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# Water Availability Analysis of Sangkulirang-Mangkalihat Karst in Kutai Timur Regency, East Kalimantan Province

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## ABSTRACT

The Sangkulirang-Mangkalihat area has tremendous natural resources one of them is water resources. The availability of water in karst area needs to be recognizing in order to fulfill the water demand of the community around karst area. This study aims to identify water availability and water demand in karst area. Water availability identified by Thornthwaite-Mather water balance method and calculation of water demand performed for domestic water demand, agricultural water demand and livestock water demand. The result shows that annual rainfall of karst area is 2036 mm/year. The amount of water availability is 177.6 million $m^3$/year, while domestic water demand is 1.33 million $m^3$/year, agricultural water demand is 73 million m3/year and livestock water demand is 142.8 thousand $m^3$/year. Comparison between the availability of water and the water demand of karst area shows that the water conditions are still able to meet the needs of the community.

**Keywords:** Water balance, Water availability, Water demand, Karst.

## I. INTRODUCTION

Water is a very important natural resources for all living things. Human being must able to fulfill their need of water therefore to keep the availability of water utilized optimally and efficiently requires good understanding and management. Management areas against high water resources potential to be considered and improved to keep the water resources preserve available, unthreatened or damaged. One of the potential areas which can store large water reserves is the karst. According to [9], karst is a region with a typical hidrological system and it was formed through a combination of high rock dissolution and well porosity.

Karst landscapes are formed by the dissolution of soluble rocks, limestone and dolomite. More than 25% of the world's population either lives or depent karst aquifer aas their source of water. Due to the absence of surface water storage possibilities, people living in karst regions are often suffering from acute water shortage, especially during dry seasons. However, in many karst regions large networks of underground rivers exist which lead water continuously [14].

Sangkulirang-Mangkalihat Karst is one of the karst areas that have considerable as potential natural resources, one of which is water resources. Sangkulirang-Mangkalihat Karst has a major area lies within 2 districts, Berau district and east Kutai district. The total width area is 1,8 million hectares and karst itself reaches 505.000 hectares. This area is an upstream of 5 major rivers, Bengalon river; Karangan river; Tabalar river; Lesan river and Pesab river. More than 105.000 inhabitants settled in Sangkulirang Karst. Currently, the karst is a strategic area in Kalimantan Island [15].

Several researchs about karst in Indonesia has been carried out. Spatial analysis investigated shows that there are still inconsistencies in the management of space, in protected areas or areas that should be conserved there are still activity for other land uses, especially mining permit entry in the national park area [6]. There are 19 out of 22 villages that experienced water shortages, especially during dry season in kasrt area of Taman Nasional Manupeu Tanah Daru [10].

Regarding to water resources in Sangkulirang-Mangkalihat Karst, this study aims to estimate the water availability to know the amount of water in the area and estimate the water requirement for domestic uses, agriculture uses and livestock uses. Thronthwaite-Mather water balance method will be used to estimate the potential of water availability especially to determine the availability of water in the area. The result of this study can be used as reference to regulate the water uses so that water in karst area is will be utilized properly by the population to meet the daily water needs and their livelihood activities and to prevent the massive exploitation of karst area that can be threated to water resources sustainability.

## II. METHODS AND MATERIAL

### Research Location and Data

Research was conducted in the Sangkulirang karst area, east Kutai district, east Kalimantan. Data used in this study were rainfall and air temperature during year of 2007-2016. Rainfall data used in this study was CHIRPS (Climate Hazard Group Infrared Precipitation with Station Data) rainfall data. CHIRPS rainfall data was a reanalysis of rainfall data assimilation results between satellite rainfall data and rainfall data observation land stations [7] [8] in grid form with spatial resolution 0.05o x 0.05o (± 5km x 5km) which available from 1981 until present. CHIRPS data used because the minimum information of rainfall data available in that particular area. According to study by [13] CHIRPS rainfall data has a fair correlation against rainfall in Central Java. Meanwhile for temperature, using CRU (Climate Reseach Unit) data 4.03 TS version with resolution 0.5° x 0.5° (+ 55 km x 55 km) available in year 1910-2018 [12].

