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Water Shortage at Several Sub Watershed into Wonogiri DAM

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Abstract

The study was conducted at several selected sub-watersheds (Temon, Wuryantoro, Alang, and Keduang Sub-watersheds) in Wonogiri District. These four sub-watersheds are main rivers whose outlets flow into Wonogiri Dam. The study calculated the water supply and water demand for various uses at four sub-watersheds. The Thornwaite and Mather method was used to estimate the water supply. The results indicated that: (1) The water supply of Temon Sub-watershed was 35,435,875 m3 and the annual water demand was 51,053,247 m3, therefore there was a deficit of 30,59 % per year; (2) The water supply of Wuryantoro Sub-watershed was 17,788,417 m3 and the water demand was 22,413,430 m3 per year, therefore the deficit was 20.64% per year; (3) The water supply of Alang Sub-watershed was 31,372,317 m3 per year and the water demand was 69,566,500 m3 per year, therefore the deficit was 54.90% per year; (4) The water supply of Keduang Sub-watershed was 438,527,889 m3 and the water demand was 452,611,219 m3 per year, thus, the deficit was 3.11% per year; (5) those sub-watersheds need improvements especially effective water resources plans, water allocation and distribution based on the determined priority, e.g., retention basin, low evapotranspiration re-vegetation, well-managed infiltration, water resources protection, and water reservoir construction.

INTRODUCTION

As one of natural resources, water is a basic requirement for the survival of living things on earth. In the hydrological cycle, water has a high mobility in which water continuously moves *around* the system all the time through precipitation, evaporation, transpiration, and run-off. Human population growth is accompanied by an increased demand of food, paddy field area, and industry along with extensive technology development that can lead to relatively decreased water quantity and quality. Despite the fact that the amount of water on the earth is essentially constant, the distribution is uneven either in geographic location or time (Soewarno and Srimulat Yuningsih, 2000).

Watershed management is a series of interrelated activities with full consideration to achieve a goal (Pusposutarjo, 1989). The objective of watershed management is to maintain the watershed sustainability in providing the maximum and perpetual benefit for human welfare. To achieve this goal, watershed management is constructed from various aspects including ecosystem management, land management, water management, and human resource management.

Hydrological process of a watershed can be simply depicted by the relation between input of rainfall and process and output of run-off. A particular rainfall will generate a specific run-off. This run-off is affected by the watershed characteristics and highly dependent on the characteristics of the rainfall. The rainfall characteristics consist of the rain density, intensity, and duration, while the watershed characteristics include topography, geology, geomorphology, soils, land cover/vegetation, and land management as well as watershed morphometry (Pramono Hadi, 2006).

Water management is essential to provide the society welfare and security, hence, the information on water supply and demand of a respective area

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is required. Despite the fact that water is plentiful, its quality is limited in addition to its uneven availability in accordance to time and geographical location, as well as its unstable quality. Therefore, without any human intervention, more or less, it is not possible to use the water for human prosperity and security based on the amount, quality, and expected time and location.

In the past time, water was used for a few of daily needs and its availability was abundant, it hardly became a real problem as the supply always meets the demand. On the contrary, current demand on water is increasingly agitating regarding with water quality and quantity. People should manage the water wisely so as the entire human needs are completed in well, organized, and sustainable situation particularly in the management of sectors and time, location and quantity, economic or social and cultural needs. Therefore, management of water resources is definitely essential.

For the evaluation of watershed management, one of its parameters is water supply to find out the condition of watershed. To calculate the value of water supply, the potential of water supply is required to be compared with the water demand, both for human consumption (settlement) and land-use pattern determined by the agenda of respective watershed. Thus, the measurement of water supply and demand in a watershed is required. The study aimed to figure out the water supply and the use of surface run-off of Temon, Wuryantoro, Alang, and Keduang Sub-watershed in Solo Upper Watershed.

