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Management Strategy of Water Resources Base on Rainfall Characteristics in The Semi-Arid Region in Indonesia

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Abstract — Every area has its own rainfall characteristics, which needs to be analyzed for the shake of water management in a particular areas such as Kupang whose location lies in the semi-arid area in the Indonesian archipelago. This study assesses rain characteristics by means of indicators of hydrology alteration. Results analysis from five rain stations reveal that rain fall intensity is high within a very short time interval. Generally, there is an increasing of rainfall magnitude, rainy days, and maximum daily rainfall, although there are also stations experiencing decrease. During rainy season, the area is mostly wet, in reverse to the dry season where the site is completely dry. This is to imply that rainwater run-off is very high, in one hand while on the other hand infiltration of ground water in very low. As a result, flood and dryness could not be avoided. Building reservoirs or ponds might be one of the solutions of water management in the researched area for the purpose of harvesting more rain water during brief rainy season period for use in the long drought time. This research study should facilitate users of water management institution to continuously comprehend, not only the risks but also resistances in rainfall characteristics in this researched area.

Index Terms— Indicators of hydrology alteration, Indonesia, Rainfall, Semi-arid, Tilong, Water resources management.

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1 Introduction

Water cycle that occurs in the earth is known as hydrologic cycle caused by the processes that follow the meteorological and climatological indications [1, 2]. The main components of the hydrological cycle are precipitation, and discharge, which become important parameters in input of water resources infrastructure planning and management [3]. The Earth's global climate change has an impact on the extreme weather and climate conditions, both on regional scale in Indonesia, as well as on local scale [4] included in the study area. The occured changes could potentially affect the management of water resources in the present and future.

Climate and rainfall patterns in Indonesia spatially have different variations [5], and this was due to its territory which is in the form of islands and is located in the tropics area [6]. The uniqueness of Indonesian climate and rainfall patterns is also influenced by its position which lies between two oceans and two continents. Climate element that is interesting to be studied in Indonesia is rainfall, because not all Indonesian regions have the same rainfall patterns [5, 7].

Indonesian rainfall patterns are influenced by several factors, such as, monsoon, Inter-tropical Convergene Zone (ITCZ), El Nino - Southern Oscillation (ENSO), and other regional circulations in Pacific and Indian oceans. Aldrian and Susanto [5] and Boerema [7], shows that Indonesia rainfall patterns are divided into three main areas, they are: (i) monsoon region (type A) is the dominant pattern in Indonesia, because it covers almost the entire territory of Indonesia. The area has a peak in November to March (NDJFM), which is influenced by wet northwest monsoon, and a trough in May to September (MJJAS), that is affected by the dry southeast monsoon, so it can be distinguished clearly between dry and rainy seasons, (ii) equatorial region (type B) has two peaks in October to November (ON) and March to May (MAM). This pattern is influenced by a shift to the north and south from ITCZ or equinox point (culmination) of the sun and (iii) local climate region (type C) has a peak in June to July (JJ) and a trough in November to February (NDJF). This pattern is the opposite of pattern A. Boerema [7) show that, Type A region is affected by monsoon, type B by equinox, while type C is a superposition of walker circulatory system, Pacific Ocean tropical cyclones and very complex local conditions.

Dupe [4] show that, Indonesian as an archipelago country causes the influence of received solar radiation on weather patterns vary considerably compared with the tropics or sub-

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tropics continental areas. This condition causes the pressure pattern variations from one island to another and at the top of the island itself. This situation raises the very complex pressure domain and affects the local atmospheric circulation systems such as land-sea breeze, the mountain valley winds and convection cell systems or corridors wind in urban areas that map the local weather. The study area is a monsoon pattern area (type A) [5, 7], as well as semi-arid climate area in Indonesia [8, 9]. FAO [10] mentions that semi-arid areas are characterized by high precentage of potential evapo-transpiration (ETo) which is greater than rainfall, in which the semi-arid regions as part of the arid regions in the world which covers almost 31% of the entire areas on earth.