### Water Balance Calculation

Water availability analysis using land water balance approach was assumed by Thornthwaite-Mather method. The step of calculating water balance by Thornthwaite-Mather method was described as follows:

a. Potential Evapotranspiration Calculation (EP).

$$EP_i = 16 \times \left(\frac{10 \times T_i}{I}\right)^a$$

$$I = \sum_{i=1}^{12} \left(\frac{T_i}{5}\right)^{1,514}$$

EPi is potential evapotranspiracy of month-i (mm), Ti is average temperature of month-I (˚C), I is heat index accumulation in one year and = 0.000000675I3-0.0000771I2 + 0.01792I + 0.49239.

b.Soil Moisture Determination (ST) and Soil Moisture Changes (ΔST) Every Month.

$$ST = ST_o \times e^{-(APWL/ST_o)}$$

Where:

e = 2,718, APWL is total cumulative of rainfall deficit and STo is soil moisture during field capacity conditions.

c. Actual Evapotranspiracy Determination (EA) Based on Rainfall (P) and Potential Evapotranspiracy (EP).

Wet month (P > EP), then EA = EP

Dry month (P < EP), then EA = P + |ΔST|

d. Deficit Condition Determination (D)

Deficit conditions occur when the total of monthly rainfall is smaller than potential evapotranspiration.

$$D=EP-EA$$

e. Surplus Condition Determination (S)

Surplus condition occur when the total of monthly rainfall is bigger than potential evapotranspiration, Where :

ST = STo, then $S=P-EP$

ST < STo, then $S=(P-EP)-\Delta ST$

f. Water Availability Level Determination

Surplus x Karst landscape width area

**Water Requirement Analysis**

The calculation of water requirements of the karst region is intended for domestic, agricultural and livestock water requirements.

1. Domestic Water Requirements

   Domestic water requirements are calculated using a standard approach to individual water requirements per day. Individual water requirement standard in rural areas is 60 liters/day/person [2]. Total domestic water requirements calculated using formula :

$$Q = q \times P \times 365\ days$$

Where:

Q = Total domestic water requirements (liter),

q = Standard water used (60 liters/person/day)

P = Total population (person)

2. Agricultural Water Requirements

   Agricultural water requirements are the total of irrigation water needed to irrigate rice fields. Irrigation water needs were obtained from the difference between plant evapotranspiracy (ETC) and effective rainfall. If ETC is bigger than effective rainfall then the region needs water. Agricultural water demand was supposed to come from plant evapotranspiration based on the plant coefficient as follows:

$$Kc\ x\ ETP\ x\ \text{Width Area}$$

Where:

Kc = Plant coefficient (Table 1)

ETP = Evapotranspiration (mm).

3. Livestock Water Requirements

   Calculation of water requirements for livestock is based on the type of livestock suck as cattle, buffalo, horses, goats, sheeps, pigs and avian [Table 2] using standard water requirements determined [3] regarding the water resources balance establishment, the daily needs of livestock are very dependent on the number of livestock breed by the population.

Water requirements for livestock are calculated by multiplying the number of livestock with water requirements level, based on the following equation:

$$Q_E = \{(q_1 \times P_1) + (q_2 \times P_2) + \cdots + (q_n \times P_n)\}x\ total\ days$$

Where :

$Q_E$ = Water requirements for livestock (liter/year)

$q_1$ = Water requirements for livestock type-1 (liter/head/day)
$q_2$ = Water requirements for livestock type 2 (liter/head/day)
$q_n$ = Water requirements for livestock type-n (liter/head/day)
q(po) = Water requirements for avia (liter/head/day)
$P_1$ = Total livestock-1 (head)
$P_2$ = Total livestock-2 (head)
$P_n$ = Total livestock-n (head)

## III. RESULTS AND DISCUSSION

### Water Balance

Water availability analysis concept is carried out using land water balance. According to study area the land water balance calculated to be 38.25 ha. The calculation requires several climatic elements such as rainfall and temperature. Rainfall in the study area has en equatorial rain pattern characterized by two bimodial peaks, the condition of the first rain peak occurred in May with a rain average amount of 218 mm while the second peak occurs in December with 226 mm. The most wet rainfall occurred in December and the driest in October with 105 mm of rainfall [Figure 1]. The total annual rainfall was 2036 mm.