METHODS

Location

The study was carried out in four sub-watersheds. Administratively, those four sub-watersheds are included in Wonogiri District. Temon Sub-watershed is located in Baturetno Sub-district, Alang Sub-watershed is located in Pracimantoro Sub-district and Giritontro Sub-district, Wuryantoro Sub-watershed is located in Wuryantoro Sub-district, and Keduang Sub-watershed is located in Ngadirojo Sub-district, Nguntoronadi Sub-district, and Slogohimo Sub-district. The selection was based on several considerations as follows: (1) they are main rivers as the intakes of Wonogiri Dam whose sedimentation level is quite high; (2) they

Table 1. Location, Latitude, Geological Formation, and Area of Sub-watersheds.

Sub-watershed	Latitude	Geologic Formation	Area (ha)
Temon	7^0 49' 48.24" - 7^0 52' 51.89" S 110^0 49'' 56.70" – 110^0 52'' 38.50" E	Mixed old volcanic-limestone soil	4.250
Wuryantoro	7^0 49'' 48.24""- 7^0 52'' 38.5"" S 110^0 49' 56.70"" – 110^0 52' 38.50"" E	Mixed old volcanic-limestone soil	1.692
Alang	8^0 01'' 49"" - 8^0 06'' 06"" S 110^0 46' 49.7"" - 110^0 54'10.7"" E	Limestone soil	5.439
Keduang	7^0 42'''27.16" - 7^0 55'' 35.51"" S 110^0 59' 29.29 "" - 111^0 13' 30 "" E	Young volcanic	35.993

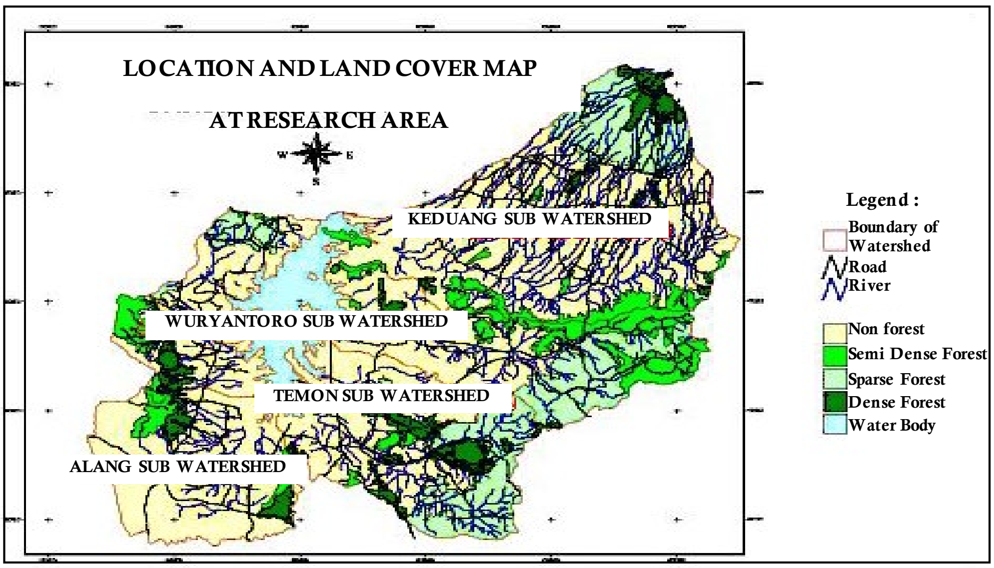

Figure 1. Location and land cover of Temon, Wuryantoro, Alang and Keduang Sub-watershed.

have serious water shortage; and (3) their geological formations are diverse, mixed old volcanic soil-lime in Temon and Wuryantoro, limestone in Alang, and young volcanic soil in Keduang. The latitude of each sub-watershed is presented in Table 1.

Climate

According to Köppen climate classification, the research site is included in Group A or Tropical Climate of Type Aw and Type Am. Temon sub-watershed and Alang Sub-watershed are included in climate type of Aw, Wuryantoro Sub-watershed is included in climate type of Am, Keduang Sub-watershed is included in climate type of D, the rainy season takes place in November–April, meanwhile the dry season occurs in May–October, total wet month is 6–7 months (Schmidt and Ferguson, 1951).

Geology and Geomorphology

Based on the Geological Map of Surakarta Quadrangle 1408-03, Giritontro Quadrangle 1407-6, Pacitan Quadrangle 1507-4 of 1992, scale 1:100.000, Ponorogo Quadrangle 1508-1 of 1997, scale 1:100.000, and Geological Map of Java and Madura Quadrangle III East Java of 1963, scale 1:500.000, a brief description of the geology and geomorphology of the research site is presented as follows.

