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Water harvesting techniques for sustainable water resources management in catchments area

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Abstract Available quantity and quality of water resources in catchments area has been deteriorated, yet the management pertaining water resources has not been done in a proper way. Water harvesting techniques are alternative by which the water resources can be maintained to cope with the sustainable use of water resources in catchments area. We reviewed experiences of Indonesia in managing water resources in some of catchments area to come up with the recommendation of best practices of water resources management in general and particularly water harvesting techniques. Despite the available fresh water (15,500 m^3 $capita^{-1}$ $year^{-1}$) is more than double of the world available fresh water (600 m^3 $capita^{-1}$ $year^{-1}$), but its distribution is varies. In Java Island for example, where the population reaches to a number of 65% of the total population of Indonesia, but the water only available for 4.5% of the total national water availability. The fact that the available water of about 30,569.2 million m^3 $year^{-1}$ in Java are not enough to cover the need and will be a deficit water in this island at least till 2015. The available water is also fluctuated during wet and dry seasons. For instance, the flow of Cimanuk River (West Java) is recorded as much as 600 m^3 $second^{-1}$ during the wet season, but only 20 m^3 $second^{-1}$ in the dry season. How to manage water in the area with water surplus and deficit is a crucial question to be answer. Water harvesting is becoming very important to cope with sustainable management of water resources. There are different techniques of water harvesting that have been successfully applied as part of water resources management in catchments area in Indonesia. Channel reservoir, on-farm reservoir or "Embung", infiltration ditches, infiltration well, water harvesting dikes, etc. Channel reservoir with cascade system is one of many rainfall and runoff harvesting techniques, which has been proven to be an effective method to reduce peak runoff, extend the time response to runoff generation and to some extend to increase available water for irrigation during the dry season. In Cibogo micro catchment in West Java for example, river flow can be reduced as much as 63% after construction of 2 channel reservoirs with cashcade system and also delay response time of the river flow up to 1 hour. This two important points are very significant to reduce the risk of flood in the down stream areas where the cities are generally situated. On-farm reservoir has also been applied by farmers for supporting their farming to extend cropping. Other water harvesting techniques such as infiltration ditches, infiltration wells, dams, water harvestinmg dikes are also discussed in this paper.

Keyword water harvesting techniques, water resources management, channel reservoir, Embung, catchments area

INTRODUCTION

Water is a crucial need for human in many aspects of live such as agriculture, domestic, industry, municipal, etc. Yet, its availability for those particular needs is depleted due to change in environmental condition pertaining water and to some extend to the increase of water requirement. In addition, there is a significant change of the water status and it's dynamic during wet and dry seasons. It is well known that the need of water is always hampered due to the limited availability during drought period (dry season), while flood frequently and intensely occurs in the wet season.

World Water Forum II in Denhaag, the Netherlands on March 2000 projected that Indonesia has facing water crisis problem on 2025, which due to inefficient water use and water resources management. The magnitude and distribution of water scarcity increase with time, while rapid growth of population and the demand of water to cover human needs have come up with pressure to the available water. The water from the public services such as PDAM has provided the domestic need of the community especially in the city, but it seems not enough to cover whole requirement. The use of groundwater by pumping has becoming popular leading to deplete groundwater level and allowing the salt water intrusion from the sea. In addition, farmers in the irrigated areas have facing a difficulty in accessing irrigation water due to the depletion of the amount of water in the canal. During the wet season, flood frequently occurs and the intensity increases during the last 2 decades. It is very rare that people are aware with water conservation. Further understanding and knowledge gained from the experiences on water harvesting is also lack.

The effort to collect water for completing the need and the use of water in efficient ways is becoming very urgent. Water harvesting techniques are promoted to be introduced to community for handling the water scarcity and disaster due to flood. Collected water from direct rainfall and runoff will be very valuable for covering the needs. Water harvesting may also increase recharge of the groundwater leading to increase groundwater storage. This is the reason why water harvesting techniques is important for sustaining water resources management. The paper is addressed to discuss water harvesting techniques and their role in sustaining water resources management.