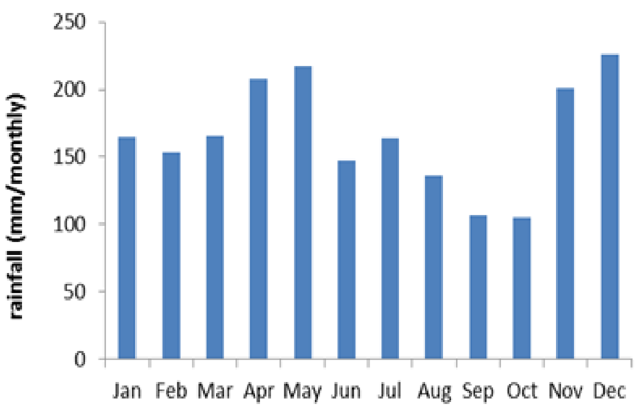


Figure 1. Monthly average rainfall number Sangkulirang Mangkaliat karst period 2007-2016

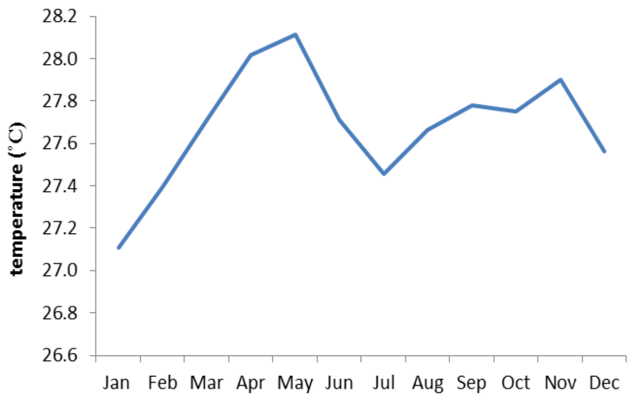


Figure 2. Monthly average temperature Sangkulirang–Mangkaliat karst period 2007-2016

The average temperature pattern in research area [Figure] 2) indicates that the temperature ranges from 27.1˚C-28.1˚C when the highest average temperature occurs in May and the lowest average temperature occurs in January. Potential evapotranspiration (ETP) is the amount of water lost from certain land area through land, water even plantation that is determined by climate elements [11]. ETP that has happened in Sangkulirang–Mangkaliat Karst the year 2007-2016 [Figure 3] trend to stable every month. Maximum ETP occurs in May, potential evapotranspiration number for that month reached 174 mm with rainfall only 218 mm. This was caused by temperature and rainfall [Table 3]. High evapotranspiration also could occur when air temperature is high, while the lowest ETP occurred in February with rainfall only 140 mm.

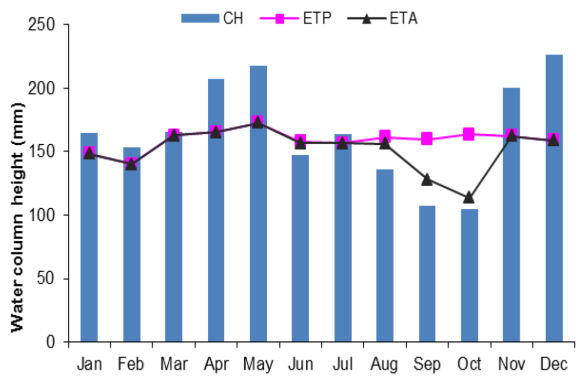


Figure 3. Comparation of rainfall (CH), potential evapotranspiration (ETP), and actual evapotranspiration (ETA) at Sangkulirang–Mangkaliat karst period 2007-2016

