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IMPROVING CARRYING CAPACITY BY DEVELOPING RAINWATER HARVESTING: A CASE OF OYO WATERSHED, GUNUNGKIDUL, INDONESIA*

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Abstract

Oyo watershed, which mainly consists of rural area with 517,352 inhabitants and 0.65%/annum population growth, is one of degraded watersheds in Indonesia. Although the local government has formulated various watershed developments, the agriculture productivity of this area is still low. Water resources are the main factor that influences the low carrying capacity of its agriculture sector. Its abundant water availability (225,278,277 m3/year) indicates the potential water carrying capacity. With the annual rainfall of 1,858 mm and the low water demand (25,095,223 m3/year), it has a potential water surplus of 200,183,054 m3/year. In reality, due to the low rainwater harvesting, the carrying capacity is also low, indicated by the value of 0.67 with the population pressure of 1.49. This causes a revenue deficit for farmers who earn Rp 160,017.36 million/year while the normal living cost is Rp 2,483,289.60 million. This indicates the low optimality of water resources management. Therefore, the main target of Oyo Watershed management program is to use the available rainwater optimally to guarantee the stability of water availability in dry seasons.

1. Introduction

Indonesian Law No. 7/2004 on Water Resources stated that a river as the core of a watershed is one form of surface water that must be handled by a fully integrated management with respect to the environment to actualize sustainable water resources usefulness for people's prosperity. However, due to the population development and urbanization, watersheds are seriously degrading. Widodo (2006) illustrated that there were 22 critical watersheds in 1984, 29 in 1992, and 39 in 1994. Then, in 1998, there were 42 critical watersheds, 58 in 2000, and 60 in 2002. It means the management of watershed is very urgent to implement.

Oyo watershed is one of the watersheds that have been degrading in quality. Flowing along the northern part of Gunungkidul Regency, Yogyakarta Province and ending in Opak River,

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this watershed is mainly curvy and hilly with infertile land due to the topography, erosion, lithology, and geohydrology factors. Oyo River is one of the main water resources for agriculture and domestic in Gunungkidul where most of the inhabitants are poor farmers. Various efforts to develop Oyo have actually been formulated. However, the implementation faces some problems, of which water resources is the main factor. The high water availability and low water demand are not supported by the carrying capacity. This irony indicates the low optimality of the existing water resources management. Therefore, the water-resource management program with emphasize on rainwater harvesting (RWH) in Oyo watershed is important to arrange and implement.

2. Carrying Capacity

The carrying capacity of Oyo Watershed is focused mainly on farmland carrying capacity influenced by the water resources and land condition. In this context, farmland carrying capacity means the capacity of water resources, indicated by the water availability, to support the ecosystem. Utilizing the approach of rainfall rate and actual evapotranspiration, the water availability of Oyo River considers the meteorological availability of water because its largest input is from rainfall and the physical condition of the area is not potential to provide groundwater and springs.

The water availability is calculated by multiplying the runoff in a region by the area width. The meteorological secure condition of water availability is 25% - 35% of runoff in an area because, in reality, not all of the runoff available in an area can be the overall water availability. The meteorological water availability of Oyo River is assumed 35% of runoff (Indra Karya, 2003). This is also for anticipating water infiltration, which is not specifically analyzed. The calculation result of water availability in this area is presented in Table 1. Based on Table 1, in general, the water availability of Oyo Watershed is very high. This water availability will then be compared to the water demand of each sub district. The water demand in this watershed is divided into water demand of domestic use, rice field, dry farming, cattle, fishery, and industry. The total water demand of the entire sectors of Oyo Watershed is presented in Table 2.

The potential of water resources can be calculated by subtracting the water availability by the water demand. According to Table 3, all of the sub-districts have a water surplus, indicating that the water resources carrying capacity is high.