The issues of quality, quantity, affordability and continuity are fundamental problems in the study area, in the provision of water for people's basic daily needs. From the observations in the study area, it was observed that during the rainy season there are large amounts of water which can even lead to flood, but during the dry season, a very large water deficit occur in the previous area. Subsequent observation is water spring discharge variabilities between rainy and dry season very extreme, even rivers are dry and there is no surface water at all, so that the sustainability of water use by the people becomes constrained. Devit and Morits [11], shows that the sustainable use of water is the use of water that supports the community's ability to survive and thrive into the future which are not limited, without damaging the integrity of hydrological cycle or hydrologic system that depended on it.

Research on rainfall has been established about the time-series of annual rainfall, number of rainy days per-year, and monthly rainfall in 20 rainfall stations to assess regional climate variability in arid and semi-arid of Iran [12]. The results showed a decreasing and increasing trends from 20 rainfall stations were observ [12]. Similar results were also report about the rainfall in China. The research data showed that, each rainfall station has different characteristics [13]. Because of that, understanding the characteristics of rainfall from recorded time series data is essential in the sustainability of water resources management in the future. This research specifically examines the relationship between water resources management and rainfall characterization in Indonesian semi-arid regions, case in Kupang, East Nusa Tenggara Province.

2 MATERIALS AND METHODOLOGY

Series of rainfall data for 34 years (1977-2010) came from five rainfall stations, they are: Lasiana, Tarus, Oekabiti, Camplong and Baun (table 1 and fig. 1). Analysis of rainfall characteristics are performed on each rain station using five indicators of hydrology alteration which consists of magnitude, timing, duration, frequency, and variability.

Statistical analysis was done by descriptive and analytical statistics, it is the calculation:

(a) magnitude of monthly and annual rainfall.
(b) monthly and annual rainfall average.
(c) trends of annual rainfall data for the parameters of the magnitude of annual rainfall, the annual magnitude of rainy days and a maximum daily rainfall that occurred in each year, the method used is the five-year moving average.
(d) temporal variation in annual rainfall variability was analyzed by using the variability index to describe the annual rainfall variability, with the formula:

for positive anomalies,

$$RAI = +3 \frac{[RF-MRF]}{[MH10-MRF]} \quad (1)$$

and for negative anomalies,

$$RAI = -3 \frac{[RF-MRF]}{[ML10-MRF]} \quad (2)$$

where, RAI (rainfall anomaly index) is represents the annual, RF is the actual rainfall for a given, MRF is mean for the total length of record, MH10 is the mean of the 10 highest values of rainfall on record, ML10 is the mean of the 10 lowest values of rainfall on record [14].

Classification of monthly rainfall which is aim to determine the month of wet or dry season in this research is conducted by water availability index approach which is based on FAO [10] with modification, it is:

classification wet months,

$$\frac{P}{ETo} > 1 \quad (3)$$

classification dry months,

$$\frac{P}{ETo} < 1 \quad (4)$$

where, P is rainfall (mm), and ETo is potential evapo-transpiration (mm).

The relationship between the magnitude of rainy days, the rainfall magnitude and rainfall classification is stated in the rainfall intensity that occurred per-day, divided into four kinds, namely [15]: the light rain (0-99 mm per-day), the moderate rain (10-24.99 mm per-day), the heavy rain (25-49.99 mm per-day), and the extreme rain (≥ 50 mm per-day).

The above data analysis method is expect to provide an overview of the results of indicators of hydrology alteration.

TABLE 1
Rainfall stations in study area

Station	Coordinate	altitude asl (m)
Oekabiti	10°12′0.00″ SL; 123°49′59.88″ EL	50
Baun	10°18′0.00″ SL; 123°43′0.12″ EL	370
Lasiana	10°08′19.9″ SL; 123°40′01.6″ EL	20
Tarus	10°7′25.16″ SL; 123°41′0.01″ EL	20
Camplong	10° 3′0.00″ SL; 123°55′59.88″ EL	200

explanation: *SL* is south latitude, *EL* is east longitude

3 Results and Discussion

3.1 Description of Study Area

In this study, Kupang region consists of Kupang district administrative region and Kupang city, located in the western part of Timor Island, East Nusa Tenggara Province (NTT) (fig. 1).