Temon Sub-watershed

There are 4 (four) geology formations, namely, Semilir, Wonosari–Punung, Mandalika, and Nglanggran. Semilir formation was formed in early Miocene in the form of tuff, breccias, dacitic pumice, tuffaceous sandstone and shale. Formation of Punung Wonosari was formed in the middle Miocene to Pliocene consisting of napalan-tuffaceous limestone, conglomerates limestone, tuffaceous limestone, and siltstone. Mandalika was formed in the early Miocene in the form of dacite-andesite lava and dacitic tuff with diorite dike. Nglanggran formation was formed in the early Miocene of volcanic breccias (agglomerate) and basaltic andesite lava and tuff.

Wuryantoro Sub-watershed

Wuryantoro sub-watershed has the Oyo Formation consisting of hornblende andesite, tuff sandstone, vitreous tuff, tuffaceous marl, and clay. Limestone breccias and conglomeratic limestone are also found out in this formation. The upper of Wuryantoro sub-watershed contains old andesite, in which there are 2 (two) ranges, namely *Igir* Plopoh (Plopoh Range) and *Igir* Kembengan (Kembengan Range). Those two ridges have resistant rocks of tuff and old andesite composed of volcanic sediments at the time of Miocene epoch. Regarding with the climatic and geological conditions, significant geomorphologic processes in the research site included weathering, erosion, and sedimentation. Relatively high temperatures of the site affect the weathering, however, soil formation is hampered by the erosion process, especially in the upstream. In Wuryantoro sub-watershed, erosion rate is advanced in which the sediments transported by the river is relatively low.

Alang sub-watershed

Alang sub-watershed has Kepek Formation whose area is the largest. The major components are marls and gallstones. Marls are composed of calcium carbonate and clay or silt. On the upstream of the Kepek formation, there is Wonosari formation of rocky limestone.

Keduang sub-watershed

Keduang sub-watershed is included in Blitar Sub-zone formation as its dominant area. It is mainly composed of Notopuro breccias and young volcanic. The south of the area is Kembengan Range while the west is alluvial land adjacent to Plopoh Range.

Land use

The land use in the research site consists of dry fields, paddy fields, settlement, and forest. The largest part of the area is in the form of dry fields. The paddy fields in the site are in the form of rainfed, the settlements are villages, forest area in the four sub-watersheds is relatively small, and the lar-

Table 2. Land Use of the Research Site (ha)

Sub-watershed	Dry-field		Paddy field		Village		Forest	
	(ha)	%	(ha)	%	(ha)	%	(ha)	%
Temon	1446	34.00	942	22.20	805	18.90	1057	24.90
Wuryantoro	1035	57.76	238	13.28	305	17.02	214	11.94
Alang	3284	60.50	686	12.63	1145	21.09	314	5.78
Keduang	17210	47.81	11798	32.78	4424	12.29	2561	7.12

gest is in Temon sub-watershed with a percentage of 24.9%. The area of each land use is presented in Table 2.

Soil

The research site has 3 (three) main soil group, namely, laterite, margalite, and limestone soil. Laterite soil is reddish andesite. It has sufficient permeability and water-holding capacity. In the high or steep slopes, the rate of erosion is relatively high, therefore they have an extremely thin layer of soil with numbers of outcrops. This type of soil was found in the upstream of Temon and Wuryantoro sub-watershed.

There were 2 (two) types of margalite soil in the research site found during the study, namely black margalite and black andesitic margalite. Black margalite is clamminess in wet condition and moderate plasticity in hard block formation in dry condition. Generally, it can be found in hilly area with shallow solum. The soil texture of black margalite is very smooth and composed from sand, loam, and clay. Clay is dominant with 70% total content, while black andesitic margalite is also rich in lime (Dames, 1955) Limestone soil in Alang sub-watershed has its reddish-brownish lateric characteristic. It contains of more than 97% CaCo3 mineral, plastic and adhesive, low permeability and water-holding capacity. In dry condition, the soil is cracked in the form of hard blocks. The solum is relatively shallow. Its depth varies from zero at the steep slope to a few meters in the valley.