Table 1. Water availability of each sub district in Oyo Watershed

Sub district	P (mm/year)	EA (mm/year)	P – EA (mm/year)	RO = P - EA (m/year)	35% RO (m/year)	Sub district Width (ha)	Water Availability (m^3/year)
Ngawen	2137	1338	799	0.799	0.2797	4659	13028894
Nglipar	2209	1330	879	0.879	0.3077	7387	22726106
Patuk	2347	1336	1011	1.011	0.3539	7204	25491354
Gedangsari	1960	1130	830	0.830	0.2905	6811	19785955
Karangmojo	1665	1120	545	0.545	0.1908	8012	15282890
Playen	2434	1321	1113	1.113	0.3896	10526	41004033
Semin	1632	1143	489	0.489	0.1712	7892	13507158
Wonosari	1893	1232	661	0.661	0.2314	7551	17469239
Ponjong	2123	1215	908	0.908	0.3178	10449	33206922
Paliyan	1755	1225	530	0.530	0.1855	5807	10771985
Dlingo	1850	1185	665	0.665	0.2328	5587	13003743

Note: P: precipitation; EA: actual evapotranspiration; RO: run off. Annual rainfall: 1858 mm
Source: Calculated from the Rainfall Data (1981-2005); Bakosurtanal/Topographic Map (2003); Gunungkidul in Figures (2005); Bantul in Figures (2005)

Table 2: Total water demand per sub district and the entire Oyo Watershed (m3/year)

Sub-district	Water Demand (m3/year)						
	Domestic	Rice Field	Dry farming	Cattle	Fishery	Industry	Total
Ngawen	1058062	1086	960	94655	0	809935	1964698
Nglipar	1033213	270	1277	139027	153300	688938	2016024
Patuk	930137	1145	1447	120435	0	547683	1600846
Gedangsari	1184848	1286	1615	83345	25550	412815	1709460
Karangmojo	1666269	602	1106	138389	408800	576883	2792048
Playen	1761315	235	2128	176424	0	584000	2524101
Semin	1614994	1916	1860	160878	0	921990	2701638
Wonosari	2889158	81	2319	176849	25550	1298123	4392079
Ponjong	1659378	681	3481	197364	306600	539288	2706791
Paliyan	935977	31	1356	107759	0	390733	1435855
Dlingo	1086269	505	1063	120595	25550	17703	1251685
Total	15819618	7837	18611	1515720	945350	6788088	25095223

Source: Calculated from Indra Karya (2003); Public Work Department of Yogyakarta Province (2005); Nippon Koei, Co. Ltd. (2003); and Sutikno (1999)

Based on the value of WRCC in the table, the optimal population (OP) and time required to elapse WRCC can be estimated. OP is the number of people who can be supported by the existing water resources. Based on the value of OP, the elapsing time is determined. In this case, it is assumed that the water availability per year and number of water users, such as industry, agriculture, fishery, and cattle are normally static, whereas the population is dynamic because the variable that can be calculated using the projection method is only population.

Table 3: Water availability, water demand, water surplus, and water resources carrying capacity (WRCC)

Sub district	Water Availability m^3/year	Water Demand m^3/ year	Water Surplus m^3/ year	WRCC
Ngawen	13028894	1964698	11064195	663,15
Nglipar	22726106	2016024	20710081	1127,27
Patuk	25491354	1600846	23890508	1592,37
Gedangsari	19785955	1709460	18076495	1157,44
Karangmojo	15282890	2792048	12490842	547,37
Playen	41004033	2524101	38479932	1624,50
Semin	13507158	2701638	10805520	499,96
Wonosari	17469239	4392079	13077160	397,74
Ponjong	33206922	2706791	30500131	1226,80
Paliyan	10771985	1435855	9336130	750,21
Dlingo	13003743	1251685	11752058	1038,90
The entire watershed	225278277	25095223	200183054	897,69

Table 4: Estimation of optimal population and elapsing time of water resources carrying capacity

Sub district	Population (people)	Optimal Population (people)	Population Growth (%)	Elapsing Time (Year)
Ngawen	36235	415146	0,54	6
Nglipar	35384	744633	0,54	7
Patuk	31854	850022	0,75	6
Gedangsari	40577	659635	0,53	7
Karangmojo	57064	484833	0,12	19
Playen	60319	1378125	0,28	13
Semin	55308	425360	0,06	35
Wonosari	79155	437433	0,74	3
Ponjong	56828	1101353	0,43	8
Paliyan	32054	351784	0,51	6
Dlingo	37201	439669	2,68	2
The entire watershed	521979	7287993	0,65	10

