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Water Balance Modelling to Estimate Water Needs of The New Rice Field Expansion Area in Buru District, Maluku

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ABSTRACT

Water balance modelling is one of the common used modeling methods to estimate water equilibrium in a region. Land use land cover change in a region on a large scale will potentially affect the water balance in a region. In 2016, the government of Indonesia had planned the extensification program of new rice fields in Maluku Province. Buru District had a large scale area potentially change to new rice fields. Land cover change into rice field allow to increase water demand in the area. This study aimed to determine the water balance in waeapo watershed (Waeapo, Lolong Guba and Waelata sub-districts) with the expansion plan of new rice fields. Water balance consist of water availability and water needs. The water availability analysis was done by Mock Water Balance method which presented with spatial approach using geographic information system on different land use land cover for the parameter. The water needs calculated with CROPWAT 8.0 and crop coefficient of rice field and soybean with modification of time plant. Water balance modelling show that it have surplus period that occurred more than 6 months, so it is potentially planted with rice field two times a year after rice field expansion. There were 5 months deficit, but still leaving of 118.111,28 l/sec water availability in a year.

Key words : Buru Island, Geographic Information System (GIS), Land Use Land Cover Change (LULCC), Water Balance Model

1. INTRODUCTION

Buru District had a 7.207 area of rice field by 2015 [1]. The area was spread in three rice barns sub-districts in Buru, namely Waeapo sub-district, Lolong Guba sub-district and Waelata sub-district. Waeapo sub-district had 2,813 ha of rice field area, Lolong Guba sub-district with 1,144 ha and Waelata sub-district of 3,250 ha. Buru District is the largest rice supplier after Central Maluku District to Maluku Province [2]. Maluku Province's rice production was 70,674 tons in 2015, but it‘s still below the needs of rice in Maluku Province which reached 121,493 tons [2]. Hence, in 2016 Maluku Province, through a new rice field extensification program was planning to increase rice field area in Maluku Province, centered in Buru District and Central Maluku District. Maluku Province has a large potentially area for extensification of agricultural areas, as seen from the comparison between the potential land area on the agro-ecological zone map (ZAE) and BPS data. According to Susanto et.al (2007), the potential land for crops, vegetables and fruits based on BPS data in 2004 reached by 41,012 ha, while the potential is 775,586 ha, and the extensification available area is 734,574 ha. In his journal, Susanto et.al (2007) described the distribution of land use directives and extent based on agroecological zones, for 19,459 ha of Buru Regency for dry land crops and 40,040.2 ha for rice crops. Based on land suitability for rice field, there were 13.275,82 ha potentially land to be developed for landfarm [3].

Prospective rice fields in Waeapo, Lolong Guba and Waelata sub-districts were part of the waeapo watershed. Watershed is a land area that holds and stores rainwater, then channel it into the sea through the main river [4]. The land area is called a water catchment area, ecosystem including it's main elements form of natural resources and human resources. The catchment area has a major contribution to maintaining hydrological functions in wetland areas, particularly water and energy balance, so it is important for monitoring long-term land-use land-cover changes (LULCC) in water catchments [5]. Water balance, closely related to water availability and water needs. Water balance in the vadose zone soil, should be influenced by irrigation practices [6]. Although in a wet area, water availability is the main limiting factors for food crop production [7], so the assessing, managing, planning and arranging is requisite [8]. Understanding the water cycle and water use is neccesary to ensure water resources and food supply sufficiency [9]. Without any good management, agricultural demand was being the caused of water scarcity [10].

In the hydrologic cycle, there is a relationship between input and output for a certain period called water balance [11]. Water balance is the measurement of each component of the water flow cycle that enters and exits the root zone of plants [7]. Differences land cover in an area, will affect the water balance in a region [5, 8, 12]. Extensification of agricultural areas for the new rice field expansion program in Buru District will result LULCC in the large scale area which will certainly increase water demand for crops, especially rice crops. Water balance method of irrigation scheduling is one method of estimating the required amount and timing of irrigation for crops [13]. Water balance modelling can be used to accurately predict the potential of crop yield, prediction of groundwater content and optimum cultivation time in a region [14]. Water balance model can also be used to analyze and simulate various water balance components, once validated [14]. The purpose of this study was to examine the effect of LULCC become wetland rice rice in Buru district, especially on waeapo watershed, with water balance approach.