Surface Water Supply

Calculation of available water supply was done by Thornthwaite-Mather method by considering the obtainable data in the research site, which was the monthly air temperature to find out the potential evapotranspiration, average precipitation, land use, and soil type to estimate the water holding capacity. This method was preferred since the parameters were eligible in representing the measurement of available surface water.

Precipitation

In calculating the available surface water by applying Thornthwaite-Mather method, on-going precipitation data is required. In this study, the required data (precipitation of 1991-2007) is available as the area has been observed by the Research Institute of Forestry Solo.

Air temperature

Air temperature of the research site was calculated by using the data of Pabelan Meteorology Station (106 m above sea level) of PWS Bengawan Solo Project with the equation as follows (Mock,1973).

$$\mathbf{T = 0.006\ (H - H_1)^0C}$$

where: (1). T = temperature difference; (2). H = height of the local station (meter); and (3). H_1= average height of the research site

Calculation of Uncorrected Potential Evapotranspiration (EP*)

The uncorrected monthly potential evapotranspiration (EP*) was identified based on the air temperature with the equation as follows:

$$(1).\ EP^* = 1.6\left(\frac{10\,T}{i}\right)^{a};\ (2).\ I = \sum_{n=1}^{12} ;\ (3).\ i = \left(\frac{T}{5}\right)^{1.514};$$

and (4). $a = 0.000000675\ I^{3} - 0.000077\ I^{2} + 0.017921 + 0.49239$

Where : (1). Ep * = uncorrected potential evapotranspiration; (2). T = monthly air temperature; (3). I = annual temperature index; (4). i = monthly temperature index; and (5). a = constant. In addition to the equation, it is also available in Table Thornthwaite-Mather based on the air temperature.

Corrected Monthly Potential Evapotranspiration (EP)

The corrected monthly Potential Evapotranspiration (EP) was calculated by using the equation as follows:

EP = f. EP*

Where:

f = correction factor based on the latitude of research site

Monthly Precipitation minus Corrected Monthly Potential Evapotranspiration (P-EP)

P - EP is the difference of precipitation and potential evapotranspiration. The value was required to determine the water surplus and deficit in the humid or wet period, the negative value of P-EP indicated the precipitation has insignificant effect on supporting the water supply of vegetation-covered area. Meanwhile, the positive value of P-EP indicated the water surplus in a given period in a year to return soil moisture and surface water (run-off).

Accumulation Potential of Water Loss (APWL)

Accumulation potential of water loss (*APWL*) is significant information to figure out the potential of water loss in the dry months. Measurement of the value of APWL is based on the negative value of P-EP, furthermore, it was sequentially summed with the subsequent negative values of P-EP to the last negative value of P-EP, therefore a cumulative value was obtained.

Soil Moisture Difference (D St)

The value of changes in soil moisture is calculated based on the difference between soil moisture reserves of previous months and soil moisture reserves of the month.

Actual Evapotranspiration (AE)

The value of actual evapotranspiration is obtained from the conditions of:

1. If P > EP thus AE = EP
2. if P < EP thus AE = P + D ST

Deficit

The value of deficit (D) is obtained from the difference of EP - AE,

Surplus

The value of surplus (S) is obtained from the equation of S = (P - EP) - D ST

Available surface water/runoff

Available surface water is obtained from the water surplus whose amount is presumed of 50% and the remains will be the supply for the subsequent month.

Water Demand

Water demand is calculated based on the domination of land use in the research site as follows: (1). Dry fields consist of water demand for annual and seasonal crops; (2). Paddy fields/irrigated fields consist of once and twice harvest a year and also 5-times harvest in two years; (3). Settlement; and (4). Forest.

Dry fields

Generally, the plant composition of dry fields is peanuts, corn, and cassava. Peanut and corn are usually harvested twice a year (planting season I and II). In the third planning season, cassava is usually the only planted crop. The water demand for this kind of composition is estimated at 1200 mm/year (Dumairi, 1992).