WATER RESOURCES IN INDONESIA

Current Status of Water Resources

Indonesia is the fifth rich countries in annual renewable water resources following Brazil, Russia, Canada and United State of America, which has 2838 km^3/yr (Table 1) as it was estimated in www.worldwater.org/data 20062007 as it was recited from FAO (1999). Unfortunately this amount of water is not well distributed all over the country. In Java island, for example, where the population reaches to a number of 65% of the total population of Indonesia, but the water only available for 4.5% of the total national water availability or about 30,569.2 million m^3/year. Unbalance distribution of water over the country consequently addresses to surplus and deficit water as described in Table 2. Papua is the island having the biggest amount of available water and predicted will not have a deficit at least till 2015. Despite the number is not as high as in Papua, deficit will also not happen in Sumatra, Kalimantan, Maluku and West Nusa Tenggara. It is not only fresh surface water such as those stored up in the lakes, rivers, dams, depression areas, water storages etc., groundwater, brackish water, salty sea water are also available. Two third of the country area is covered by sea water. Unfortunately, the amount of available water decreases due to several reasons, one is prior to impact of extreme climate condition. Global and local climate change affects much on the current water resources status. The water stored in the dams, for example, has already declined as the capacity of the dam and the rainfall intensity and pattern have changed (Figure 1).

Table 1 Top ten rich countries in annual renewable water resources.

Country	Annual Renewable Water Resources (km^3/yr)	Year of Estimate	Source of Estimate
Brazil	8233.0	2000	FAO (2000)
Russia	4498.0	1997	Goscomstat, USSR, 1989; FAO (1997)
Canada	3300.0	1985	Pearse, P. H., Bertrand, F., MacLaren, J. W. (1985)
USA	3069.0	1985	United States Geological Survey
Indonesia	2838.0	1999	FAO (1999)
China	2829.6	1999	FAO (1999)
Colombia	2132.0	2000	FAO (2000)
Peru	1913.0	2000	FAO (2000)
India	1907.8	1999	FAO (1999)
Congo (Zaire)	1283.0	2001	Margat, J./OSS (2001)

Source: http://www.worldwater.org/data20062007

Table 2 Available and demand of water in Indonesia.

Islands	Available Water (Million m^3/yr)	Water Demands (Million m^3/yr)			Surplus/Deficit (Million m^3/yr)		
		1995	2000	2015	1995	2000	2015
Sumatra	111,077.7	19,164.8	25,297.5	49,583.2	91,912.9	85,780.2	61,494.5
Java	30,569.2	62,927.0	83,378.2	164,672.0	-32,357.8	-52,809.0	-134,102.8
Kalimantan	140,005.6	5,111.3	8,203.6	23,093.3	134,894.3	131,802.0	116,912.3
Sulawesi	34,787.6	15,257.0	25,555.5	77,305.3	19,530.6	9,232.1	-42,517.7
Bali	1,067.3	2,574.4	8,589.5	28,719.0	-1,507.1	-7,531.2	-27,651.7
West Nusa Tenggara	3,508.6	1,628.6	1,832.2	2,519.3	1,880.0	1,676.4	989.3
East Nusa Tenggara	4,251.2	1,736.2	2,908.1	8,797.1	2,515.0	1,343.1	-4,545.9
Maluku	15,457.7	235.7	305.2	575.4	15,222.0	15,152.5	14,882.3
Papua	350,589.7	128.3	283.4	1,310.6	350,461.4	350,306.3	349,279.1
Total	691,317.6	110,762.3	158,367.2	358,596.2	584,553.3	536,960.4	336,763.4

Source : Sjarief (2003) as recited from Sutopo, Kompas 27/03/2003.

Lost of water in catchments area is also major determination of water status in Indonesia. It is much affected by factors which significantly determine the capacity of the catchments to conserve rainfall and minimize lost of water through runoff. The major factors determining the lost of water are (a) rapid growth of land use change, (b) increase the degraded (critical) land, (c) increase the distribution of degraded watershed, and (d) other factors affecting the change of hydrological function of the

