analytical method used is Penman Monteith's evapotranspiration, water balance analysis of the F.J Mock model, climate change detection and projection using the Makesens model, Cumulative Distribution Frequency (CDF) statistical analysis and weighting of hazard levels. The data used in the form of rainfall data from the Dolago Dam and Dolago Padang rain stations in 1993-2018 (26 years) and Olaya Station climatology data in 1993-2018 (26 years). The results showed that climate change had occurred in the Dolago watershed, which was marked by the value of $Z \neq 0$. There was a very high decrease in water availability for all periods except the 2013-2022 periods which was classified as moderate. Potential flood hazards increase for each decade. Drought has occurred for all periods with very high potential. With climate change occurring at the study site, there will be a significant potential for drought in the dry season and a potential flood hazard that continues to increase throughout the year.

Keywords: climate change, water sector, hazard level, dolago watershed.

1. INTRODUCTION

Climate change affects the hydrological process that occurs in the watersheds, and the flow of the river. The available water discharge is very influential in the continuity of life. Increased population density is the main driver of water demand; meanwhile, the availability of water is influenced by an increase in evaporation due to an increase in the surface temperature of the earth (Sutapa I. , 2014).

The Dolago watershed in Parigi Moutong District is the second-largest producer of rice granaries in Central Sulawesi Province after Banggai Regency, so water availability is very influential, where the Dolago Irrigation area has a potential area of 2,557 Ha and functional area of 1,990 Ha. In addition to irrigation water needs, the Dolago River is also used as a source of clean water and freshwater fish farming. The problem that often arises in this area is that in the dry season the irrigation area often experiences drought and results in crop failure, whereas in the rainy season floods occur.

The purpose of this study is to detect the presence or absence of climate change in the Dolago watershed in the water sector (decreasing water availability, flood hazards, and drought hazards). Investigations were carried out by calculating evapotranspiration using the Penman Monteith method then analyzing the water balance using the F.J. Mock model. The data used are monthly rainfall and monthly evapotranspiration, resulting in a total runoff (TRO).

2. RESEARCH METHOD

2.1 Research Location

The location of this study is located in the Dolago watershed, Parigi Moutong Regency, Central Sulawesi Province, Indonesia. Geographically located at 120° 30 '-120° 12' East Longitude and 0°12 'South Latitude and 01°30' North Latitude with an area of Dolago watershed 169.24 km². The research location can be seen in the following map:

Figure-1. Research location.

2.2 Supporting Data

The data used in this study are secondary data obtained from the Sulawesi River Region Regional Office in Palu, Central Sulawesi. The data is in the form of daily rainfall data and climatology data. The closest rain station locations for the Dolago watershed are Dolago Dam Station and Padang Dolago Station, while the climatology data uses Olaya Station. The hydroclimatological data (rain and climatology) were observed from 1993-2018 (26 years).

2.3 Research Stages

To investigate the effect of climate change on the water sector, the following stages are carried out:

a) Regional rainfall

Regional rainfall is calculated using algebraic mean (Nugroho, 2011).

$$P = (P1 + P2 + P3 + \ldots\ldots + Pn)/n \qquad (1)$$

b) Detection of climate change

Analysis of trends and climate projections using the Mann-Kendall-Sens (Makesens) method with rainfall data (maximum daily, monthly and annual). Resulting in a value of "Z" which indicates the presence or absence of climate change and producing a projected TRO value for the next few years (Sutapa, I W.; Ishak, M. Galib, 2016) (Sutapa, I W.; Bisri, Moh.; Rispiningtati; Montarcih, Lily, 2013) (Sutapa I. , 2014) (Sutapa W. , 2015a) (Sutapa I. , 2015b) (Sutapa I. W., 2015c) (Sutapa W. , 2017) (Hakan, Aksu; Kuşçu, Savaş; Şimşek, Osman, 2010) (Timo, S; Anu, M.; Pia, A.; Tuija, R.A.; Toni, A., 2002):

$$s = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sgn}(X_j - X_k) \qquad (2)$$

$$\sigma s = \sqrt{n\,(n-1)(2n+5)/18} \qquad (3)$$

$$Z = 0 \text{ if} S = 0 \begin{cases} (S - 1)/\sigma s \text{ if} S > 0 \\ (S + 1)/\sigma s \text{ if} S < 0 \end{cases} \qquad (4)$$

