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Rainwater Harvesting for Drinking Water in Bali, Indonesia

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Abstract
The water source on the island of Bali, Indonesia, tends to be uneven and depends on geographical and climatological factors. In the remote area at Kubu Subdistrict, Karangasem Regency experiences with very limited water supply, due to the absence of water sources and lack of water services from the piping system. In such conditions, people harvest rainwater and then collect it with cubang (water reservoir) to meet their daily drinking water needs. This study aims to find out how effective the cubang that has been made by the community to meet drinking water needs and how ideal cubang model for the community should be made so that water needs can be fulfilled throughout the year. The results showed that cubang which had been built less effectively to meet drinking water needs, which was caused by the age of the cubang which had reached 20 years old, even more, most of them had already leaked, the size of cubangs varied greatly with the volume of water collected was not sufficient with needs all the time. Water collected in a cubang, harvested through the roof of a house is only able to meet water needs for 4 months a year, the rest for 8 months, the community buys water from tank trucks. To meet water requirements every year, a new cubang model is needed and equipped with a roof as a rainwater harvester. For cubang in leaked conditions can be repaired with ferrocement layers to function properly and last longer.

Key Words: Drinking Water, Rainwater Harvesting, Cubang, Effectiveness, Kubu Subdistrict, Bali

1. Introduction

The island of Bali, Indonesia, which is very well known as a world tourist destination in the world, however, the availability of water resources is uneven and depends on geographical and climatological factors. In the southern part of the island, there tends to be greater availability compared to the northern part. This is directly related to the existing rainfall, and the southern part tends to have higher rainfall than the northern part. One of the areas that have a very limited water supply due to low rainfall is Kubu Subdistrict, Karangasem Regency, Bali Province (JICA, 2006). The low coverage of drinking water services from the piping system causes people in the area to be more likely to meet water needs by harvesting rainwater and to accommodate rainwater in a water reservoir called "*cubang*." According to Geredeg (2011) in the Medium-Term Development Plan of Karangasem Regency 2010-2015, in Karangasem Regency, there are around 9000 *cubangs* scattered in various places including in Kubu Subdistrict. Beritabali.com (2016) describes that residents of Kubu Subdistrict are still in need of *cubang* because in this area until now they have not received drinking water services through piping systems from Government Water Company (PDAM), and in the future, it is expected that the government can provide *cubang* in each household. This research was focused on Kubu Subdistrict, which is one of the sub-districts with dry land and it is very difficult to reach by drinking water supply with piping systems because this area is mostly very remote. This research is expected to be able to identify the current *cubang* conditions and to provide solutions for people, especially those who live in rural areas, to get a *cubang* model that is effective and is able to meet drinking water needs throughout the year.

2. Methodology

This research was conducted in 2018 and using qualitative and quantitative descriptive methods. As many as 3 household *cubang*s were taken as samples in each village and a total of 27 samples from 9 villages in Kubu Subdistrict. The samples were selected using the principle of purposive sampling, which was chosen in such a way that has the criteria of a remote place and has very little chance of being reached by drinking water with a piping system. The data were collected through interviews and by observing the existing *cubangs*. The types of data collected include number of family members; education; socio-economic conditions; water use from a *cubang*; size, construction, and utilization of *cubang* water; age and condition of *cubang*; the reliability of available *cubang* water; catchment area for rainwater harvesting. In addition, rainfall data were also collected for 10 years. That data analysis was done qualitatively and quantitatively and is expected to provide answers and recommendations for the current *cubang* conditions and reliability, as well as recommendations for improvement; making *cubang* model designs that are effective in accordance with local rainfall conditions in order to be able to meet drinking water needs throughout the year.

3. Results and Discussion

1) Description of the study area
   Kubu is one of the sub-districts in Karangasem Regency, geographically located around $115^0$25'20 "and $115^0$36'50" East Longitude and around $8^0$13'20 "and $8^0$17'10 'South Latitude and has an area of 234.71 km², and is dry land. Kubu Subdistrict consists of 9 (nine) villages, including Dukuh Village, Tulamben Village, Kubu Village, Batu Ringgit Village, Sukadana Village, Tianyar Village, Tianyar Tengah Village, Tianyar Barat Village and Ban Village (Fig 1). The climate in the study area is not much different from the climate in general in Karangasem Regency, which is a tropical climate, influenced by two types of seasons: the dry season (April-October) and the rainy season (November - March). The daytime air temperature is around 29^0C and at night around 26^0C with humidity reaching 70-80% during the day. The annual average rainfall is 1461.96 mm / year in Kubu Station and 1173.08 mm / year at Tianyar Station, and the annual average rainfall from both stations was obtained at 1317.52 mm/year. Kubu Subdistrict is very pronounced as a very dry area, because inexperience to low rainfall, there is no indication that there are rivers that flow water throughout the year which can be used as a source of raw water for drinking water supply. According to information from the Director of the Government Water Company (PDAM) of Karangasem Regency, the current service coverage of PDAM for Kubu Subdistrict has only reached 18.69% of the total population. The people who get drinking water services from the PDAM are only people who live around the main highway of Karangasem-Singaraja. In addition, there are village water supply services (PAM Desa) which cover services as much as 27.86% of the total population. Communities living on highlands and far from the highway, practically only rely on household *cubang* besides buying water distributed by tank trucks.