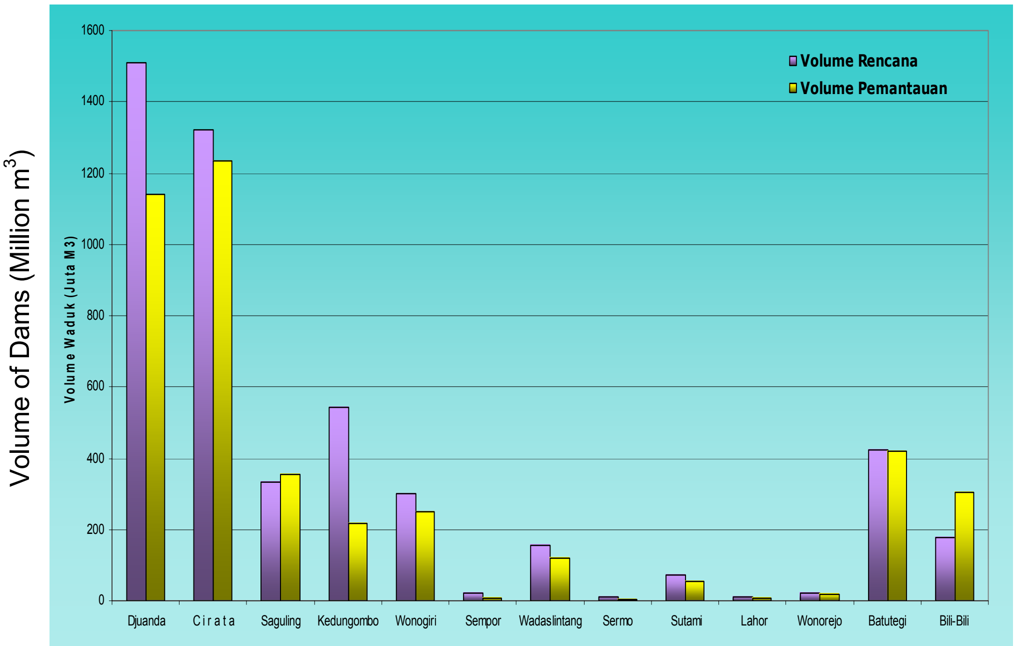

Fig. 1 Available water in the major dams in Indonesia.
Source: PJT II in Subagyono and Surmaini (2007).

watershed. It has been recorded that the critical land in the country has been rapidly developed as it has been as large as 13.1 million ha in 1984 become 51.3 million ha in 2002. Wide spread distribution of the critical land is also factor that must be taken into account in the evaluating the status of water resources in the catchments. It has been recorded as many as 22 critical watersheds in 1984 become 59 critical watersheds in 1998. In addition, other factors determining the hydrological function of watershed such as incorrect land clearing and land management systems, deforestation and over exploitation of water resources in the catchments influence the water resources status.

Water resources status of the country is also believed to be deteriorated due to the impact of climate extreme. Volume of water during the period of El-Nino and La-Nina is fluctuated and varies from season to season. This leads to the change of available water stored in the dams. Figure 2 depicts the distinct of available water in the major dams in Java as affected by the extreme climate events. During La-Nina event, the stored water in the dams exceeds the volume of water in the normal years. In contrast, water scarcity is almost the major phenomenon that has been facing by community in every occasion to cover their need for domestic, industry, agriculture etc. In addition, the volume of available water fluctuates from season to season, where it will be enough water in the wet season but in the dry season.

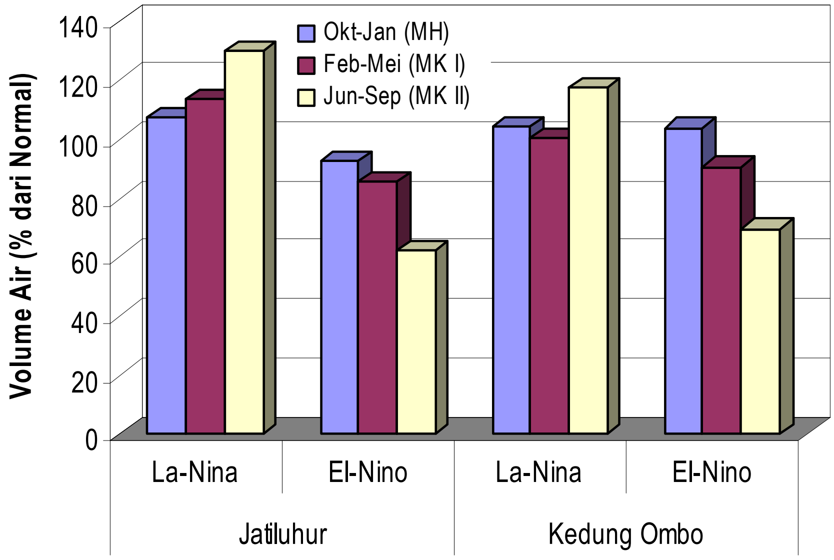

Fig. 2 Average of volume of water at the main water storage in Java during La-Nina, El-Nino, and normal years. WS: wet season, DS: dry season. Source: Las et al. (1999) with modification.