Where Xj and Xk are the data values for "j" and "k", j> k. After detecting whether there is an increase or decrease trend with the Mann Kendall test, then to determine the magnitude of the trend non-parametric Sen's method is used with the assumption that the trend is linear. The procedure starts from equations 2 to 4. The two methods are combined so they are called the Makesens method.

$$f(t) = Qt + B \qquad (5)$$

where: Q is slope and B is a constant. To obtain the estimated slope Q in equation (5), it is first necessary to calculate the slope for all data with the equation:

$$Qi = \frac{Xj - Xk}{j - k} \qquad (6)$$

where is j> k. If there is an "n" value of "Xj" in the time series, then N = n (n-1) / 2 slope of Qi estimation is obtained. Slope Sens estimation is the median of N Qi values. The N value of Qi is ranked from small to large, with the estimated Sens being:

$$Q = Q[(N+1)/2] \text{ if N is odd or } Q = 0{,}5\,(Q(N/2) + Q((N+2)/2)) \text{ if N is even} \qquad (7)$$

To obtain estimation B in equation (5), the n data values of the difference (Xi - Q.ti) are calculated. The median of this value is estimate B.

c) Potential evapotranspiration

Evapotranspiration analysis using the Penman Monteith method. The equation used is: (Ansari, Sutapa, & Ishak, 2017) (Sutapa, I W.; Ishak, M. Galib, 2016) (Richard, 1998) (Sutapa, I W.; Bisri, Moh.; Rispiningtati; Montarcih, Lily, 2013) (Sutapa I. , 2014) (Sutapa W. , 2015a) (Sutapa I. , 2015b) (Sutapa I. W., 2015c) (Sutapa W. , 2017):

$$ET_0 = \frac{0{,}408\Delta Rn + \gamma \frac{900}{(T+273)} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0{,}34U_2)} \quad (8)$$

d) Water balance

Water balance analysis uses the water balance model Dr.FJ. Mock (Mock, 1973). The calculation stages are:

A. Rainfall

Monthly rain value (R) is obtained from recording monthly rain data (mm) and the number of rainy days in the month (h)

B. Evapotranspiration

Limited evapotranspiration is actual evapotranspiration taking into account the condition of vegetation and land surface so that the equation is as follows:

$$E = ETo^* \times \frac{d}{30}.m \quad (9)$$

The number of semi-monthly dry surfaces (d) is calculated assuming that the soil in one day is only able to hold water 12 mm and always evaporate by 4 mm. Based on the frequency of rainfall in Indonesia and the nature of infiltration and evaporation from surface soil, a relationship is obtained:

$d = 3/2\ (18 - h)$ or $d = 27 - 3/2\ h$ (10)

h = the number of rainy days in a month

Then substitute the equation above so that we get:

$E / ETo^* = m/20\ (18 - h)$ (11)

$E = ETo^* \times (m/20 \times (18 - h))$ (12)

$ET = ETo^* - E$ (13)

ET = Unlimited evapotranspiration

Soil water surplus is the volume of water that will enter the soil surface.

Soil water surplus = (P - ET) - soil storage (14)

Soil water surplus = 0 if deficit, that is: (P - ET) > soil storage

C. Balance the water at the ground surface

Water balance at the ground surface is calculated based on the amount of monthly rainfall minus the value of a limited monthly average evapotranspiration to obtain an equation:

$\Delta S = P - ET$ (15)

Water Surplus (WS) is the volume of water that will enter the surface of the land, namely:

$WS = \Delta S - SS$ and $WS = 0$ if $\Delta S < SS$ (16)
$WS = 0$ if $\Delta S < SS$

D. Groundwater storage

The amount of runoff and groundwater depends on the balance of water and soil conditions. Data needed is:

The infiltration coefficient (I) is taken 0.2 - 0.5

Recession factor groundwater flow (k) taken 0.4 - 0.7

Equation:

$In = WS \times I$ (17)

$Vn = k \cdot V_{n-1} + 0{,}5\ (1 + k).\ In$ (18)

$\Delta Vn = Vn - V_{n-1}$ (19)

e) River flow

Base Flow (BF) = Infiltration (I) - changes in groundwater volume (ΔVn) (20)

Direct Run-Off (DR) = water surplus (WS) - Infiltration (I) (21)

Discharge = Base Flow (BF) + Direct Run-Off (DR) (22)

E. Hazards Potential and its Analysis Method

The analytical method used is FJ. Mock and Cumulative Distribution Frequency (CDF) statistical analysis. In this case, it is used (BAPPEDA, 2009):

a) CDF analysis of TRO data (total runoff) as a result of FJ. Mock analysis for rainfall and temperature data in normal climatic conditions for hazard analysis of decreased water availability.