TABLE 3

WATER FIELD BALANCE AT SANGKULIRANG–MANGKALIAT KARST PERIOD 2007-2016

| Parameter | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T | 27.1 | 27.4 | 27.7 | 28.0 | 28.1 | 27.7 | 27.5 | 27.7 | 27.8 | 27.8 | 27.9 | 27.6 |
| CH | 165 | 153 | 166 | 208 | 218 | 147 | 164 | 136 | 107 | 105 | 201 | 226 |
| ETP | 148 | 140 | 163 | 165 | 173 | 158 | 156 | 161 | 160 | 164 | 162 | 159 |
| CH - ETP | 16 | 13 | 3 | 42 | 45 | -11 | 7 | -25 | -53 | -58 | 38 | 67 |
| APWL | 0 | 0 | 0 | 0 | 0 | -11 | 0 | -25 | -78 | -136 | 0 | 0 |
| KAT | 54 | 54 | 54 | 54 | 54 | 44 | 54 | 34 | 13 | 4 | 54 | 54 |
| dKAT | 0 | 0 | 0 | 0 | 0 | -10 | 10 | -20 | -21 | -8 | 50 | 0 |
| ETA | 148 | 140 | 163 | 165 | 173 | 157 | 156 | 156 | 128 | 114 | 162 | 159 |
| DEF | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 5 | 31 | 50 | 0 | 0 |
| SURP | 16 | 13 | 3 | 42 | 45 | 0 | 7 | 0 | 0 | 0 | 38 | 67 |

Actual Evapotranspiration (ETA) is the total water lost from a certain area of land through land or water or plantations determined by climate elements, soil conditions and plant properties [11]. If the rainfall higher than ETP, then ETA will be same as ETP. Meanwhile, if the rainfall is lower than ETP, then ETA will be lower from ETP. From August to October ETA would be lower compare to ETP. August to October ETA is lower than ETP, if the condition of the land surface is dry that is when the ETA number is lower than ETP.

The type of soil inside Karst region was generally inceptisol soil with clay loam texture [4]. That typically soil texture contains moisture soil at about 54 mm. Soil moisture value would decrease if rainfall was smaller than potential water loss (ETP). Soil moisture values decreased from June until October. Compared to other landscape, karst has a low moisture value due to its thin soil. The depth of thin soil was caused by a lot of limestone below the surface of the soil [16].

Surplus and deficit condition of water in water area based on the calculation of the water balance presented in [Table 3]. Surplus conditions occur from November to May. The highest surplus condition occurred in December at 67 mm/month and the lowest surplus conditions occur in March at 13 mm/month. Deficit conditions occur in june to October with highest number occuring in October and the lowest deficit in June.

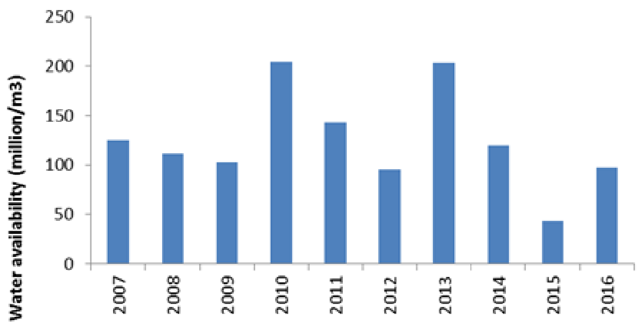


Figure 4. Yearly water availability at Sangkulirang–Mangkaliat period 2007-2016

## Water Requirements at Sangkulirang–Mangkaliat Karst Region

Available water at Sangkulirang–Mangkaliat karst region used for domestic demand, agricultural and livestock. The amount of water demand is influenced by population number, livestock and width area of rice field that was included in research. Water requirements were also calculated in 4 sub-districts included in the study area. Domestic water requirements is the amount of water used by local residents in daily life. Water needs of each individual are different depending on the activity. Residents who live in rural areas tend to use less water than those who live in urban areas. The difference was because people in urban areas tend to use more water then than people in rural areas.

Calculation of domestic water requirements for the period 2007-2016 [shown in Figure 5], for 2007 and 2008, there was no calculation of the water requirements due to no data obtained from BPS. Domestic water demand in the research area tends to increase over the period 2007 to 2016. This increasing number occurs because of the increasing population every year. Water demands number in 2009 was 0.97 million $m^3$/year with population of 44267 people. The demands has increased in 2016 became 1.63 million $m^3$/year with population of 74631 people.