Water Resources Management

Management pertaining water resources is addressed to control a balance between the availability of water and the water requirements. The availability of water is much determined by the hydrological cycle spatially and temporally, while the water requirements often increase in amount and varies uses. Integrated water resources management is urgently to be implemented with aimed to improve community welfare. Figure 3 shows the water resource management concept involving the analysis of balance between the water availability and water requirements.

Despite many aspects of water resources management are significant to be done, but the present paper is addressed to the water harvesting for sustainable water resources management. Since the hydrologic cycle has been changed due to several phenomena such as climate change, catchments degradation as well as over exploitation of water resources, the availability of water resources has been deteriorated quantitatively and qualitatively. An impact of those phenomena is that the appearance of water scarcity in many aspect of lives.

As extreme climate has frequently occurred with increase in its intensity, the pressure to water resources is growing. Inter-annual climate variability in the form of drought and flood (generally those are termed as El-Nino and La-Nina respectively) occurred more frequently and caused much damage. These phenomena have been well understood as the global phenomena. In addition, seasonal variation has also occurred for rainfall, which is characterized by the variability in increasing and decreasing rainfall in the Indian and Pacific oceans. Water resources are often deteriorated by these phenomena leading to lose its available quantitatively and qualitatively.

Land conversion in the watershed system is also the major issues that cause deterioration of the hydrological function of a watershed in Indonesia. The present of

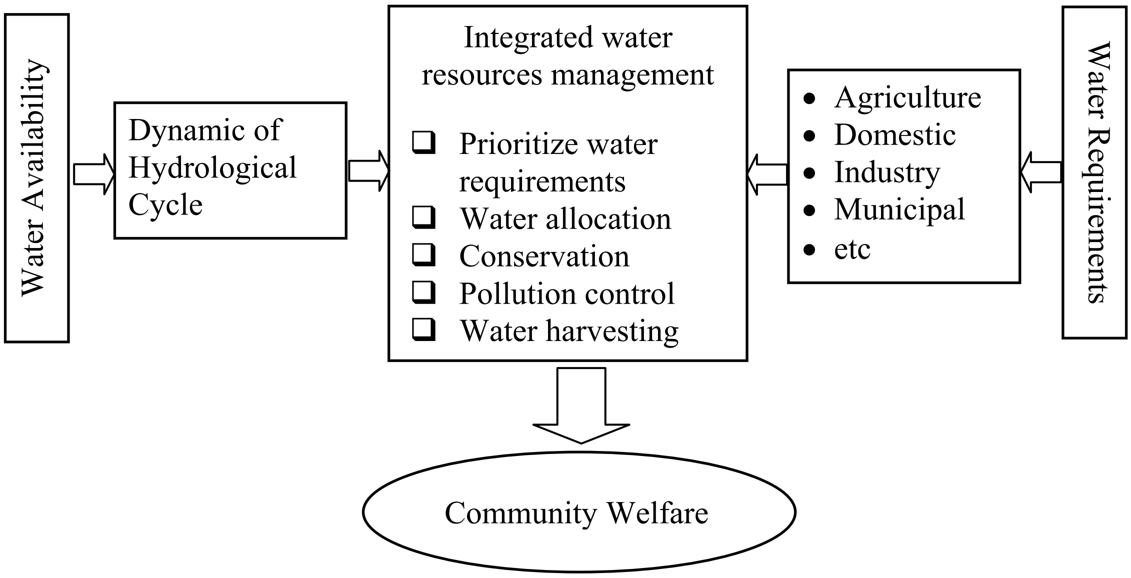

Fig. 3 Diagram of integrated water resources management concept.

critical land, deforestation in the catchments area and other causes of change in watershed function are the major factors causing high surface runoff. The fact that water deficit has increased in the water scarce areas and the available water has decreased in the surplus areas. Reduce in the number of water reservoirs in many watersheds is a proven of the change of hydrological function of the watershed.

The magnitude of vulnerability of water resources to extreme climate should be identified and delineated to address the methodology and approaches to cope with. Adaptation to extreme climate events will be a strategy to sustain the available water resources. Combating to water scarcity during El-Nino event is a key to promote available water resources through water harvesting techniques. Water management is also addressed to use water in efficient ways. Combating the water scarcity and promoting appropriate water management strategies and to some extend developing climate information system to strengthen climate prediction are the best options.