Based on the estimation in Table 4, the average carrying capacity of Oyo Watershed will be elapsed in 10 years, a quite short and worrying figure. Only Semin Sub district can stand more than 25 years. However, the carrying capacity mentioned here does not describe the actual condition. Generally, the physical condition of Oyo Watershed, except Wonosari as part of riverside, still does not support the demand of inhabitants. The geological and morphological condition does not support the hydrological aspect of absorbing rainwater and supplying groundwater. Consequently, the rainwater potential is not fully utilized, and it only becomes runoff to the sea. The long dry months worsen this problem. So far, the people count on rainwater for domestic use in rainy seasons and some sort period after that; in dry seasons, they purchase water. Furthermore, most of the agricultural lands are dry-farming lands and rainwater-catching lands. The engineering effort to optimize rainwater is still insufficient, indicating the low rainwater harvesting effort in domestic as well as communal scale. As this area depends mainly on rainwater, the effort should be focused on systematic rainwater harvesting.

To approach contextually the agrarian condition of Oyo Watershed, the carrying capacity analysis should be connected to farmland carrying capacity that is more relevant to the agricultural aspect. The calculation of farmland carrying capacity uses the following formula (1) (Lupiyanto, 2005).

$$PP = Z\,(1 - a)\,\frac{f\ Pn}{b\ Ltot} \qquad \text{.................................(1)}$$

Note:

PP	: population pressure over farmland
Z	: land width for a proper life (Ha/person)
f	: ratio of farmers to population
Pn	: population (people)
Ltot	: total width of farmland (Ha)
b	: ratio of farmers' farmland width
a	: ratio of revenue from other sources than agriculture

To determine the land width required to live properly (Z), the following mathematical operation is used formula (2).

$$Z = \frac{(LL1 \times K/N1) + (LL2 \times K/N2) + \ldots + (LLn \times K/Nn)}{LL1 + LL2 + \ldots + LLn} \qquad \text{..................(2)}$$

$$Nn = na + nb + \ldots + nk$$

Note:

Z	: land width for a proper life (Ha/person)
LL1,2,..n	: width of farmland types 1,2,…,n (herein are rice field and dry-farming land) (Ha)
K	: proper life necessities (Rupiah/person/year)
Pn	: number of household members (people)

N1,2,..,n	: average production of all crops in each type of farmland (Rupiah/Ha/year)
na,b,…k	: average production of each crop in a certain type of agriculture (Rupiah/Ha/year)

The value of farmland carrying capacity is the opposite ratio of population pressure (PP) with the formula: CC = 1/PP, where CC: environment or farmland carrying capacity and PP: population pressure. The formula can be developed to estimate the balance between population and CC, which is:

1. Optimal Population (farmers) that farmlands are able to support (if CC is not elapsed); OP: Optimal Population = CC x f Pn
2. Population (farmers) that farmlands are not able to support (if CC is elapsed); UP (Unsupported Population) = (1- CC) x f Pn
3. Optimal width of farmland that are able to support certain population (farmers) (if CC is not elapsed); OF = b.Ltot x 1/ CC
4. Additional width of farmland (if CC is elapsed); AF (Additional Farmland) = (1/CC – 1) x b.Ltot:

The formula can also be developed to estimate the time required to elapse the carrying capacity (if CC is not elapsed), which is:

$$Tt = \frac{\text{Log OP} - \text{Log Po}}{\text{Log }(1+r)} \quad \text{................................(3)}$$

Note:

Tt	: time required to elapse CC (year)
OP	: optimal population (farmers) that farmlands are able to support (people)
R	: population growth (%/year)
Po	: population of the basic year (people)

The calculation result of PP and CC is presented in Table 5 as follows.