b) CDF analysis of TRO data (total runoff) as a result of FJ. Mock analysis for rainfall and temperature data in above normal climate conditions for flood hazard analysis.

c) CDF analysis of TRO data (total runoff) as a result of FJ. Mock analysis for rainfall and temperature data in sub-normal climatic conditions for drought hazard analysis.

a. Hazards of reducing water supply

The danger of decreasing water availability is analyzed by looking at reducing TRO under projected conditions against baseline conditions. Then, the hazard is given weight to determine the degree of danger in each period. The weights of the danger of decreasing water availability (PKA) can be explained as follows:

- Weight 1: There is no dangerPKA (0 < decease TRO < 50 mm/year)
- Weight 2:Low PKA danger (50 mm/y ≤ decrease TRO < 100 mm/year)
- Weight 3:The danger of PKA is being (100 mm/y ≤ decrease TRO < 150 mm/year)
- Weight 4:The danger of high PKA (150 mm/y ≤ decrease TRO < 200 mm/year)
- Weight 5:The danger of PKA is very high (decrease TRO ≥ 200 mm/year)

b. Flood hazards

Potential flooding in terms of hydroclimatology is above normal rainfall. Flood hazard identification is done based on the CDF analysis approach to total runoff (TRO) data from FJ. Mock results. The weight of a flood hazard can be explained as follows:

- Weight 1: The hazard of flooding is very low (0 < increase TRO < 75 mm/year)
- Weight 2: Low flood hazard (75 mm/y ≤ increase TRO < 150 mm/year)
- Weight 3: The hazard of moderate flooding (150 mm/y ≤ increase TRO < 225 mm/year)
- Weight 4: High flood hazard (225 mm/y ≤ increase TRO < 300 mm/year)
- Weight 5: The hazards of flooding are very high (increase TRO ≥ 300 mm/year)

c. Drought hazards

Under normal climate patterns, in this case, rainfall below average can be identified as a drought hazard. Drought hazard identification is carried out based on the CDF analysis approach to total runoff (TRO) data from FJ. Mock results. The drought weights can be explained as follows:

- Weight 1: Drought hazard is very low (0 < decrease TRO < 30 mm/year)
- Weight 2:Low drought hazard (30 mm/y ≤ decrease TRO < 60 mm/year)
- Weight 3:Moderate drought hazard (60 mm/y ≤ decrease TRO < 90 mm/year)
- Weight 4:High drought hazard (90 mm/y ≤ decrease TRO < 120 mm/year)
- Weight 5:Drought hazard is very high (decrease TRO ≥ 120 mm/year)

3. RESULTS AND DISCUSSIONS

3.1 Climate Change Detection

Climate change that occurs is indicated by a negative "Z" value. In the monthly rainfall climate change occurs, where the value of Z ≠ 0 but not all are significant. For annual rainfall, climate change is significant in the negative direction. Whereas for maximum daily rainfall climate change occurs in a negative direction but not significant. The full results are presented in Table-1.

Table-1. Results of recapitulation of climate change calculations based on the Mann-Kendall Method.

Rainfall	Year		Mann-Kendall Test Trend											
	From	To	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Daily Max. Rainfall (mm/day)	1993	2018	-0.22 NNS											
Monthly Rainfall (mm/month)	1993	2018	-0.55 NNS	-1.83 NYS	-2.63 NYS	-1.92 NYS	-1.41 NNS	-1.85 NYS	-2.71 NYS	0.42 PNS	0.82 PNS	-0.68 PNS	0.55 NNS	-1.74 NYS
Yearly Ranfall (mm/year)	1993	2018	-1.94 NYS											

Abreviation
PYS = Positive Yes Significant
PNS = Positive No Significant
NYS = Negative Yes Significant
NNS = Negative No Significant
NT = No trend
Table Z for Normal Standard
$Z_{0.1} = 1.645$ ………… $\alpha = 10\%$

$Z_{cal.} > Z\alpha$ …………… Yes Significant (YS)
$Z_{cal.} < Z\alpha$ …………… No Significant (NS)
$Z_{cal-} = 0$ ……………… No Trend (NT)

3.2 Cumulative Distribution Frequency (CDF)

The CDF value is connected to the TRO parameter value so that a table and graph are obtained between the TRO parameter value from the minimum value to the maximum value with the CDF percentage value from 0-1. The results are shown in Table-2 and Figure-2. To find out more about the potential danger of decreasing water availability (PKA), flooding and drought hazards in the Dolago watershed, the total runoff value (TRO) was arranged into 6 decades.