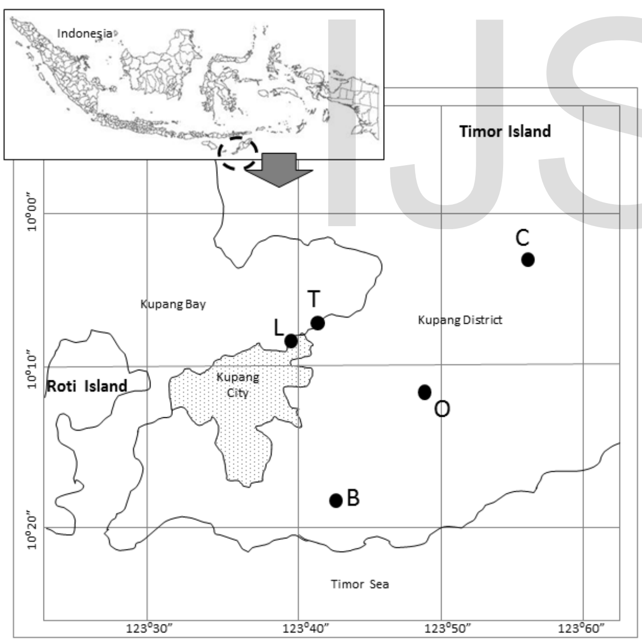

Fig. 1. Rainfall stations in study area (B: Baun, O: Oekabiti, C: Camplong, T: Tarus, L: Lasiana)

NTT Province is one of the 34 provinces in Indonesia today. As other regions in Indonesia, in the study area, there are only two seasons, the dry season and the rainy season. Geographically, the study area which is close to Australian continent, causing the dry southeast trade winds from Australia resulted the study area has less rainfall than other Indonesian regions [6]. Based on the climate types stated by Schmidt-Ferguson, NTT has fairly climate diverse, such as climate type B (wet) 2%, climate type C (moist) 10%, climate type D (slightly moist) 16%, climate type E (slightly dry) 51%, climate type F (dry) 20% and climate type G (very dry) 1%. The rainfall has uneven distribution which tends to gather in a short period [6]. In the world, the study area is known as one of the arid areas [8, 9].

3.2 Annual Rainfall

The results of rainfall analysis which are recorded in five rainfall stations in the study area showed an average rainfall ranges from 1,429 to 1,595 mm per-year (fig. 2). Oekabiti station recorded the highest annual rainfall average is 1,595 mm, higher than all the other four stations. From its location, that Oekabiti station is located in the valley of mountain, in the middle of Timor Island, with a height of 50 m above sea level (asl). Baun station is located in a mountainous area with an altitude of 370 m asl with 1,512 mm per-year. Lasiana and Tarus stations are located in the coastal areas in which Lasiana lies more to the west than Tarus. Rainfall in Lasiana station is 1,507 mm per-year, higher than Tarus station which has 1,458 mm per-year. While Camplong station has the lowest rainfall which is 1,429 mm per-year, and it is located in the eastern part than other rainfall station with a height of 200 m asl.

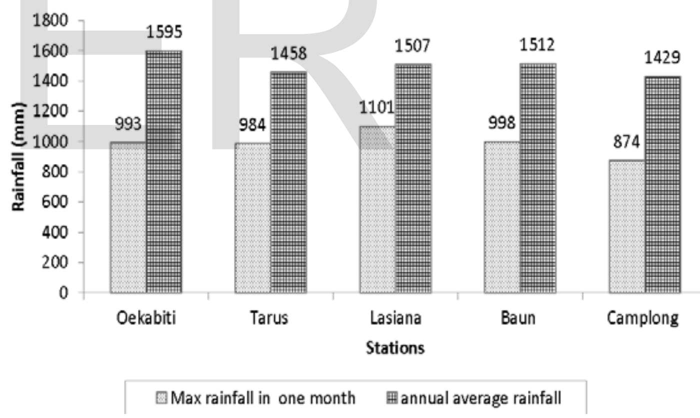

Fig. 2. Average of annual rainfall and the highest magnitude of rainfall that occurred in one month in five rainfall stations in the study area (1977-2010)

The highest rainfall occurs within one month, the range of 874 mm in Camplong station, until 1,101 mm in Lasiana station. This precentage includes about half to three-quarters of rainfall magnitude in a year from each stations in the study area. The remaining half or a quarter of the total rainfall in a year is distributed in the span of other eleven months. The monthly rainfall average is 119 to 133 mm per-month, but in fact the rain only occurs in a short span of time duration which is only about three to four months. If it is observed the annual rainfall during the 34 years of the five rainfall stations, the recorded annual rainfall at Oekabiti station, it is ranging from 877

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up to 2,380 mm. In Tarus station, it is ranging from 912 mm up to 2,609 mm. Lasiana station, from 761 mm up to 2,452 mm. Baun station, from 868 mm up to 3,022 mm. Camplong station, from 783 mm up to 2,046 mm.