According to Table 5, the population pressure in Oyo Watershed is generally high, except in Patuk Sub district. The criteria for measuring the level of population pressure is if the value of PP is more than 1 (PP>1), the population pressure over the farmland in the area is high. Meanwhile, if the value of PP is less than 1 (PP<1), the population pressure in the area is low. The farmlands herein are the lands producing crops, such as rice fields and other dry farming lands. High population pressure means the crop production is lower than the population demand for proper life.

Table 5. PP (population pressure) and CC (environment carrying capacity) of Oyo Watershed

No	Sub district	PP	CC
1	Paliyan	6,01	0,17
2	Playen	4,56	0,22
3	Wonosari	4,36	0,23
4	Karangmojo	5,61	0,18
5	Semin	1,84	0,54
6	Ponjong	3,17	0,32
7	Nglipar	3,64	0,27
8	Gedangsari	2,70	0,37
9	Patuk	0,19	5,19
10	Ngawen	2,97	0,34
11	Dlingo	6,18	0,16
	Total	1,49	0,67

Farmland carrying capacity is the opposite of population pressure. If PP is high, CC is low. CC is low if the value is less than 1 (CC<1) and high if the value is more than 1 (CC>1). The most significant effect of PP is the high level of poverty. According to the data of Statistic Bureau/BPS (2005), all areas of Oyo Watershed have a high poverty level, indicating the low farmland carrying capacity. The low farmland carrying capacity occurs generally because of farmland productivity factor rather than population factor. The data from BPS (2005) indicated that the population growth and population density were still low, except in Wonosari Sub district. It means the population factor does not much influence the population pressure and the low farmland carrying capacity. On the other hand, the farmland factor indicates the low productivity. Table 6 shows the average crops productivity compared to the population demand for proper life (BPS, 2005) in the area.

The problem raises a greater concern considering the decrease in agriculture contribution. Table 7 shows the decrease in agriculture contribution in Gunungkidul and Bantul, which is assumed as influencing the condition of Oyo Watershed, while the increase occurs to non-real sector.

Table 6. Agriculture productivity and proper life demand in Oyo Watershed in 2005

No	Sub-districts	Average Productivity (Rupiah/Ha/ yr)	Farmland Width (Ha)	Agriculture Revenue (Million Rupiah/yr)	Population	Total Proper Life Demand (Million Rupiah/yr)
1	Paliyan	2.072.666	2088,15	4.328,04	31657	151.953,60
2	Playen	1.495.553	4140,92	6.192,96	59896	287.500,80
3	Wonosari	1.525.572	4813,37	7.343,14	78464	376.627,20
4	Karangmojo	2.348.643	3638,6	8.545,77	56597	271.665,60
5	Semin	3.456.229	5461,17	18.875,06	54906	263.548,80
6	Ponjong	2.364.827	7997,79	18.913,39	56331	270.388,80
7	Nglipar	1.589.026	3112,53	4.945,89	35048	168.230,40
8	Gedangsari	2.360.015	4605,36	10.868,72	40221	193.060,80
9	Patuk	19.178.758	4043,38	77.547,01	31569	151.531,20
10	Ngawen	2.340.679	3194,64	7.477,63	35867	172.161,60
11	Dlingo	2.227.261	1966,46	4.379,82	36796	176.620,80
	Total	3.723.566	42974,22	160.017,36	517352	2.483.289,60

Source: Adapted from Gunungkidul and Bantul in Figures 2005 (BPS)

Table 7. Growth rate of each sector contribution based on the prices valid in Gunungkidul and Bantul Regency in 2004 and 2005

No	Sector	Gunungkidul (%)		Bantul (%)		Growth Rate (%)	
		2004	2005	2004	2005	Gunung kidul	Bantu l
1	Agriculture	35,73	35,4	22,98	22,02	-0,92	-4,18
2	Mining	2,37	2,21	1,07	1,01	-6,75	-5,61
3	Manufacturing Industry	12,18	11,48	21,09	20,89	-5,75	-0,95
4	Electricity, Gas, and Clean Water	0,69	0,7	1,18	1,21	1,45	2,54
5	Construction	7,3	7,55	8,26	8,64	3,42	4,60
6	Trading, Hotel, and Restaurant	14,04	14,38	17,43	17,21	2,42	-1,26
7	Transportation and Communication	6,44	6,62	6,53	7,19	2,80	10,11
8	Finance	4,63	4,66	6,55	6,81	0,65	3,97
9	Services	16,62	17,01	14,91	15,03	2,35	0,80