WATER HARVESTING FOR AVAILABLE WATER RESOURCES

Water harvesting has been developed by local community since they did their business to cultivate their land for many uses including agriculture. In Indonesia, many local wisdoms regarding water harvesting are the fact that people have already aware with water for their sustainable business pertaining water. In the recent decade when people have already been aware the deterioration of water they took efforts to obtain water to cover their needs. One of the efforts is water harvesting.

Significance of Water Harvesting

Water harvesting is a technique by which the water can be collected either surface or sub-surface to store up during wet period and used during dry period by applying a proper technique such as channel reservoir, on-farm reservoir, infiltration ditches, infiltration well, check dams, water harvesting dike etc. The water harvesting is addressed and very significance for several objectives including (a) increase recharge groundwater, (b) increase base flow, (c) reduce peak runoff, (d) reduce the risk of flood in down stream areas, (e) extend the time response to runoff generation, and (f) increase available water for irrigation and other uses (domestic, industry, municipal, etc).

Water Harvesting Techniques

Many techniques have been used by various beneficiaries to harvest and store water including (a) channel reservoir, (b) on-farm reservoir (local name of Embung), (c) infiltration ditches, (d) check dams, (e) infiltration well (local name of Sumur Resapan), and (d) water harvesting dikes.

Chanel reservoir

Channel reservoir is a water harvesting technique to store water in the stream channel aimed to support irrigation for agriculture. In Indonesia, it has been widely developed and spread up over the irrigated agriculture areas. An example is those applied in Cibogo micro catchment, West Java. In this micro catchment 2 channel reservoirs have been constructed with a capacity of 300 m^3 and 800 m^3 situated at the elevation of 910 and 950 m asl respectively. The first channel reservoir was constructed to collect water and sediment, while the second one was to collect water and sediment as well as distributing water for irrigation of agricultural land. Both channel reservoirs can collect water from the area of 125 ha, where the collected water was used to irrigate the area of 26 ha through the distribution of water from second channel reservoir. The channel reservoir that have been constructed is depicted in Figure 4.

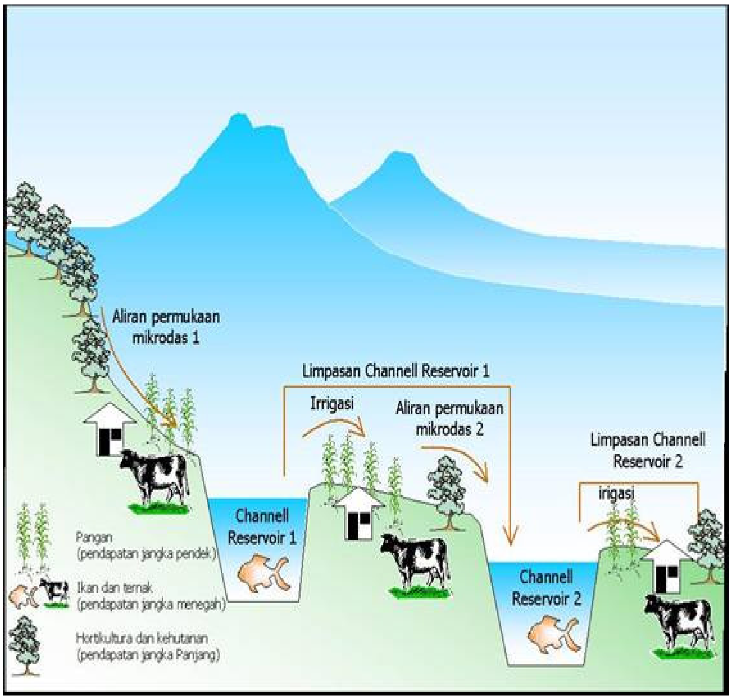

Fig. 4 Channel reservoir for water harvesting and irrigation purposes in Cibogo micro catchment, West Java.

Channel reservoir can also reduce flow of the stream or river from upstream to the downstream areas. Consequently, it may also provide a positive impact on flood reduction in the downstream areas. In the catchment studied, river flow can be reduced as much as 63% after construction of 2 dams (channel reservoirs) with cashcade system (Figure 5). In addition both dams can also delay response time of the river flow up to 1 hour. This two important points are very significant to reduce the risk of flood in the down stream areas where the cities are generally situated.