Observing the mentioned rainfall data above, shows the high variability of rainfall that occurred in the period of 1997 until 2010, the highest rainfall can reach 3,022 mm per-year and the lowest rainfall only reaches 761 mm per-year. This occurance, is influenced by the El Nino and La Nina which has a strong correlation to the rainfall in Indonesia [4].

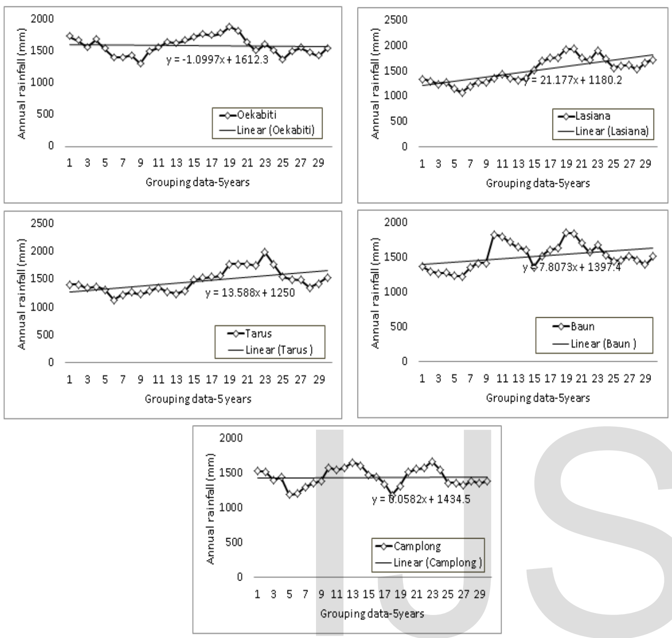

Fig. 3. Trend of annual rainfall with a five-year moving average method (1977-2010)

Rainfall change trend analysis is performed with an annual rainfall data using the five-year moving average method (fig. 3). The results showed that, the rainfall in four stations showed an increasing trend of rainfall, such as in Lasiana, Tarus, Baun and Camplong, while the Oekabiti station tends to decrease. The variability that occurs in rainfall trend is a result of climate change, as proposed by [15, 17] that, in some areas there will be a tendency in changing of rainfall patterns with rainfall increase, although in other areas showed a decline trend. The results of research in Iran arid and semi-arid areas [12], mentions the rainfall increases and decreases mixture trend from the observed 20 rainfall stations. Zhai, et al. [13] reported that the total annual rainfall decreased significantly in the Eastern and North part of South China Sea, but increased significantly in the western part of China, Yangtze River valley and the Southeast coast. The results of this research show that, magnitude of rainfall has different trends in different regions.

3.3 Monthly Rainfall Distribution

The monthly rainfall distribution average in five rainfall stations is shown in fig. 4. The monthly value of potential evapotranspiration (ETo) ranges in the lowest value of 141 mm in February, to a highest value of 262 mm in August, with the annual value of ETo is 2600 mm [18]. The determination of wet and dry month is done with the formula number three and four, based on the obtained data, wet months consist of four months, they are December to March, with the index of water availability is greater than the value of one. Other eight months are the dry months; April to November, with the index of the water availability is smaller than the value of one. According to the classification of Oldeman and Frere [19], there are four wet months they are December to March, and eight dry months they area April to November. From these type of classification, shows that the dominant dry season occurs in the study area.