2. METHOD

2.1 Study Site

Waeapo watershed is one of the largest river basins in Buru District with an area of 219,391.30 ha. According to *Letter No.22 of the Ministry of Forestry* in 2017 on forest area, Waeapo watershed covering 8 sub-districts namely, Namlea Sub-district, Waeapo Sub-district, Lilialy Sub-District, Lolong Guba Sub-District, Fena Leisela Sub-District, Waplau Sub-District, Kayeli Sub-District and Waelata Sub-District. The Waeapo watershed also covers the northern area of South Buru District with an 22,000 ha area. The Waeapo watershed consists of mountains as well as extensive terrain so that on flat areas commonly referred to as waeapo plains. Based on the calculation of the Q value ratios, Waeapo Plains has an average number of dry months (<60 mm) divided by wet months (> 100 mm) multiplied by 100% [15], this region according to Schmidt and Ferguson (1951) is divided into two types of climate, namely A and C and Aw climate in northern Buru [15, 16].

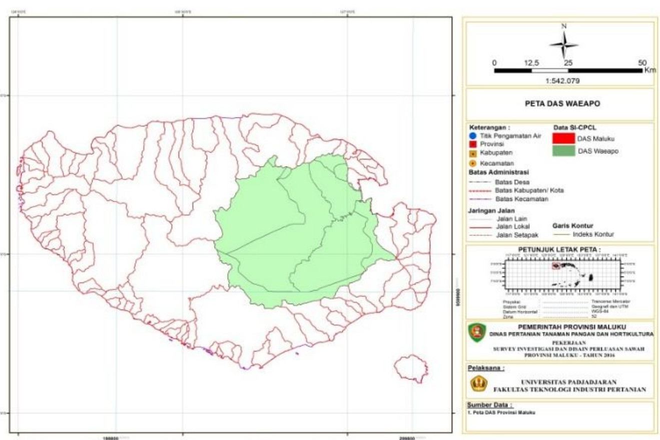

Figure 1: Waeapo Watershed

2.2 Land Use Land Cover Classification

The methods to observe the land use is done by geographic information system software. The land use in Waeapo watershed refers to the land cover map data released by the Maluku Provincial Development Planning Agency [17]. The land cover map of Maluku Province overlay by *CLIP* tools in geographic information system software with a watershed map issued by the Ministry of Forestry.

Table 1: Sub-Districts Area in Waeapo Watershed

No.	Sub-District	Area (ha)
1.	Waeapo	17,813.13
2.	Lolong Guba	65,834.33
3.	Waelata	43,436.26
4.	Namlea	2,473.20
5.	Lilialy	3,607.94
6.	Kayeli	10,367.43
7.	Fena Leisela	52,280.76
8.	Waplau	1,603.59

The results obtained land cover map of Waeapo watershed that consists of Primary Forest, Secondary Forest, Secondary Mangrove Forest, Plantation, Dry-Land Farm, Swamp, Rice Fields, Grassland, Shrub and Open Land. Waeapo, Lolong Guba and Waelata sub-districts administration are incorporated into the Waeapo watershed. However, some other sub-districts are also included in the Waeapo watershed. Table I describes the distribution and extent of each sub-district belonging to the Waeapo watershed. The watershed maps, then covered with a map of new rice field measurements in Buru District, to obtain a new prospective rice field map that belongs to the Waeapo watershed.