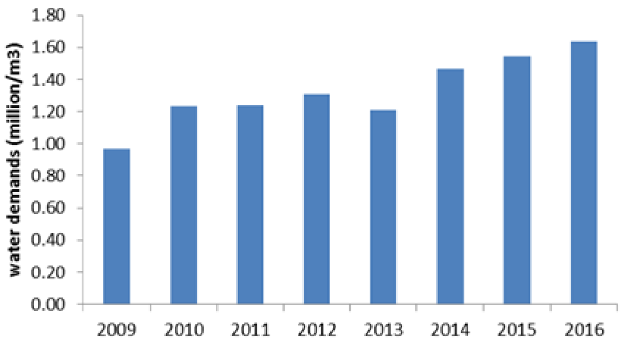


Figure 5. Domestic water demands at Sangkulirang–Mangkaliat karst period 2007-2016

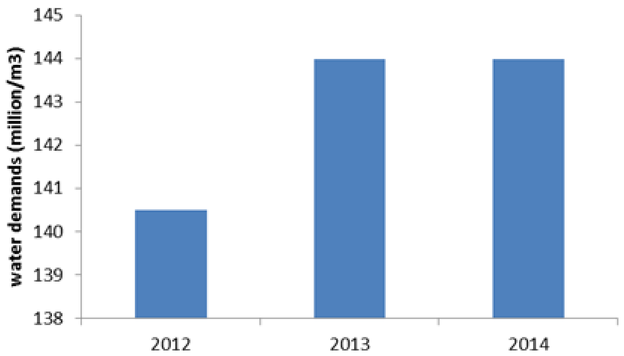


Figure 6. Livestock water requirements at Sangkulirang–Mangkaliat period 2012-2014

Livestock water needs were used for the demands of various types of livestock in 4 sub-district in the research area. The types of livestock for the water requirements calculation were cows, buffaloes, goats, pigs and poultry. Data taken for 3 years period during 2012-2014 [Figure 6], because the data available only valid on that certain year. Livestock population had increased and the impact to water demands for livestock also increased. Water requirements in 2012 was 140.5 thousand $m^3$/year. The requirements increased in year 2014 became 144 thousand $m^3$/year. Compared to other sector, the agricultural sector has the greatest water requrements. Water that irrigates rice fields was only used for consumptive needs in the form of plant evapotranspiration (ETC). Water for agricultural activities was influenced by cropping patterns in the area. The cropping pattern in this research assumed to be Paddy-Paddy-Secondary crops.

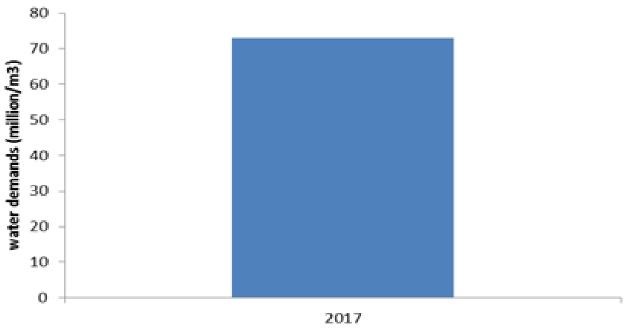


Figure 7. Agricultural water requirements at Sangkulirang–Mangkaliat in 2017

The first planting season is assumed that all paddy fields are planted with rice, the second planting season was 85% rice plants of the total area of rice fields, the third planting season was secondary crops which was 75% of the total area of rice fields. The calculation of water requirements only conduct in year 2017 because the only valid data available in 2017 [Figure 7]. Based on the agricultural water requirements calculation in 2017, the water demand for agricultural was 73 juta $m^3$/year.

## IV. CONCLUSION

Water availability analysis in Sangkulirang-Mangkalihat karst indicated that the total amount of available water was 177.6 million $m^3$/year. Water requirements for domestic needs was 1.33 million $m^3$/year and water requirements for livestock was 142.8 thousand $m^3$/year. Comparation between water availability and water requirements indicated that water conditions was still able to meet people needs (not yet a threshold/critical).

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