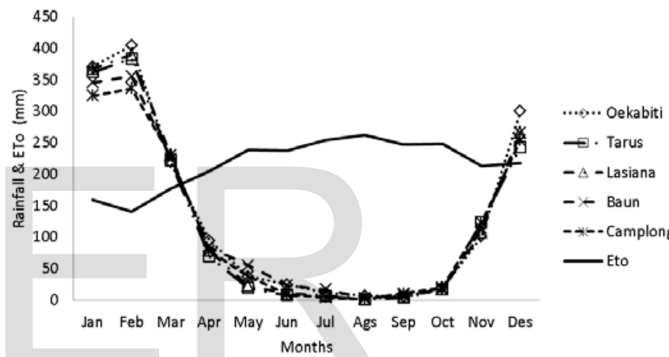

Fig. 4. Distribution of monthly rainfall (1977-2010)

3.4 Number of Rainy Days

The number of rainy days in five rainfall stations ranged from 35 to 144 days in a year. The number of rainy days in Oekabiti station ranged from 56 to 119 days with an average of 79 days per-year. In Tarus station ranged from 35 to 120 days with an average of 82 days per-year. In Lasiana station ranged from 81 to 144 days with an average of 110 days per-year. In Baun station, ranged from 36 to 115 days with an average of 76 days per-year, and Camplong station, ranged from 38 to 113 days with an average of 67 days per-year. From five analyzed rainfall stations, four stations: Oekabiti, Lasiana, Tarus and Baun show the trend of magnitude of rainy days that tend to increase, while Camplong rainfall station showed a decrease trend (fig. 5). The trend difference in the number of rainy days between different regions is different, also reported by [13] that the number of rainy days decreased in almost all parts of China except in areas of China Ocean that have increased.

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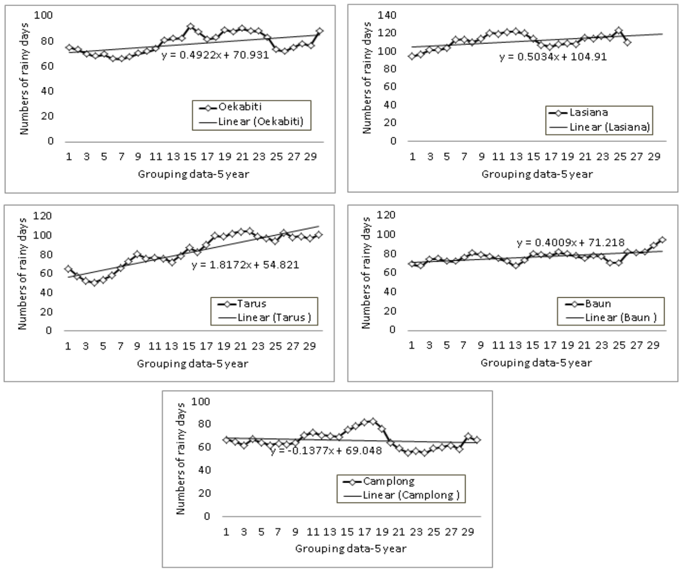

Fig. 5. Trend of number of rainy days with a five-year moving average method (1977-2010)

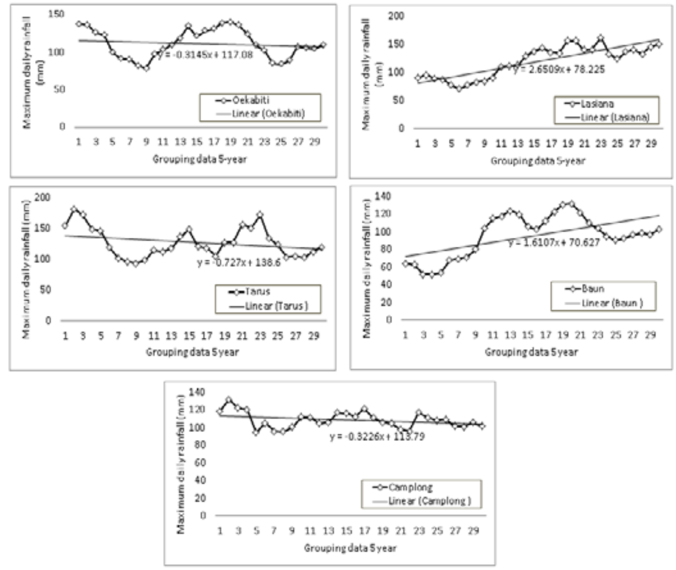

Fig. 6. Trend of maximum daily rainfall with a five-year moving average method (1977-2010)