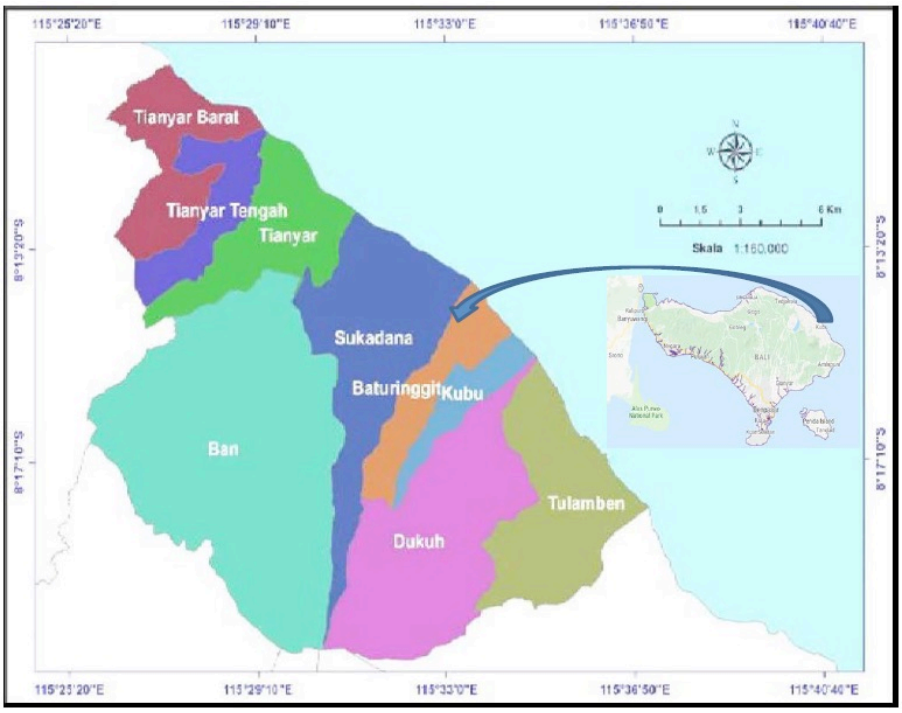

Figure 1. Map of Kubu Subdistrict in Bali.
(Source: Kubu Subdistrict in Numbers, 2017)

2) Socio-economic counseling

The socio-economic conditions of the respondents indicated that the majority of their livelihoods were farmers and also as breeders, with income below IDR 1,000,000 (USD 70) and even less than IDR 500,000 (USD 35) per month. Besides being a farmer, a small percentage of respondents also work as employees earning more than IDR 1,000,000 (USD 70). The family size of the majority of respondents (55.5%) is as many as 4 people or less (2 or 3 people per family), while the remaining 44.5% the number of family members varies from 5 to the largest reaching 10 people. Based on the existing socio-economic conditions, it is felt that the economic conditions of most people are very heavy and still have not reached a decent standard of living. In addition, there is a scarcity of drinking water sources as a daily necessity, forcing them to buy water from 1-4 tanks each month with prices varying from IDR 100,000 (USD 7) to IDR 150,000 (USD 10.5) per tank.