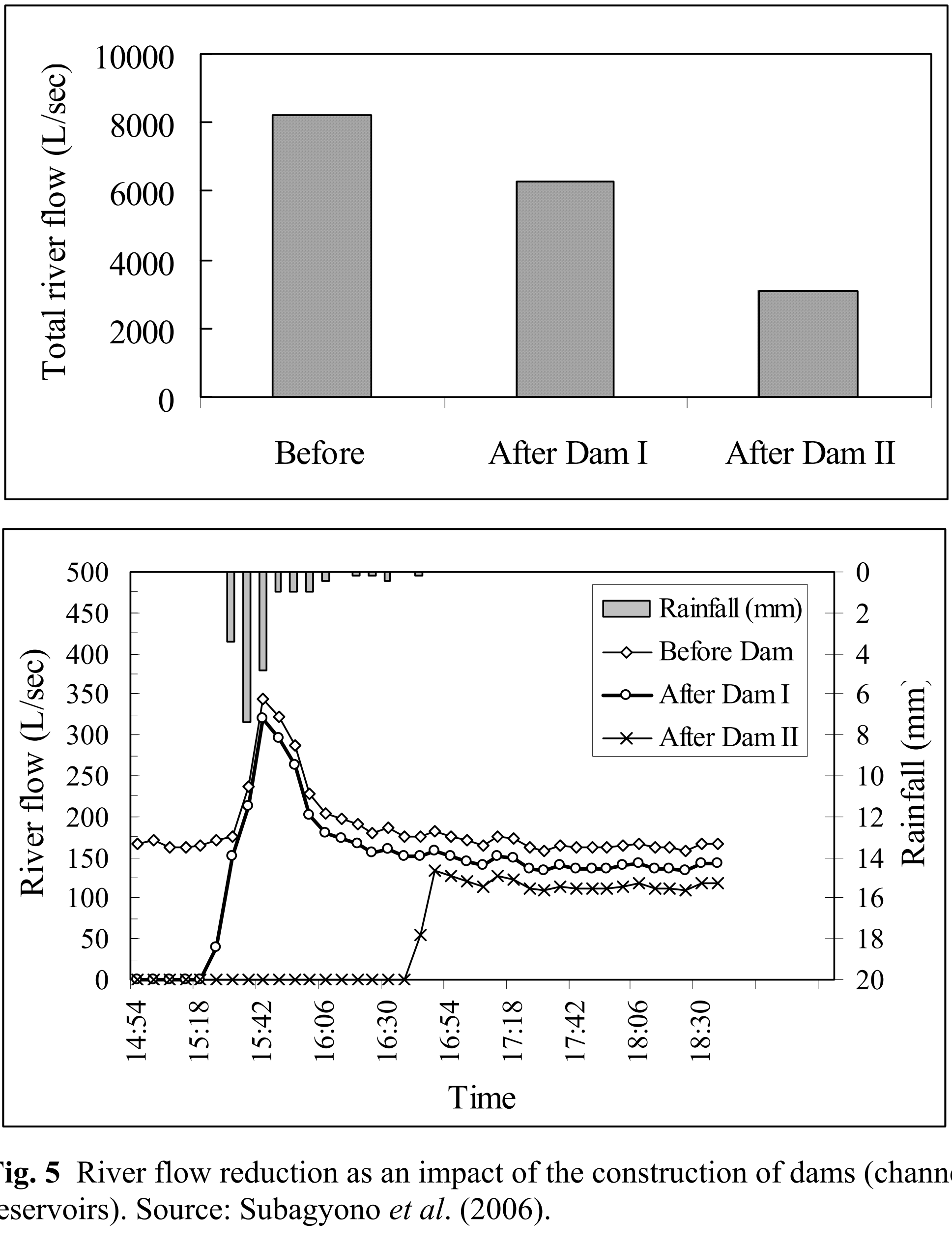

Fig. 5 River flow reduction as an impact of the construction of dams (channel reservoirs). Source: Subagyono *et al*. (2006).

The harvested water during the rainy season can be used to supply water for agricultural areas and domestic uses during the dry season. Since water should be distributed for different uses, water sharing is becoming important to be implemented to overcome a conflict. To do so, the available water capacity and the amount of water for each use need to be identified and quantified.