3.5 Maximum Daily Rainfall

Analysis results of the highest daily maximum rainfall in Oekabiti station occurred in 1980 for 203 mm per-day, and the lowest in 2002 for 60 mm per-day with an average of 113 mm per-day. In Tarus station, the highest rainfall occurred in 1981 for 275 mm per-day and the lowest one in 1985 for 45 mm per-day, with an average of 127 mm per-day. In Lasiana station, the highest rainfall is 256 mm per-day in 1999, and the lowest is in 1985, at 50 mm per-day, with an average of 118 mm per-day. In Baun station, the highest rainfall occurred in 1990 and 1991 for 180 mm per-day, and the lowest one is in 1984 for 51 mm per-day, with an average of 94 mm per-day. Camplong station showed the highest rainfall occurred in 1980 for 200 mm per-day, and the lowest one is in 1998 for 36 mm per-day, with an average of 103 mm per-day. Changes trend in the maximum daily rainfall with a five-year moving average method is shown in fig. 6.

From fig. 6 shows that, there was an increasing trend of the maximum daily rainfall in two stations, they are Lasiana and Baun. While the other three stations: Oekabiti, Tarus and Camplong showed a decrease trend. This shows the rainfall uniqueness in each different region, but on average, shows the occurance of more extreme maximum daily rainfall, and this condition is caused by global climate change which also occurs on a local scale in the study area.

3.6 Rainfall Change Trend In The Wettest and Driest Months

From the research results, the wettest month in all rainfall stations occurred in February, while the driest month is in August. Fig. 7 shows the trend of change in rainfall in the wettest months, the majority of rainfall stations showed an increasing trend, except on Oekibiti station. In fig. 8 shows the rainfall change in the driest months, where in all rain stations show a decrease trend. From the obtained results shows that, wet months are likely to become wetter, while the dry season tends to be drier. Consequently, the dry season will take place increasingly dry and take long time, so potentially lead to drought catastrophic, while the rainy season will take place with the increasingly wet, and potentially lead to flood catastrophic.

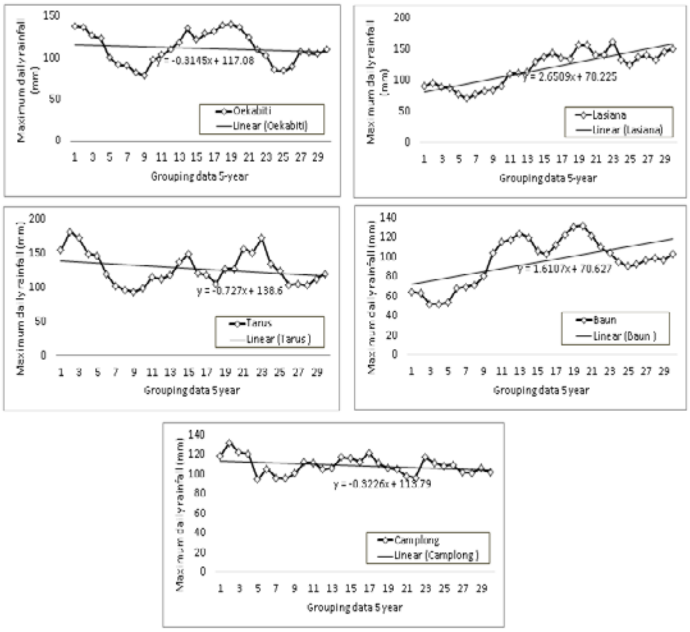

Fig. 7. Trend of average rainfall in the wettest month with a 5-year moving average (1977-2010)

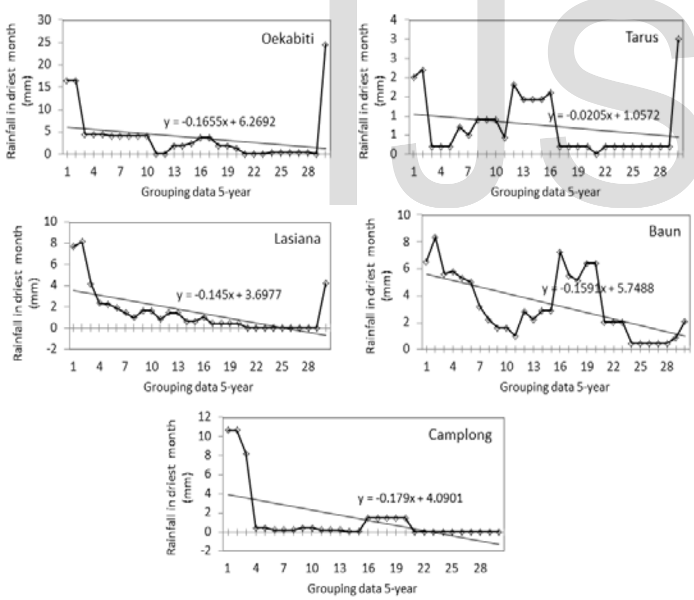

Fig. 8. Trend of average rainfall in the driest month with a 5-year moving average (1977-2010)