Source: AdaptedProcessed from Gunungkidul in Figures and Bantul in Figures 2004 and 2005

The productivity of farmlands is influenced by the natural factor and processing technology. The natural factor or physical environment is for example the climatology, water potential, soil fertility, hydrogeology, topography, etc., while the technological factor is the system and processing technique. According to the existing condition, it is reasonable if the agriculture productivity is low. Most of Oyo Watershed areas climatologically have 5-6 successive dry months (Rainfall Data 1981-2005), while technically the irrigation system and technique is still limited (Public Work, 2005), shown by the fact that most of the farmlands are rainwater catching, and some depend on a simple and half-technical irrigation system (Table 8). Consequently, in dry seasons, agriculture productivity is less optimal than in rainy seasons because of poor rainwater harvesting that leads to water deficit.

Table 8. Farmland width according to irrigation system in Oyo Watershed 2005 (Ha)

No	Sub- district	Technical	Half-Technical	Simple	Non Public Work	Rain fed	Polder	Total
1	Paliyan	-	-	-	-	31	-	31
2	Playen	-	-	125	-	113	-	238
3	Wonosari	-	32	26	24	-	-	82
4	Karangmojo	-	382	153	45	30	-	610
5	Semin	-	175	76		1592	-	1843
6	Ponjong	156	118	88	129	199	-	690
7	Nglipar	-	-	144	-	130	-	274
8	Gedangsari	-	30	-	-	1256	18	1304
9	Patuk	-	149	185	-	827	-	1161
10	Ngawen	-	13	8	-	1080		1101
11	Dlingo	-	110	53	50	299	-	512
	Total	156	420	478	179	3791	18	5042

Source: Gunungkidul and Bantul in Figures 2005 (BPS)

Geomorphologically and geologically, Oyo Watershed is dominated by hills with narrow valleys, rock exposures, and relatively thin soil layer. This condition obstructs the development of agriculture if people still depend on a simple technique and system. Moreover, the soil condition also indicates low fertility, requiring more water contribution and agriculture commodity adjustment. Therefore, the influence of water resources condition to agriculture and carrying capacity is quite significant. Consequently, it requires a water-resource management system in Oyo Watershed to support the agricultural sector and people’s lives.

The low farmland carrying capacity indicates the low contribution of non-agricultural sector. Therefore, the development of this sector is urgently needed. The existing condition of non-agricultural sector is still left behind and not integrated to the agricultural and environmental sector. Oyo Watershed as an agrarian area with the domination of natural environment factor needs a synergic direction in developing the environment and natural resource based development of non-agricultural sector.

Generally, the population unsupported by farmlands (UP) is quite significant, i.e. 236,461 people or 45.71% of total population (Table 9). It means the existing farmlands can only support 44.20% people. Assuming that the land productivity is constant, additional farmlands required are very large, i.e. 112,624.20 Ha or 249.93% of the existing farmland. Adding the number of farmlands for rice fields and dry-farming lands is very difficult to implement considering that the existing non-productive lands are critical lands; on the other hand, farmlands are converted and their width keeps decreasing. The most possible alternative is to optimize the community-based forest management system by intercropping forest cultivation. This is supported by the general condition that people's forests have high development potential. As an overview, according to the data from Forestry and Plantation Agency of Gunungkidul Regency (2005), of 52,399 Ha people's forests that can be benefited, only 16,119 Ha or 40.76% are managed. It means there are about 38,280 Ha or 69.24% potential to develop.