3) Current *cubang* conditions

The limited availability of access to drinking water forces a large number of people in Kubu Subdistrict to harvest rainwater through the roof of a house and to be accommodated in a *cubang*. Interview with respondents indicated that, each household had at least 1 (one) *cubang*, only a few families had more than one *cubang* (having 2 *cubangs* even one respondent had 4 *cubangs*) with very varied capacities, ranging from 5.16 m^3 to almost 120 m^3, but if overall, 74% of the *cubang* volume built is less than or equal to 40 m^3, only 26% of the volume is greater than 40 m^3. There are 2 types of *cubang* cross-section, round and rectangular, but the size of *cubang* is very varied. *Cubang* which has a round cross-section shape with diameters varying from 2 meters to 4 meters with depths varying from 2 meters to 6 meters, as well as *cubang* with rectangular or square cross-section shapes with varying sizes 1.6 x 1.6 m^2 up to 5 x 5 m^2 with depth varies from 0.8 meters to 3.9 meters (as shown in Fig 2). Most of the *cubang* age (78%) is more than 10 years, even more than 20 years, only 6 respondents (22%) with the age of 5 years or less. *Cubang* conditions that have been more than 10 years generally have leaked, but those in good condition are the result of repairs by coating with a kind of leak-proof paint, the repairs carried out are only temporary. The *cubang* material is made of stones, using only a small amount of material from the concrete blocks. In addition, the *cubang* built is located underground; especially those made of stones, while the ones built from the concrete blocks are built on the ground (Fig 2a and Fig 2b).

a. *Cubang* made of stone. b. *Cubang* made of blocks. c. Roof as a rainwater harvester

Figure 2. *Cubang* made of stones and blocks and the roof as rainwater harvester.
(Source: Survey results)

Furthermore, the interview results indicate that the catchment area for harvesting rainwater is mostly less than 50 m^2 using the roof of a residential house, then the rainwater harvested from the roof of the house is channeled using plastic gutters into the *cubang*, as shown in Figure 2 c. The water in *cubang* is only to fulfill the needs for 4 (four) months or only in the rainy season, the rest for 8 (eight) months they buy water from the water provider. The amount of water purchased by respondents varies from 1 to 2 tanks each month. Each tank contains 5 m^3 at an average price of IDR 120,000 (USD 8.27) per tank and can be more or less depending on the distance of the respondent's residence from the location of the available water source.

Cubang which has been built at this time is ineffective and unreliable as a reservoir of rainwater harvested, because some are in a leaky condition or only good after being repaired, besides the existence of *cubang* is unable to provide water throughout the year because most respondents buy water from tank trucks throughout the dry season, even the duration of buying water reaches 8 (eight) months in a year (from April to November).

4) *Cubang* models are needed because a *cubang* which was built independently by the community turned out to be ineffective and reliable to meet the needs of drinking water and livestock throughout the year, a design was needed that was based on water requirements and the amount of rainwater that could be utilized. There are several things that need to be taken into consideration in making the design of *cubang*s to be effective and reliable enough to meet water requirements throughout the year, including:
   a) Water requirements
      For water needs, according to the standard of the Directorate of Cipta Karya, it is 60 liters/person/ day (Mediatataruang.com, 2016). Water needs for livestock are assumed that every livestock (cattle or pig) requires as much as 5 liters of water/livestock/ day.
   b) Number of family members
      The number of family members according to the results of interviews with respondents is dominated by families with a number of family members of 2; 4 and 5 people per family, with the consumption for families with 2 members raising 1 livestock, while for families with 4 or 5 members raising 2 cattle (cows or pigs).
   c) Rainfall and catchment area
      The annual average rainfall for Kubu District is 1317.52 mm. The amount of rainfall is used to determine the roof area of the building that is used as the area of rainwater catchment/rainwater harvesting according to the amount of water needed for each *cubang* model. Furthermore, based on the

average annual rainfall the catchment area needs to be calculated to meet water needs throughout the year.

The calculation results of various *cubang* models, water requirements, and required catchment area are presented in Table 1, assuming that each *cubang* model is closed with a roof to reduce the amount of free water evaporation and is used as a catchment area for rainwater harvesting, while the lack of roofing still uses the existing ones. To drain rainwater from the roof of a house or *cubang* roof, a gutter from a plastic pipe is used. For *cubang* placement, it is placed in such a way near the house to facilitate the flow of water harvested from the roof of the house and water from *cubang*. After going through interviews and in-depth discussions with building structure experts (Made Sukrawa Ph.D.), *cubang* construction is suggested being made of sturdy reinforced concrete structures to prevent construction failure due to earthquakes, cracks and being able to have a lifetime of 50 years or more.