Paddy fields/Irrigated fields

The water requirement for irrigated field is assumed of 1 liter/sec/ha. It is converted into the unit of mm and the result is 1200 mm/yr, in the case the field has once harvest a year. Harvesting twice a year will make the water requirement increases into 2400 mm/yr. The field with once paddy and once crop harvest in the same year, thus the water requirement will be 2000 mm/yr (Dumairi, 1992).

Settlement/population

In providing the water supply, we can utilize a variety of resources classified into ground water resources, surface water resources, rain water, and sea water. The variation of resources used as the water supply of household consumption will also determine the different pattern of respective water utilization (Alif Noor Anna, *et al.*, 2000).

The water demand for the population in the research site was estimated to 1200mm/yr. It was obtained by assuming the population density of 700 people/km^2. The water demand of an individual was 80 liters/day. Bigger animal livestock density of 40/ km^2 requires approximately 25 liters/day/ animal, meanwhile, small animal livestock density of 150/km2 need requires approximately 5 liters/ day/animal (Dumairi, 1992).

Forest

The evapotranspiration rate of broad-leaved forests ranges from 800-1400 mm/yr based on the environmental conditions. In the condition of moderate soil fertility, its evapotranspiration rate is approximately 1000 mm/yr. The evapotranspiration rate of mountainous natural forests ranges between 500-1200 mm/yr regarding with the elevation of the area. The higher the elevation, the lower the evapotranspiration rate will be. For area with an elevation of +1000 m above sea level, its evapotranspiration rate is 1200 mm/yr. In addition, in area with an elevation of +2500 m above sea level, its evapotranspiration rate ranges between 500-600 mm/yr. In accordance to those conditions, the water demand for broad-leaved forest is 1000 mm/yr.

Water demand on various land cover

Based on the calculation, the water demand of an area can be estimated. Water demand is highly relied on the pattern of land use. Land use of paddy fields requires the highest level of water demand. It needs relatively high amount of water particularly in the beginning of plantation in January-April depending on the area and slightly declining in May to December (the detail of monthly water demand can be seen in Table 3).

Table 3. Monthly Water Demand (mm) based on Land Use

Land use	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Forest	88	81	90	88	88	79	74	73	75	87	85	92	1000
Paddy field 1x harvest in a year	264	115	39	38	38	34	32	32	33	38	255	276	1200
Paddy field 2x harvests in a year	264	243	270	264	264	115	108	106	110	125	255	276	2400
Paddy field 5x harvest in 2-years	264	243	270	264	264	237	222	219	225	261	255	276	3000
Dry fields	119	109	121	119	119	107	100	99	101	117	115	124	1350
Settlement	106	97	108	106	106	95	89	88	90	103	102	110	1200

Source: Dumairi (1992).

RESULT AND DISCUSSION

Surface Water Supply

Measurement of the surface water supply used Thornthwaite-Mather method by obtaining the data of monthly air temperature to calculate the potential of evapotranspiration, precipitation on average, land use, and soil type for estimating "Water Holding Capacity" (WHC), the result is presented in Table 4.

Water Demand

Measurement of water demand was based on the demand of land use pattern consisting of dry-fields, paddy-fields, settlement, and forest area. In the calculation, mm unit was converted into m^3, by converting the unit of mm into m (divided by 1000) and then converting the unit area of hectares to m^2 (multiplied by 10,000), so as to convert the unit of mm into m^3 was by simply multiplying 10 X land area (ha). Results of the calculation of surface water supply and demand are presented in Table 4.

Water Supply

Water supply in Temon sub-watershed was 35,435,875 m^3/yr, while the demand of was 51,053,247 m^3/yr, therefore, the water supply used to fulfill the water demand was 69.41% with the deficit of 15,617,372 m^3 (30.59 %). Water shortage took place in January and May–December ranging between 1.51–99.24% and the highest was in November of 99.24% with water supply was only 44,326 m^3 and water demand was 5,841,317 m^3, hence, it is vital to solve this water shortage particularly in those months.

The annual water supply in Wuryantoro was 17,778,417 m^3, while the demand was 22,413,430 m^3, therefore the water supply was merely 79.36% of the demand with the shortage of 4,625,013 m^3 (20.64%). The shortage took place in May–November ranging between 27.17–97.92% and the highest shortage happened in October of 97.92% with water supply only 37,585 m^3 and the demand was 1,806,340 m^3. Maximum effort should be made in this month.