The total amount of water can be quantified for an area of 125 ha under the mean annual rainfall of 3.340 mm is 4,175,000 m^3 per year. Some of this available water will be loss trough percolation, runoff, evapotranspiration and interception by crops canopy, while the rest is becoming available water for varies uses. It was observed during August and September 2005, that water yields were respectively 10,821 and 14,789 m^3.

Sawiyo (unpublished), reported that the amount of water needed for agriculture was 147,019.0 m^3 per year, as much as 51,051 m^3 per year for domestic use and 182m^3 per year for livestock (Figure 6). There are 7 different cropping patterns have been applied in the studied catchment, i.e. 1) Carrot – Carrot –Carrot; 2) Carrot – Carrot – Chilli; 3) Carrot – Buncis – Tomato; 4) Cabage – Carrot – Cabage; 5) Carrot – Carrot – Cabage; 6) Cabage –Tomato – Buncis and 7) Multiple cropping of those pattern with Banana. The water for domestic use is covering the need for 550 people, while that for livestock is covering for 100 cattle and others.

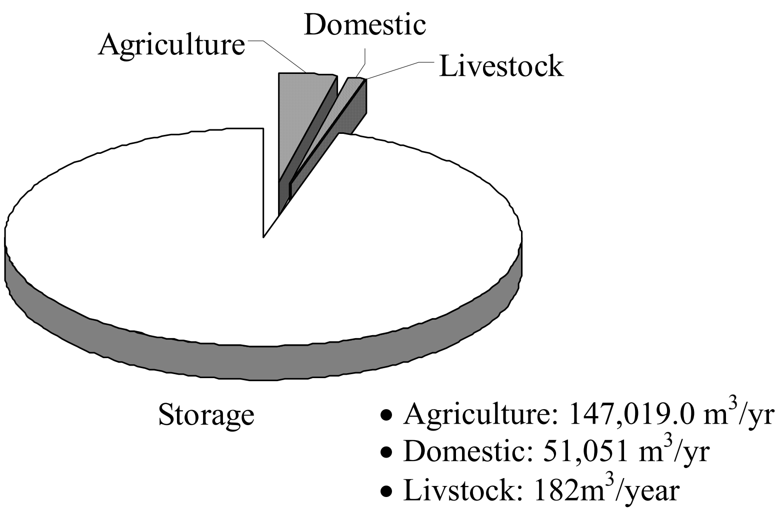

Fig. 6 Water availability at Cibogo micro catchment and the annual use for agriculture, domestic and livestock. Source: Sawiyo (unpublished).

On-farm reservoir (Embung)

Other water harvesting technique is a farm reservoir, the local term is “Embung” (Figure 7). This water reservoir can be used to collect water during wet season and to use for irrigation during dry season. An example can be taken from the experience where “Embung” had been developed to support dry land farming system in Selopamioro, Bantul, Yogyakarta. It had been reported by Irawan et al. (1999), mini water reservoir with a dimension of 7 m x 2.5 m x 3 m and capacity about 52.5 m^3 can contribute to the increase of rainfed rice production up to 176%, production increased from 4,230 kg to 11,700 kg (Table 3). The cultivated area used for this mini water pond was not more than 7% of the total cultivated area.

Fig. 7 On-farm reservoir (Embung) prototype to store water for supporting agricultural irrigation.

Table 3 Effect of mini water reservoir on cropping pattern and crops production in rainfed and dry land areas in Selopamioro, Bantul, Yogyakarta.

Indicator at each land use types	Without mini water pond	With mini water pond
Rainfed		
• Cropping pattern	Rice – fallow	Rice – Tobacco – Maize
• Production (Kg)	4,230	11,700
Dry land		
• Cropping pattern	Peanut – Cassava	Peanut – Maize – Cassava/Vegetables
• Production (Kg)	3,545	4,300 – 6,260

Source: Irawan *et al*. (1999). * Conversion of farming yields based on market price.

Several benefits can be gain from this water harvesting technique using the on-farm water reservoir i.e. (a) runoff and rainfall harvesting, (b) store water during wet season and use in dry season, (c) collect sediment, and (d) support farming irrigation. However, the limitation of implementing this water harvesting technique is that farmers have to spend part of their land for this on-farm reservoir. This needs institutional building which will facilitate collaboration among the farmers in using part of the land for on-farm reservoir, otherwise the implementation of this technology will not be sustained.