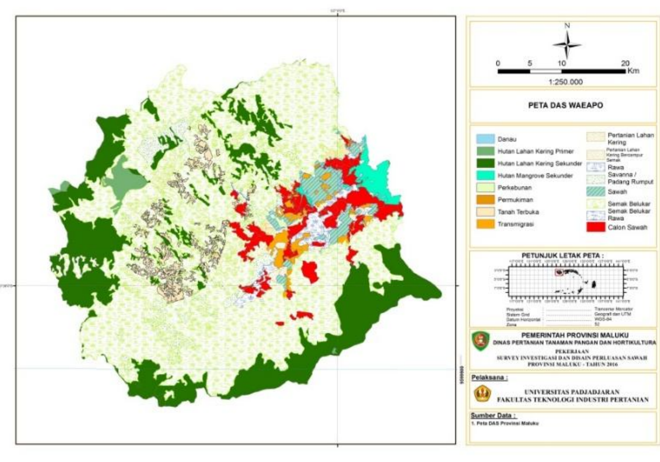

Figure 2: Land Use Land Cover on Waeapo Watershed

2.3 Dependable Discharge

Water balance modeling is obtained by comparing the amount of water needs and availability in a region. To analyze the availability of water in a watershed in this study performed dependable discharge calculations on waeapo watershed with Mock method. Mock method developed by F.J. Mock in 1973 based on the hydrological cycle [18]. The Mock method is one of the methods that describes the relationship between rainfall-runoff [19]. Mock method have been used in Indonesia and tropical watershed, because it developed in Indonesia [20, 21]. Any advantages of Mock method it could be used in no discharge gauge, because the Mock method was developed for the average monthly discharge in a watershed. The data required in the calculation of the discharge by Mock method is climatological data, watershed area and watershed land use [18]. The climatology data used were precipitation, temperature, solar radiation, relative humidity and wind speed. On this study, the climatology data collected from Namlea Meteorological Station. The data used for analysis from 2003 to 2013, for potential evapotranspiration was done using CROPWAT 8.0 software.

Table 2: Exposed Surface Parameter

No.	Exposed Surface (m)	Description
1.	0%	Forest
2.	10 – 40%	Erosion Area
3.	30 – 50%	Crops

Source: Mock, 1973

Actual evapotranspiration ocurred in limited water availability condition. It depends on exposed surface percentage (m). Exposed surface (m) affect actual and potential evaporation, caused the differences of the land cover percentage. Mock give the exposed surface parameter shown in Table 2. The stages in the process of water balance analysis of areas in the waeapo watershed area follow:

$$P = Ea + \Delta GS + TRO \qquad (1)$$

P = Precipitation
Ea = Evapotranspirasi
ΔGS = Groundwater Change
TRO = Total Run Off

Ea = Actual evapotranspiration is calculated by CROPWAT 8.0

$$\frac{\Delta E}{Ep} = \left[\frac{m}{20}\right](18 - n) \qquad (2)$$

ΔE = Difference between actual evapotranspiration and potential evapotranspiration
Ep = Potential Evapotranspiration
m = Exposed Surface
n = Precipitation Days

$$WS = (P\text{-}Ea) + SS \qquad (3)$$

WS = Water Surplus
P = Precipitation
Ea = Actual Evapotranspirasi
SS = Soil Storage

$$SMS = ISMS + (P\text{-}Ea) \qquad (4)$$

ISMS = Initial Soil Moisture Storage, SMC in the previous month
P-Ea = Precipitation which have evapotranspiration
According to Mock experiment in Bogor, the average SMC value in Indonesia was 200 mm / month

$$I = WS \times if \qquad (5)$$

I = Infiltrasi
WS = Water Surplus
If = Coefficient infiltration (0 – 1)

$$BF = I - \Delta GS \qquad (6)$$

BF = Base Flow
I = Infiltration
ΔGS = Groundwater Change

$$DRO = WS - I \qquad (7)$$

DRO = Direct Run-off
WS = Water Storage
I = Infiltration

$$SRO = P \times PF \qquad (8)$$

SRO = Surface Run-Off
P = Precipitation
PF = Percentage Factor

$$TRO = BF + DRO + SRO \qquad (9)$$

TRO = Total Run-Off
BF = Base Flow
DRO = Direct Run-Off
SRO = Storm Run-Off

The final result obtained in dependable discharge calculation is TRO (Total Run-Off) expressed in mm/month. To obtain dependable discharges in watershed area, the TRO value then multiplied by the area of the catchment area (watershed). Dependable discharge with a probability of 80% is exceeded used for agriculture. The discharge every month compared with the water needs to obtain the water balance in watershed.

2.4 Water Needs

Water requirement is done by collecting daily evapotranspiration (ETo) data and effective rainfall (Re) obtained from CROPWAT 8.0 software. Modeling on CROPWAT could offer an option to estimate the actual evapotranspiration of the water balance using the monthly rainfall data and ETo [22]. In this research the determination to determine evapotranspiration and effective rain (Re) is done the default setting used in CROPWAT by using USDA equation. There were any research that used CROPWAT 8.0 for estimating the water irrigation of rice and wheat in Hindi [23, 24]. Beside rice plants, CROPWAT 8.0 used for dryland farm, such as sweet potatoes red bean, corn and cassava in Indonesia and also coconut in India, wheat, barley, white corn, and tomatoes in Iraq [25–27]. CROPWAT became have used in any research because the model helps engineer to analyze the water need in any different culture and condition [23], the optimum irrigation scheduling that needed for better crop productivity [24] and it's computerized program that could easily used [24, 28]. The procedure and formula in CROPWAT, refer to FAO publication No. 56 and No. 33 [29]. Irrigation water needs in weir or Diversion Requirements (DR) is an accumulate water irrigation ratio in the rice field with the assumption efficiency of all channel as a surface irrigation is 65%. Cropping pattern that is done on irrigation water demand modeling is Rice - Rice - Soybean. The modelling used for a year cultivation and based on the farmer habit in waeapo watershed. The irrigation water demand in a watershed is described in the following equation:

$$ETc = ETo \ x \ C_{average} \qquad (10)$$

ETc = Crop Evapotranspiration
$C_{average}$ = Crop Coefficient

$$NFR = ETc + P - Re + WLR \qquad (11)$$

NFR = Net Field Requirement
ETc = Actual Evapotranspiration
P = Percolates
Re = Effective Rainfall
WLR = Water Layer Replacement

$$DFR = NFR / 0,65 \qquad (12)$$

DFR = Diversion Requirement

3. DISCUSSION

Measuring the potential of rice field in Buru Regency in 2016 is optimized by considering the number of population and prospective farmers so that there is an area of 15,858.96 ha, with distribution in Waeapo Sub-District, Lolong Guba and Waelata Sub-districts above 70%. According to Susanto, et.al (2007) the extent of the directive for wetland food crops is around 40,000 ha, but other factors such as social conditions and community appeals in hope that the program can run smoothly. The area of rice field in Waeapo watershed is 13,090.71 ha, which is then classified into 3 groups, namely category I, category II and category III. The distribution of rice fields in Table III shows that Waelata sub-district dominated the area of rice field in Waeapo watershed with an area of 6,500 ha.

Table 3: Distribution of Rice Field Planned in Waeapo Watershed

No.	Sub-District	Area (ha)	Classification
1.	Namlea	77.80	Category I
2.	Waeapo	1,348.69	Category I
3.	Lolong Guba	3,645.18	Category II
4.	Fena Leisela	332.95	Category II
5.	Waelata	6,501.45	Category III
6.	Kayeli	1,184.64	Category III

The sub-districts were classified as a reference to the planting plan and cropping pattern that will be carried out on *RTTG* (Global Cropping Plan). It was based on the adjacent aspect of location, making it possible to irrigate an area simultaneously. Prior to the analysis of water balance to the land for the determination of the cropping pattern, a calculation of land use change in the waeapo watershed was conducted. Land cover on the waeapo watershed is dominated by forest and shrublands. Primary dry-land forest has an area of 2,818.96 ha and 46,942.29 ha is secondary secondary forest. Secondary dry-land forest has a ratio of 21.81%. The most extensive land cover is shrubs in waeapo watershed reaching 125,543.47 ha or about 58.33%. Agricultural land that has been used is about 4,900.43 ha of dry land and 5,405.75 ha of rice fields. Land use change to rice field, transform the value of m (Exposed Surface) on Mock parameter. Despite the average monthly discharge change in the waeapo watershed, the percentage of land cover that occurred were not significant. The value of m_1 = 23.06% is obtained from the calculation of $percentage_1$ with the percentage of rice fields of 2.51%. Calculation using $percentage_2$ and percentage of rice field of 7.36% yields m_2 = 24.04%.

The results of dependable discharge analysis on waeapo watershed before and after changes in land use for rice fields didn't changed significantly and were even quite identical. Even so, the average monthly discharge rate in the waeapo watershed was changing and tended to be greater with changes to rice land cover. Discharge in waeapo watershed increased about 457.12 l/sec since eleven years. Land use land cover change affected in decreasing the capacity of infiltration, so it could increasing the run-off [30]. Discharges used to perform dependable discharge analysis were the discharges indicated during the land use change to the wetland area of about 15,000 ha. The average monthly debit of the calculation using the Mock water balance approach is then sorted from the largest to the smallest by omitting sequence of events [18]. Determination of dependable discharges refers to the probability values that are relied upon in several water resource engineering plans [18], namely:

1. Water Supply (PDAM) : 99%
2. Hydropower (hydropower) : 85% - 90%
3. Industrial Water Supply : 88% - 95%
4. Provision of irrigation water :
   Humidified climate : 70% - 85%
   Bright climate : 80% - 95%