Table 4. Water Supply and Water Demand (m^3) of Temon sub watershed.

No	Month	Water supply (m^3)	Water demand (m^3)	Prosentase supply (%)	Surplus/ Shortage	Prosentase (%) Surplus/ Shortage
1	January	5900901	5991320	98,49	-90419	-1,51 (Shortage)
2	February	8080412	4296365	188,08	3784047	88,08 (Surplus)
3	March	8010987	3937412	203,46	4073575	103,46 (Surplus)
4	April	5697644	3861835	147,54	1835809	47,54 (Surplus)
5	May	2848822	3861835	73,77	-1013013	-26,23 (Shortage)
6	June	1418431	3466987	40,91	-2048556	-59,09 (Shortage)
7	July	709215	3245797	21,85	-2536582	-78,15 (Shortage)
8	August	354608	3212720	11,04	-2858112	-88,96 (Shortage)
9	September	177304	3288297	5,39	-3110993	-94,61 (Shortage)
10	October	88652	3798207	2,33	-3709555	-97,67 (Shortage)
11	November	44326	5841317	0,76	-5796991	-99,24 (Shortage)
12	December	2104573	6251155	33,67	-4146582	-66,33 (Shortage)
	Total	35435875	51053247	69,41	-15617372	-30,59 (Shortage)

(Souce : Result of calculated)

Table 5. Water Supply and Water Demand (m^3) of Alang sub watershed

No	Month	Water supply (m^3)	Water demand (m^3)	Prosentase supply (%)	Surplus/ Shortage	Prosentase Surplus/ Shortage (%)
1	January	3552381	7222810	49,18	-3670429	-50,82 (Shortage)
2	February	4246432	5743550	73,93	-1497118	-26,07 (Shortage)
3	March	11792534	5769830	204,38	6022704	104,38 (Surplus)
4	April	5902012	5667930	104,13	234082	4,13 (Surplus)
5	May	2951006	5667930	52,06	-2716924	-47,94 (Shortage)
6	June	1475503	5091250	28,98	-3615747	-71,02 (Shortage)
7	July	737752	4762720	15,49	-4024968	-84,51 (Shortage)
8	August	368876	4715210	7,82	-4346334	-92,18 (Shortage)
9	September	184438	4817110	3,83	-4632672	-96,17 (Shortage)
10	October	92219	5564590	1,66	-5472371	-98,34 (Shortage)
11	November	46109	7015290	0,66	-6969181	-99,34 (Shortage)
12	December	23055	7528280	0,31	-7505225	-99,69 (Shortage)
	Total	31.372.317	69.566.500	45,10	-38.194.183	-54,90 (Shortage)

(Souce : Result of calculated)

Table 6. Water Supply and Water Demand (m^3) of Keduang sub watershed.

No	Month	Water supply (m^3)	Water demand (m^3)	Prosentase supply (%)	Surplus/ Shortage (m^3)	Prosentase Surplus/ Shortage (%)
1	January	85981258	58568244	146,81	27413014	46,81 (Surplus)
2	February	82837547	38692275	214,09	44145272	114,09 (Surplus)
3	March	62272688	32509073	191,55	29763615	91,55 (Surplus)
4	April	43128092	31907182	135,17	11220910	35,17 (Surplus)
5	May	21564046	31907182	67,58	-10343136	-32,42 (Shortage)
6	June	10782023	28652840	37,63	-17870817	-62,37 (Shortage)
7	July	5391012	26818634	20,10	-21427622	-79,90 (Shortage)
8	August	2695506	26576673	10,14	-23881167	-89,86 (Shortage)
9	September	1347753	27178564	4,96	-25830811	-95,04 (Shortage)
10	October	11353831	31404623	36,15	-20050792	-63,85 (Shortage)
11	November	36450254	57272100	63,64	-20821846	-36,36 (Shortage)
12	December	74723879	61123829	122,25	13600050	22,25 (Surplus)
	Total	438.527.889	452.611.219	96,89	-14.083.330	-3,11 (Shortage)