3.7 Relationship of Rainy Days Number, Rainfall Magnitude, and Rainfall Classification

The relationship between the number of rainy days, the magnitude of rainfall and rainfall classification, described in the rainfall intensity per-day (fig. 9), which is divided into four classes [15]. In this section, the analyzed data is sampled daily rainfall data in 1986. The year of 1986 is chosen because it is a normal year, according to the year characteristics based on stochastic Markov approach [18]. Fig. 9 shows that although each rainfall station shows the difference in value or percentage of rainy days, and the percentage of the magnitude of rainfall intensity, but in general, it shows a similar pattern that the intensity of the rainfall occurs in the most extreme rainfall classification, the smallest magnitude of rainy days. While the intensity of the lowest rainfall occurs in the classification of light rain, but the number of rainy days occur most frequently within a year.

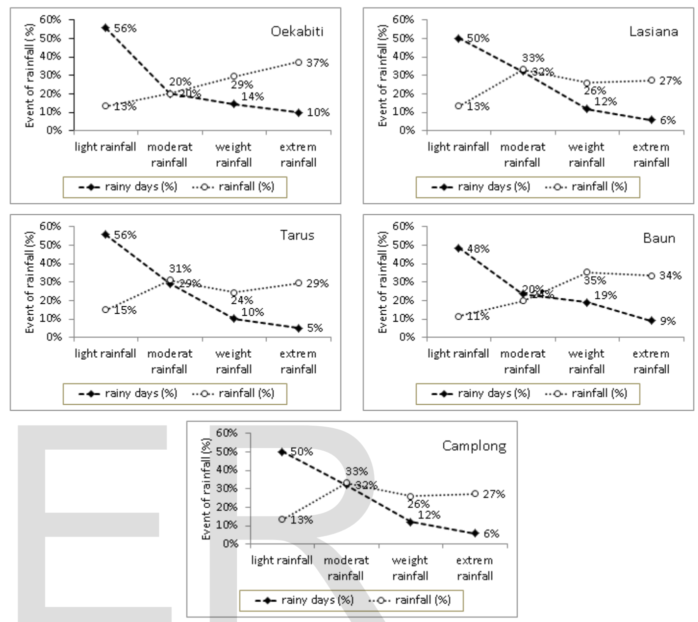

Fig. 9. Relationships of number of rainy days, rainfall magnitude and rainfall classification (1977-2010)

AWC [21] states that, rainfall decreases in frequency, but increases in its intensity. This condition will lead to frequent droughts and floods. The implication in the water resources management and water destructive force is easy to erosion, the magnitude of run-off and reduced water infiltration into the soil, result the challenges of water resource management in the study area becomes more complex. It is necessary for conservation efforts and engineering technology to be able to take advantage of the large magnitude of rainfall in a short time, so that it is as not to be wasted into the sea, but can be accommodated during the rainy season and utilized during the long dry season.

3.8 Rainfall Anomaly Index (RAI)

The RAI for Oekabiti station ranged between +5.24 in 1995 and -4.80 in 2002. In Tarus station, it is between +6.50 in 2003 and –3.08 in 1985. In Lasiana station, it is between +5.53 in 1996 and –4.36 in 1985. In Baun station, it is between +8.83 in 1990 and –3.37 in 1982. In Camplong station, it is between +4.70 in

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1980 and -4.92 in 1985 (fig. 10). The value of RAI ≤ 3 usually correlates with drought in the area [14]. From fig. 10, it is generally known that, RAI are very varied from year to year, and the worst drought occurred in 1985. Dupe [4] said that is based on the research of drought for 40 years in Indonesia, most suffered areas from drought are areas with monsoon rainfall patterns (type A), including the study area.