Table 4: Percentage of Land Use Land Cover Planned

No.	Sub-District	Percentage$_1$ (%)	Percentage$_2$ (%)
1.	Primary Forest	1.31	1.31
2.	Secondary Forest	21.81	21.73
3.	Mangrove S. F.	2.48	1.49
4.	Plantation	0.14	0.14
5.	Dry-Land Farm	0.78	0.41
6.	Dry-Land Cultivation	1.50	1.43
7.	Swamp	0.00	0.00
8.	**Rice Fields**	**2.51**	**7.36**
9.	Grassland	4.57	4.18
10.	Shrub	58.33	56.81
11.	Swamp Shrub	3.20	1.90
12.	Open Field	3.37	3.24

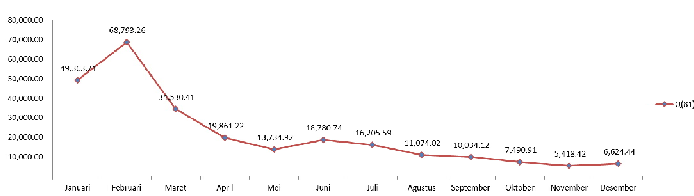

Figure 3: Dependable Discharge (Q_{81}) on Waeapo Watershed

For the determination of dependable discharges in the waeapo watershed, Q_{81} is used which means a discharge with probability of occurring at 81% throughout the year showed in Figure 4. The smallest value occurred in November with the amount of discharge reaching 5,418.42 l/sec. The largest value occurred in February with the largest value of nearly 70,000 l/sec. The high rate of discharge in February, affected by the infiltration that occurred in the previous month. Similarly in November, which was a dry wet month, resulting in a low infiltration in the preceding months, lowering the average monthly discharge of the year.

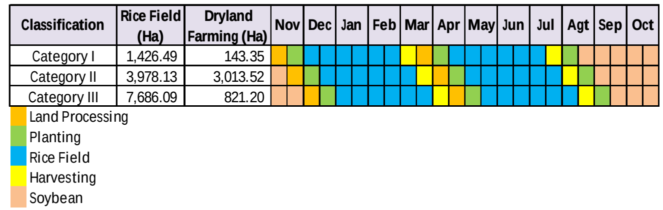

Figure 4: Global Cropping Plan (Rice-Rice-Soybean)

Determination of the water balance of the next area is to create a table need of each agricultural crops class in the waeapo watershed. The processed data then analyzed and combined with water availability data in the waeapo watershed area. To make more appropriate modelling, then made cropping pattern adapted to the conditions in the field, namely: Rice - Rice - Soybean. The water needs of plants that have been obtained, then used as a reference to create a Global Cropping Plan table. In the Global Cropping Plan table, will be compared how much the amount of water that can be conserved and that flow without infiltration. The water balance of a watershed area can be obtained in the presence of this Global Cropping Plan. Figure 5 showed the water needs of Rice-Rice-Soybean croping pattern during a year.

Water Needs in Waeapo Watershed, Buru District, Maluku
Crops : Rice - Rice - Soybean
Starting Plant : November, 15