(Souce : Result of calculated)

Table 7. Water Supply and Water Demand (m^3) of Wuryantoro sub watershed

No	Month	Water supply (m^3)	Water demand (m^3)	Prosentase supply (%)	Surplus/ Shortage	Prosentase Surplus/ Shortage (%)
1	January	2983304	2378550	125,43	604754	25,43 (Surplus)
2	February	3922771	1876150	209,09	2046621	109,09 (Surplus)
3	March	3689667	1871960	197,10	1817707	97,10 (Surplus)
4	April	2405448	1838410	130,84	567038	30,84 (Surplus)
5	May	1202724	1651400	72,83	-448676	-27,17 (Shortage)
6	June	601362	1544920	38,93	-943558	-61,07 (Shortage)
7	July	300681	1529340	19,66	-1228659	-80,34 (Shortage)
8	August	150340	1562340	9,62	-1412000	-90,38 (Shortage)
9	September	75170	1562890	4,81	-1487720	-95,19 (Shortage)
10	October	37585	1806340	2,08	-1768755	-97,92 (Shortage)
11	November	908760	2311210	39,32	-1402450	-60,68 (Shortage)
12	December	1510605	2479920	60,91	-969315	-39,09 (Shortage)
	Total	17.788.417	22.413.430	79,36	-4.625.013	-20,64 (Shortage)

(Souce : Result of calculated)

Water supply in Alang sub-watershed was 31,372,317 m^3 per year while the water demand was 69,566,500 m^3, hence, the water supply was merely 45.10% with a water shortage of 38,194,183 m^3 (54.90%). The water shortage is almost evenly in each month, which in January, February, May, June, July, August, September, October, November, and December, ranging between 26.07–99.69%. The highest percentage was endured in December of 99.69% with water supply of 23,055 m3 and the demand of 7,508,280 m3, thus maximum effort should be planned in this month. On the contrary, the surplus was obtained in March and April.

Water supply in Keduang sub-watershed was 438,527,889 m3 per year while the water demand was 452,611,219 m3, therefore the water supply used was 96.89% and the water shortage was 14,083,330 m3 (3.11%). This deficit took place particularly in May to November by 32.42–95.04%. The highest deficit level was in September by 95.04% with water supply of 1,347,753 m3 and water demand of 27,178,504 m3, therefore an effort to fulfill the shortage should be carried out immediately.

CONCLUSIONS

The annual water supply in Temon sub-watershed was 1,684,246 m3 and the water demand was 2,334,744 m3. Thus, there was a water shortage or deficit by 27.86% per year which took place in April to December by 26.07—99.69%. The annual water supply in Wuryantoro sub-watershed was 17,788,417 m3 and the water demand was 22,413,430 m3. Thus, there was a water shortage by 20.64% per year which took place in May to November by 27.17—97.92%. To solve this water deficit problem, several attempts should be carried out in Temon sub-watershed and Wuryantoro sub-watershed whose geological formations were mixed old volcanic rocks-lime, namely: (1) to develop water storage techniques by establishing infiltration wells both on settlements and dry fields; and (2) to maintain the sustainability of land and water resources particularly in the upstream. The annual water supply in Alang sub-watershed was 31,372,317 m3 and the water demand was 69,566,500 m3. Thus, the water shortage was 54.90% per year which took place in January, February, and May to December by 26.07—99.69%. To overcome the water deficit problem in the sub-watershed with lime geological formation, some attempts should be conducted, namely: (1) to develop water resources decent planning system including the preparation of development plans, utilization plans, and water use plans with regard to various purposes according to the specified priority; (2) to develop the use of groundwater in the possible area; (3) to establish water conservation (water reservoir); and (4) to preserve the land and water resources in the upstream.The annual water supply in Keduang sub-watershed was 438,527,889 m3 and the water demand was 452,611,219 m3. Thus, the water shortage was 3.11% per year that took place in May to November by 32.42—95.04%. To solve the relatively low water shortage problem in the sub-watershed with geological formation of young volcanic rocks, some efforts should be conducted, namely: (1) to maintain the prevailing irrigation and water conservation for their effectively functions; and (2) to preserve the land and water resources in the upstream, in particular.

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