Table 9. Estimation of Farmland Carrying Capacity in Oyo Watershed

No	Sub-district	OP (People)	UP (People)	OF (Ha)	AF (Ha)	Tt (Year)
1	Paliyan	-	20138	-	10461,48	-
2	Playen	-	30111	-	14746,00	-
3	Wonosari	-	25177	-	16179,42	-
4	Karangmojo	-	33821	-	16770,26	-
5	Semin	-	19335	-	4582,94	-
6	Ponjong	-	29460	-	17348,93	-
7	Nglipar	-	20010	-	8221,58	-
8	Gedangsari	-	21371	-	7823,84	-
9	Patuk	135098,3	-	778,96	-	2,60
10	Ngawen	-	16987	-	6297,22	-
11	Dlingo	-	20049	-	10192,55	-
	Total	-	236461		112624,20	-

Note: OP: Optimal Population (farmers); UP: Unsupported Population (farmers); OF: Optimal Farmland; AF: Additional Farmland; Tt: Elapsing time for Farmland Carrying Capacity

3. RWH Development

As mentioned before, the water resources potential in Oyo that has high rainfall of 1,858 mm/year is high (Table 3). However, it does not cause Oyo to have water surplus throughout the years because most rainwater becomes surface runoff rather than absorbed into the ground as infiltrated water. Moreover, the lithology condition cannot intercept and retain water in the form of aquifer and soil. The inexistence of aquifer and aquiclude causes groundwater scarcity, particularly in Baturagung Hill Range, i.e. Patuk, Gedangsari, Ngawen, Nglipar, Semin and some parts of Ponjong Subdistrict. On the other hand, the areas in Wonosari Basin, which are Wonosari, Playen, and Karangmojo, have aquifers with different capacity to flow water.

The high amount of wasted rainwater makes the areas in Oyo undergo a water deficit and drought in dry seasons. The drought is also caused by the long dry months, so the drought index of the area is very high. Therefore, the target of Water Resources Management Program of Oyo Watershed is more on harvesting rainwater optimally to guarantee the water availability in dry seasons. Meanwhile, the recommended RWH alternatives as the effort to provide water are as follows (Prinz, 1994; Prinz, and Malik, 2002; Widodo et al, 2005):

1. *Lake, ponds and small dam development;* surface runoff from agricultural area is flown using the drainage system and reserved in lake, ponds, or small dam. Water reserved in the systems is used for fulfilling domestic, cattle, fishpond, and irrigation demand. These lakes can be simply made, natural or technical.
2. *Rooftop RWH;* water-resistant wells and other material are made to catch and retain rainwater from house roofs. The model of this water-resistant ones can be on the surface (concrete walls are not plowed under) or underground (concrete walls are plowed under).
3. *River polders;* river polders are used to retain river water in rainy seasons. Water catchment by these river polders is usually used only for fulfilling domestic demand.
4. *RWH on river bedrock;* curved river bedrocks will retain water in rainy seasons when river water debit is high; therefore, in dry seasons, the reserved water can be used to fulfill domestic demand.
5. *River wells;* the wells are made in the middle of or beside the river using concrete walls as a water catchment area in rainy seasons and water reservoir in dry seasons for fulfilling the demand of domestic and irrigation of drought-resistant crops particularly in the riverside area.
6. *Reforestation;* the soil of a water catchment area that functions to catch and reserve water as an aquifer needs to be conserved in order to have a higher capacity of water infiltration. This method is suitable for Oyo Watershed area that has an aquifer, such as Wonosari, Playen, and Karangmojo. Land destruction along riverbanks can cause damage to the river morphology. Consequently, the river water debit decreases, and the

catchment capacity of river also lessens. Therefore, conservation by reforestation is required along riverbanks to retain rainwater and decrease the rate of river erosion.

7. *Terracing;* this model is expected to lessen the runoff rate, especially in sloping areas so that rainwater can be reserved longer in rice fields or dry-farming lands.

4. Outlook

The poverty of people living in Oyo Watershed, who are mostly farmers, is caused by the low environment carrying capacity. This low carrying capacity is caused by the low agriculture productivity that is due to the hilly topography, geologically infertile soil, and geohydrologically poor groundwater. Considering the high potential of rainwater that is not harvested best, one of the key to success of Oyo Watershed development is RWH development. RWH recently becomes a new trend worldwide to manage water resources (Agarwal, A., 2001; Prinz, D. and Malik, A. H., 2002).

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