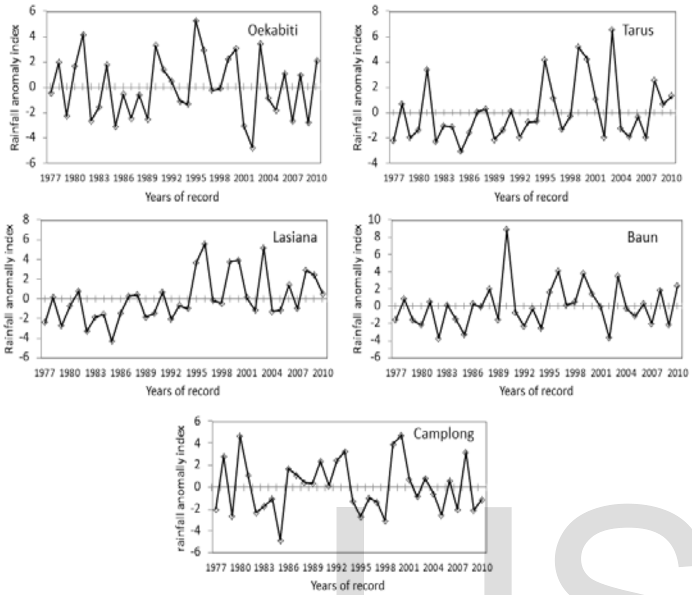

Fig. 10. Time-series of rainfall anomaly index values (1977-2010)

During the occurance of El Nino and La Nina, there will be disruption to the rainfall patterns in the tropics areas. In Indonesia, when El Nino occurs, drought becomes very dry and delayed the start of the rainy season. The drought is typically concentrated in the area around 120 and 134 South West Longitude of equator. While at La Nina, the opposite conditions develops in Indonesia that the rainy season will arrive earlier than usual [4].

3.9 Linkages of Rain Characteristics and Water Resources in Study area

The analysis results of five rainfall stations show the different characteristics of each rainfall station, despite being in a same region. This shows that each station with area coverage, differ in the rainfall characteristics that will be different in terms of water resources management. Banunaek [20] shows only about 7 to 29% of the infiltrated rainfall, the rest is wasted into the sea or experiencing evaporation. If taking the average, infiltrated water potential and utilized water directly by the people is amounted to 18%, the remaining 82% is lost water potential. The results of the rainfall characterization in the study area have implications in the water resources management, and the water destructive force, easily lead to flood and erosion, and reduced water infiltration into the soil results in prolonged drought. Considering the condition of the local topography, it is possible that the construction of reservoirs, ponds, rain water tank, or form other water resource development that can accommodate and hold water as long as possible on the mainland before discharged into the sea. It is expect that the water potential can be utilize during the dry season.

The results also show that, the impact of climate change, especially in the rain parameters, will make the challenge of managing water resources is becoming increasingly difficult, particularly in the research of semi-arid areas, where the result is in line with AWC [21]. Given the negative impact that may occur due to the rainfall characteristics in the study area are very different, it is necessary to develop an ability to predict accurately [4] to the effects of drought and floods, so that people and governments can be given early warning of the possibility of such impacts, and can be a precaution to reduce the negative impacts that may arise. AWC [21] show that 'traditional' approach is needed to manage the effects of drought through adaptation to the lifestyle to minimize water usage and maximize local wisdom in saving water. Julius [22] said that If sufficient measures are not taken up immediately, in the management of water resources, then we will face a crisis which will be detrimental to the very survival of mankind [22].

4. Conclusion

Characteristics of rainfall that occurred contribute to drought and flood in the study area, which is therefore a challenge for water resources management in the study area will be increasingly complex. It is required water resources conservation, both traditional, regional or local wisdom in accordance with engineering technology to be able to exploit the potential of rainfall occurs during the rainy season so it can be used during the dry season.

Noting the characteristics of rainfall that occurred then, the development of water resources needs to be done with the construction of a dams or ponds, to be able to collect as much water as possible during the short rainy season so that it can be used during the dry season.

The changes occured in rainfall show the presence of climate change which also occurrs in the study area, so it needs to be seen as a serious matter for the anticipated impact on the water resources management, particularly the continuous availability of water to meet the basic needs of society. The results of this research can help the stakeholder's interest in water resources management in the study area to understand

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the risks and vulnerabilities associated with the rain characteristics.

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