Period	Eto (mm/day)	P (mm/day)	Re (mm/day)		WLR (mm/day)	Kc				Etc (mm/day)		NFR (mm/day)		NFR (l/day)		DR (l/s/ha)	
			Rice	Soybean		C1	C2	C3	C Average	Rice	Soybean	Rice	Soybean	Rice	Soybean	Rice	Soybean
Nov1	4.41	2	2.22			1.05	0.50	1.15	0.90	3.97		3.75		0.43		0.67	
Nov2	4.41	2	2.22			1.10	1.05	0.50	0.88	3.89		3.67		0.43		0.65	
Dec1	3.89	2	4.13			1.10	1.10	1.05	1.08	4.21		2.09		0.24		0.37	
Dec2	3.89	2	4.13		1.1	1.20	1.10	1.10	1.13	4.41		3.38		0.39		0.60	
Jnr1	3.64	2	4.73		1.1	1.20	1.20	1.10	1.17	4.25		2.62		0.30		0.47	
Jnr2	3.64	2	4.73		2.2	1.20	1.20	1.20	1.20	4.37		3.84		0.44		0.68	
Fbr1	3.45	2	4.75		1.1	1.20	1.20	1.20	1.20	4.14		2.49		0.29		0.44	
Fbr2	3.45	2	4.75		1.1	1.05	1.20	1.20	1.15	3.97		2.31		0.27		0.41	
Mrt1	3.96	2		4.29		0.00	1.05	1.20	0.75	2.97		0.68		0.08		0.12	
Mrt2	3.96	2		4.29		1.05	0.00	1.05	0.70	2.77		0.48		0.06		0.09	
Apl1	3.69	2		3.28		1.10	1.05	0.00	0.72	2.65		1.37		0.16		0.24	
Apl2	3.69	2		3.28		1.10	1.10	1.05	1.08	4.00		2.72		0.32		0.48	
May1	3.75	2		2.67	1.1	1.20	1.10	1.10	1.13	4.25		4.68		0.54		0.83	
May2	3.75	2		2.67	1.1	1.20	1.20	1.10	1.17	4.37		4.81		0.56		0.86	
Jni1	3.22	2		2.95	2.2	1.20	1.20	1.20	1.20	3.87		5.12		0.59		0.91	
Jni2	3.22	2		2.95	1.1	1.20	1.20	1.20	1.20	3.87		4.02		0.46		0.72	
Jly1	3.13	2	2.94		1.1	1.05	1.20	1.20	1.15	3.60		3.76		0.44		0.67	
Jly2	3.13	2	2.94			0.00	1.05	1.20	0.75	2.35		1.41		0.16		0.25	
Ags1	3.58	2	2.16			0.40	0.00	1.10	0.50		1.79		1.63		0.19		0.29
Ags2	3.58	2	2.16			0.40	0.40	0.00	0.27		0.95		0.79		0.09		0.14
Spt1	3.99	2	1.45			1.15	0.40	0.40	0.65		2.59		3.14		0.36		0.56
Spt2	3.99	2	1.45			1.15	1.15	0.40	0.90		3.59		4.14		0.48		0.74
Oct1	4.61	2	1.90			1.15	1.15	1.15	1.15		5.30		5.41		0.63		0.96
Oct2	4.61	2	1.90			0.50	1.15	1.15	0.93		4.30		4.41		0.51		0.78

LP (FAO Fomulas)
CROPWAT Data

Figure 5: Water Needs in Waeapo Watershed

Kc for rice field and soybean according to analysis and modified on CROPWAT 8.0 consecutive data is 1,05 ; 1,10 ; 1,10 ; 1,20 ; 1,20 ; 1,20 ; 1,20 ; 1,05 ; 0,00 and 0,40 ; 0,40 ; 1,15 ; 1,15 ; 1,15 ; 0,50. The water layer replacement used for the rice field is 1,1 ; 1,1 ; 2,2 ; 1,1 ; 1,1 . The average Kc value on three class then used to found the ETc. ETc is used for measure the water needs in rice field. The highest ETc in week two on June with 5.12 mm/day. The water needs in irrigation rice field area on June is 0.59 mm/day. Then it convert into l/sec, and multiplied by 0.65 as efficiency of all channel.

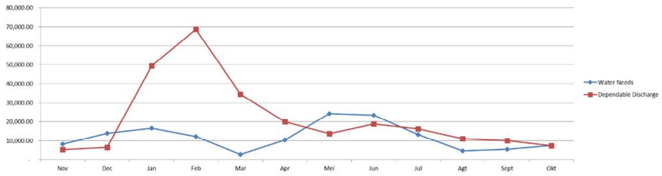

Figure 6: Water Balance Waeapo Watershed

Water balance in waeapo watershed, showed that there were five month deficit, with total amount of deficit were about 25.695,23 l/sec. Fortunately, another seven month was sufficient for the extension of new fields, with leaving water availability about 118.111,28 l/sec a year. Five months in water balance deficit condition were November, December, May, June and October. The rest is wet month with abundant water discharge, so it could be used for the deficit month with any physical or biological treatment applied [31-32].

4. CONCLUSION

Land use change into rice field on waeapo watershed didn't have any significant effect on water availability in waeapo watershed. The global cropping plan on waeapo watershed was divided into 3 groups namely Category I which includes the sub-districts of Namlea and Waeapo, Category II which includes Lolong Guba and Fena Leisela and Category III which includes Waelata and Kayeli. There were five months deficit: November, December, May, June and October, while the rest was in surplus water condition. Global Cropping Plan was very useful to forecast how water availability of a region in next one year and how to manage the water resources in an area. Cropping plan with Rice – Rice – Soybean in waeapo watershed, and planting time at November 15 with rice field, showed that the water availability in one year was about 118,111.28 l/sec of water. It should have a great result when the assumption of the analysis were reduction and comparing with field observation. Overall, LULCC into rice field in waeapo watershed have a high potential to Buru District to contribute food security in Maluku Province.

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