The results are presented in the following Table and Figure.

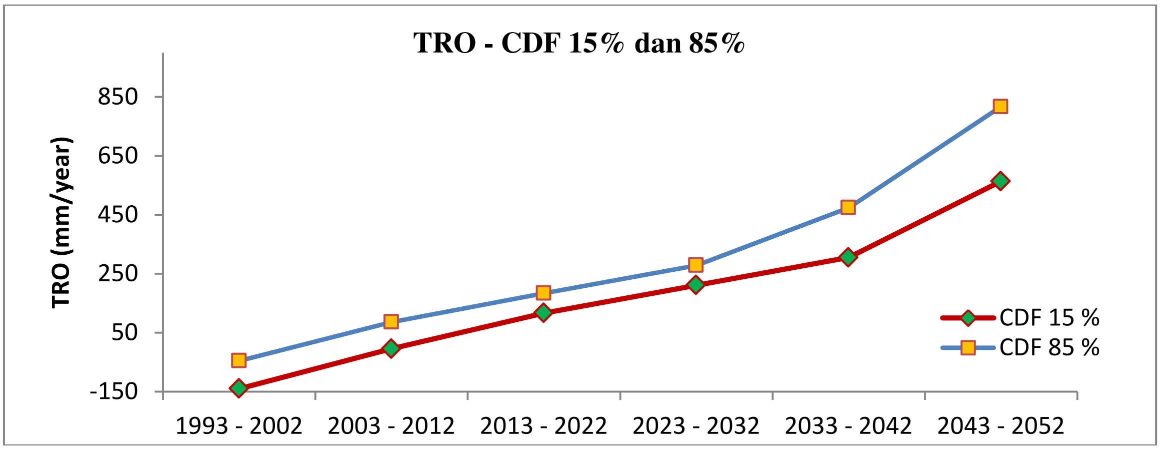

Figure-2. Total Runoff (TRO) - Cumulative Distribution Frequency (CDF).

Table-2. Total *Runoff* (TRO) - Cumulative Distribution Frequency (CDF).

No.	**TRO (mm/year)**	**TRO (mm/year) Rank**	**CDF**	**No.**	**TRO (mm/year)**	**TRO (mm/year) Rank**	**CDF**
	1993 - 2072	**1993 - 2072**			**1993 - 2072**	**1993 - 2072**	
1	583.126	-146.883	0.017	31	244.820	204.299	0.517
2	718.549	-133.376	0.033	32	231.313	217.806	0.533
3	777.755	-119.869	0.050	33	217.806	231.313	0.550
4	749.156	-106.362	0.067	34	204.299	237.954	0.567
5	404.128	-92.855	0.083	35	190.792	243.670	0.583
6	237.954	-79.348	0.100	36	177.285	244.820	0.600
7	157.592	-65.841	0.117	37	163.778	258.327	0.617
8	762.207	-52.334	0.133	38	150.271	271.834	0.633
9	659.979	-38.827	0.150	39	136.764	285.341	0.650
10	543.984	-25.320	0.167	40	123.257	296.556	0.667
11	872.159	-11.813	0.183	41	109.750	298.848	0.683
12	485.936	1.694	0.200	42	96.243	311.386	0.700
13	856.722	15.201	0.217	43	82.736	322.347	0.717
14	311.386	28.708	0.233	44	69.229	348.545	0.733
15	138.811	42.215	0.250	45	55.722	361.126	0.750
16	322.347	55.722	0.267	46	42.215	404.128	0.767
17	89.382	69.229	0.283	47	28.708	411.771	0.783
18	348.545	82.736	0.300	48	15.201	471.722	0.800
19	471.722	89.382	0.317	49	1.694	476.811	0.817
20	411.771	96.243	0.333	50	-11.813	485.936	0.833
21	687.268	109.750	0.350	51	-25.320	543.984	0.850
22	296.556	123.257	0.367	52	-38.827	583.126	0.867
23	243.670	136.764	0.383	53	-52.334	659.979	0.883
24	202.242	138.811	0.400	54	-65.841	687.268	0.900
25	361.126	150.271	0.417	55	-79.348	718.549	0.917
26	476.811	157.592	0.433	56	-92.855	749.156	0.933
27	298.848	163.778	0.450	57	-106.362	762.207	0.950
28	285.341	177.285	0.467	58	-119.869	777.755	0.967
29	271.834	190.792	0.483	59	-133.376	856.722	0.983
30	258.327	202.242	0.500	60	-146.883	872.159	1.000

Table-3. TRO - CDF 15% and 85% for all decades.