Infiltration ditch

Infiltration ditch (Figure 8) is also a technique to store and restore water which also very valuable to support supplemental irrigation for farming. This technique can be used to (a) collect surface runoff, (b) contribute to recharge groundwater, and (c) source of irrigation water. Although this technique is addressed to collect water and allowing irrigation for crops, but other important role of this technique is that it can contribute to groundwater recharge. Since the dimension is smaller than on-farm reservoir, this technique has better prospect to develop.

Fig. 8 Infiltration ditch used for supporting supplemental irrigation for union farming.

Dams

Dam (Figure 9) is also a water harvesting technique with a dimension of much bigger than other techniques. The capacity to store large volume of water is typical for this technique leading to have more functions such as (a) water harvesting, (b) flow reduction, (c) water supply for irrigation, domestic and other uses, and (d) hydro-electric power.

Fig. 9 Dam for water harvesting and hydro-electric power.

Infiltration well

Infiltration well (Figure 10), in local term named as Sumur Resapan, is a water harvesting technique set up mainly for (a) collecting rain water, (b) groundwater recharge, (c) reduce runoff and (d) flood control. Not all areas are reliable to construct the infiltration well unless the area of settlement, area with soil permeability of 2 cm/hr, area with groundwater table of 1.5 m. The infiltration well may have capacity of 1, 2, 4, 6, 8 or 10 m^3 with various shape of square or round.

Many urban areas all over the world face a problem of lowering groundwater table leading to dry out shallow aquifer. It is critical to recover this lowering groundwater table by increasing the rate and distribution of recharge. The infiltration well has been a technique that has been implemented to meet the need.

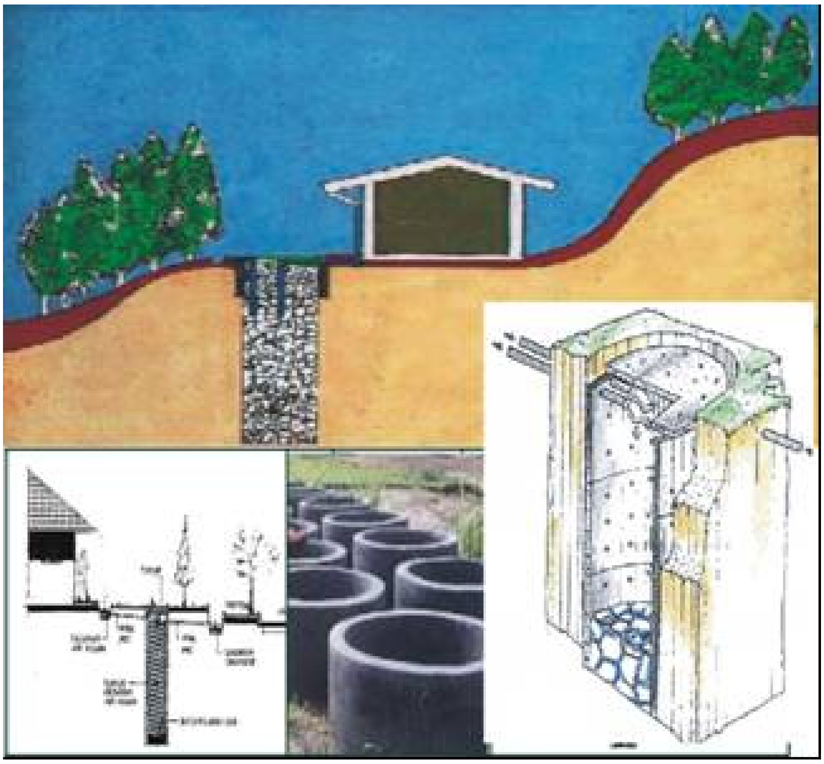

Fig. 10 Prototype of infiltration well used for increase groundwater recharge.

CONCLUSIONS

The significance of water harvesting for water resources management will meet a satisfactory impact if the water harvesting has been correctly and sustainably implemented by community. Water harvesting strategy and techniques are needed to be formulated to meet local specific approaches. Institutional building concerning water harvesting and water resources management is becoming key factor for success. Channel reservoirs, on-farm reservoirs, infiltration ditches, infiltration wells, dams, and water harvesting dikes are techniques may be implemented for sustaining water resources and water resources management.

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