Table 1. *Cubang* model designs for various family sizes

No	Description	Unit	Family *Cubang* Model		
			For 2 persons and 1 livestock	For 4 persons and 2 livestock	For 5 persons and 2 livestock
1	Family size	Persons	2	4	5
2	Drinking water needs	l/person/day	60	60	60
3	Drinking water needs	l/family/day	120	240	300
4	Water needs for livestock	l/day	5	10	10
5	Water needs for 1 year	m^3	45.625	91.25	113.15
6	Water loss	%	10	10	10
7	Total of water needs for 1 year	m^3	50	100	124
8	Amount and size of *cubang*	Amount x length x width x height (m)	2x4x3.2x2	2x5x5x2	2x5.6x5.6x2
9	Average annual rainfall	mm	1317.52	1317.52	1317.52
10	Need for water catchment	m^2	38	76	94
11	Water loss assumption	%	20	20	20
12	Catchment area needed	m^2	46	91	113
13	Catchment area from *cubang* roof	m^2	36	66	66
14	Area of the additional catchment from the house roof	m^2	10	25	47

Source: Analysis results

5) Repair of existing *cubang*

In addition to making a *cubang* model that fits the water needs, the *cubang* can also be repaired from leaks to function properly and last longer. The results of the interview with Dr. Nyoman Pujianiki recommend repairing *cubang* using ferrocement. Ferrocement is a type of thin reinforced concrete wall made from cement mortar which is reinforced with continuous chicken wire/wire (chicken mesh) and a tight layer and relatively small wire size. The technical fixes can be done as follows:

a) Material for repairs

To repair *cubang* which is leaking using ferrocement with the basic material is Portland Cement (PC) Type 1, fine sand that passes the No. 8 filter or diameter 2.36 mm, chicken wire/wire mesh (chickenmesh) with small diameter, 5 cm concrete nails, and material addition to additives as leak-proof.

b) How to repair

Mix mortar or stir PC with sand, 1 PC with 2 sand (1PC: 2 sand) with a volume proportion, with cement water factor 0.35-0.5. Mortar is added with additives to strengthen mortar and leak resistance. Chicken wire/wire mesh is installed on the inner wall of the *cubang* surface by nailing it using 5cm long concrete

nails which function to hold the woven wire on the *cubang* wall. The distance of woven wire from *cubang* wall is 2 cm. Furthermore, the mortar added with the additive plastered on the wall and the *cubang* base which has been fitted with chicken wire with a thickness of 4 cm.

6) *Cubang* Modelling and Repair Costs
   a) The cost of making a *cubang* model
   To make a *cubang* model according to the type needed based on the material and artisan prices in 2018, it is: Type 1 costs IDR 44,600,000 (USD 3075); type 2 for IDR 66,100,000 (USD 4,558); and Type 3 of IDR 74,700,000 (USD 5,150).
   c) The cost of repairing *cubang*
   The cost needed to repair the *cubang* that has been built to function properly is IDR 219,718 (USD 15.1) for each ferrocement m^2. For example, for *cubang* with a diameter of 3 meters and in 3 meters, a cost of IDR 7,800,000 (USD 538) is required.

4. Conclusions and suggestions

The conclusions and suggestions of the study can be summarised as follow:

Conclusions

Access to drinking water supply through the PDAM in Kubu Subdistrict is still very low (18.69% of the total population), most people rely on rainwater harvested and stored in water tanks (*cubang*) for drinking water (drinking, cooking, washing, and bathing) and water requirements for livestock. The volume/capacity of *cubang* built by the community is very varied, most of which have been built for quite a long time (20 years) and are in a leaky condition or only in good condition after being repaired. The amount of water stored in *cubang* is not enough to meet water needs for one year, only available for 4 months and for 8 months buying water from a tank truck of 2 tanks every month.

To meet water requirements every year, a *cubang* model with a capacity of 50 (Type 1) is needed; 100 (Type 1) and 124 m3 (Type 1) for families with 2 members and 1 livestock each; 4 people and 2 livestock; and 5 people and 2 livestock. The ideal *cubang* model can be made of bricks equipped with a roof as rainwater harvesters and can be added to the roof of the house, to meet the required catchment area according to the height of the rain, at the cost of IDR 44,600,000 (USD 3075) for Type1; Type 2 is IDR 66,100,000 (USD 4,558; and Type 3 is IDR 74,700,000 (USD 5,150).

Leaking cavity conditions can be repaired with ferrocement layers to function properly and last for a long time, at the cost of IDR 7,800,000 (USD 538) for a diameter of 3 meters and in 3 meters or IDR 219,718 (USD 15.1) for every ferrocement m2.

Suggestions

It is necessary to test the model by making it directly in accordance with the size of the family that uses it and observed for at least one year starting from the beginning of November until the beginning of November the following year. If the *cubang* model is not ideal, it needs to be modified as needed and then it can be mass-produced for those in need. It is necessary to make an model of repairing *cubangs* that leak with ferocement. The participation and support of the government and the private sector are very much needed to help realize *cubang* in an effort to meet the needs of the community for drinking water in Kubu District, especially for those who are categorized as poor.

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