No.	Year	Total Runoff (TRO)	
		CDF 15%	CDF 85%
1	1993 - 2002	-140.130	-45.581
2	2003 - 2012	-5.060	86.059
3	2013 - 2022	116.504	184.039
4	2023 - 2032	211.053	278.588
5	2033 - 2042	305.117	474.267
6	2043 - 2052	563.555	817.239

3.3 Potential Water Sector Hazards

In this research three potential hazards were analyzed as a result of climate change, namely: the hazards of decreased water availability (PKA), the hazards of flooding and the hazards of drought.

3.3.1 Hazards of reducing water supply (PKA)

The results of the water balance (WB) analysis of the F.J Mock model then it can be known the hazards of decreased water availability (PKA) in the Dolago watershed under projected conditions to baseline conditions with a CDF of 15%. The results of the calculations are shown in Table-4.

Table-4. Hazards PKA dan weight hazards (TRO - CDF 15%).

No	Year	Period	TRO (mm/year)	Hazard Indications	Hazard Weight
1	2003 - 2012	Baseline	-5.060	0	1
2	2013 - 2022	Projection	116.504	121.563	3
3	2023 - 2032	Projection	211.053	216.112	5
4	2033 - 2042	Projection	305.117	310.177	5
5	2043 - 2052	Projection	563.555	568.615	5

The hazard weight is filled in value according to the hazard criteria for decreasing water availability. From Table-4 it can be said that there was a decrease in water availability for all projection periods with a very high category except in the 2013-2022 period where the decrease in water availability was classified as moderate.

3.3.2 Flood hazards

The results of the water balance (WB) analysis of the F.J Mock model then can be known as the hazards of flooding that occurs in accordance with the increase in projected TRO to the baseline with a CDF of 85%. The results of the calculations are shown in Table-5.

Table-5. Flood hazards and weight hazards (TRO - CDF 85%).

No	Year	Period	TRO (mm/year)	Hazard Indications	Hazard Weight
1	2003 - 2012	Baseline	86.059	0	1
2	2013 - 2022	Projection	184.039	97.980	2
3	2023 - 2032	Projection	278.588	192.529	3
4	2033 - 2042	Projection	474.267	388.208	5
5	2043 - 2052	Projection	817.239	731.180	5

The hazard weight is filled in value according to the flood hazard criteria. From Table-5 it can be said that the potential for flood hazards increases for every decade. The period of 2013-2022 the potential for flood hazard is low, the period of 2023-2032 the potential for moderate flood hazard and the period of 2033-2042 and the period of 2043-2052 the potential for hazards is very high.

3.3.3 Drought hazards

The results of the water balance (WB) analysis of the F.J Mock model can then be analyzed by the drought hazards that occur in the Dolago watershed. Drought hazards are formulated by looking at reducing TRO under projected conditions to baseline conditions with a CDF of 15%. The results of the calculations are shown in Table-6.

Table-6. Drought hazards and weight hazards (TRO - CDF 15%).

No	Year	Period	TRO (mm/year)	Hazard Indications	Hazard Weight
1	2003 - 2012	Baseline	-5.060	0	1
2	2013 - 2022	Projection	116.504	121.563	5
3	2023 - 2032	Projection	211.053	216.112	5
4	2033 - 2042	Projection	305.117	310.177	5
5	2043 - 2052	Projection	563.555	568.615	5

Hazard's weight is filled in value according to drought hazard criteria. From Table-6 it can be explained that there has been a drought for all periods with very high potential.

4. CONCLUSIONS

Based on the data and analysis that has been done, it can be concluded: 1). There has been a climate change at the study site marked by the value of "Z" $\neq 0$; 2). There was a decrease in water availability for all projection periods with a very high category except in the period 2013-2022 where the decrease in water availability was classified as moderate; 3). Potential flood hazards increase for each decade. The period of 2013-2022 the potential for flood hazard is low, the period of 2023-2032 the potential for moderate flood hazard and the period of 2033-2042 and the period of 2043-2052 the potential for hazards is very high; 4). Drought has occurred for all periods with very high potential. With climate change occurring at the study site, there will be a significant potential for drought in the dry season and a potential flood hazard that continues to increase throughout the year.

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