Saving Water Through Ergonomics Rainwater Harvesting Wells in Bali Indonesia

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Abstract. The main objective of this research is to assess the harvesting capacity of the deep rainwater harvesting wells as one of the solutions to prevent the ground water crisis. Water is life, for present and future generations. Groundwater is a renewable natural resource; however, over exploitation can cause various disasters, it leads to the decreasing of water table, seawater intrusion and worse can cause land subsidence. This phenomenon has allegedly occurred in Bali, a beautiful small island with an area of 5,780 km² and a population of 4.22 million. The 3-5 stars hotels increased significantly from 120 hotels in 2010 to 498 hotels in 2022. The international community claims that this hotel growth, which considered to be less controlled, will lead Bali to face the water crisis in Bali soon. The research conducted in 2010 showed that in 11 tourism areas there was a decrease in the level of ground water and the occurrence of seawater intrusion, which reduced the quality of ground water. Based on this data, the research reconducted in the 11 tourism areas and in several other developing tourism areas. The result shows that the water quality from the chlorine content and hardness, does not meet the recommended quality standards. This shows that the area has experienced seawater intrusion. One of the alternative solutions to avoid the groundwater crisis is by saving the water through the rainwater harvesting wells. Deep rainwater harvesting wells was designed and implemented in some recharge area and the assessment showed that it can harvest the rainwater 41.087 m3/jam/wells during the wet season.
Bali has 4 wet months or around 120 rainy days per year. If each star hotel builds at least 1 well to compensate for the production well used for hotel operations, then the rainwater harvested is about 58,928,618.88 m3 per year.

Keywords: saving; water; ergonomics; rainwater; harvesting wells.

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1 Introduction

Bali has changed from an agricultural area to a very well-known of tourism destination in the world. Tourism has become the main pillar of economy and a source of foreign exchange for Indonesia. Apart from having a positive impact on people's welfare, it also has a negative impact on ecosystem sustainability, especially regarding the issue of the groundwater crisis which has become the focus of international environmental observers. The Bali Province Central Statistics Agency reports that foreign tourists coming to Bali continue to increase, from 7,002,944 people in 2010 to 16,106,954 in 2019, an increase of 130% [1]. The increase in the number of tourists is of course accompanied by an increase in the need for clean water. PDAM, a regional company owned by the Province of Bali, is only able to meet around 40-50% of the need for clean water. About 50 - 60 of the community, including the tourism industry, still uses groundwater [2]. The results of the Strategic Environmental Study (KLHS) conducted by the Bali Provincial Government in 2010 showed that 11 areas where tourism was developing rapidly indicated that there was a water crisis [3]. Based on data of the KLHS results, in 2018 the Bali State Polytechnic collaborated with the Idep Selaras Alam Foundation - a community organization that cares about the environment, conducted collaborative research to re-map the groundwater condition. The results of the study show that there has been a decline in groundwater quality. The hardness test results (chlorine content) of 270 water samples spread across Bali Province have high chlorine and are not suitable for consumption, including 73% of 44 samples in Badung, 68.3% of 60 samples in Buleleng, 65% of 20 samples in Jembrana, 35.0% of 40 samples in Karangasem, 12.50% of 40 samples in Gianyar, and 75% of 4 samples in Klungkung [4]. This is an indication that those area experienced of sea water intrusion. One of the causes of seawater intrusion is excessive exploitation of groundwater through deep drilled wells so that seawater is sucked into land. Considering that almost all hotels in Bali use groundwater to meet their operational needs, including for swimming pools, it is very natural for people to think that the development of tourism is what causes the groundwater crisis.

Groundwater conservation activities can be carried out through: (a) determination of conservation zones; (b) protection and preservation; (c) control and management of pollution, (d) control of the decline in groundwater quantity and (e) recovery. One method of restoring both quantity and quality is Rainwater Harvesting System (RHWS) through the construction of rainwater harvesting wells to replenish used groundwater sources. Rainwater harvesting wells can be built from small, simple, to those using high technology. Whatever method is chosen, it can still contribute to efforts to save groundwater. The benefits of RWHS include saving groundwater use, reducing waterlogging and flooding in the rainy season, lower carbon content, saving energy, and can be used to meet domestic clean water needs [5, 6, 7]

As a tropical region with relatively high annual rainfall, it is appropriate for Indonesia, including Bali, to establish policies related to water saving programs through the construction of rainwater harvesting wells. This has been done by Malaysia, Indonesia's neighboring country. Guideline of Rainwater Harvesting System (RWHS) has been issued since 1999 [8]. This policy was then followed by various derivative policy initiatives as presented in Table 1.

Table 1. Policies and guidelines related to RWHS under Malaysian government [9]

Guidelines	Department/Agency	Year
Guidelines for installing a Rainwater Collection and Utilization System	Ministry of Housing and Local Government	1999
RWHS: Guidebook on Planning and Design	Department of Irrigation and Drainage Malaysia (DID Malaysia)	2009
Guideline on Eco-Efficiency in Water Infrastructure for public Buildings in Malaysia	National Hydraulic Research Institute of Malaysia	2011
Urban Stormwater Management Manual for Malaysia, MSMA 2nd Edition	DID Malaysia	2012
Panduan Pelaksanaan Inisiatif Pembangunan Kejiranan Hijau—Sistem Pengumpulan dan Penggunaan Semula Air Hujan	Federal Town and Country Planning Department	2012
Garis Panduan Perancangan Kejiranan Hijau	Federal Town and Country Planning Department	2012
Garis Panduan Sistem Pengumpulan dan Penggunaan Air Hujan	Federal Town and Country Planning Department, Ministry of Urban Wellbeing, Housing and Local Government	2013
Urban Stormwater Management—Part 6: RWHS, MS2526-6:2014	Department of Standards Malaysia	2014

From the various policies in Table 1, it can be seen that the Malaysian government has great attention to the problem of the water crisis and efforts to save it through RWHS. The implementation and development of RWHS has also been carried out in various other countries such as the European Union, USA, Japan, Taiwan and Australia. How about Indonesia?

Several policies related to groundwater utilization have been regulated in Indonesia, but there are no specific groundwater conservation programs through rainwater harvesting yet. In several universities, there are actually those who have developed RWHS and have implemented it, but there is not enough policy reinforcement. Mukaromah from Universitas Sebelas Maret Surakarta reported that the Association of Urban Climate Change Resilience Networks (ACCCRN) has started a pilot project to implement RWHS in Tandang Village and Wonosari Village. However, Problems arise related to the public's perception that rainwater is only for non-consumable needs. Utilization of rainwater is only used when the availability of other water sources is running low [10]. Susilo and Jafri promoted the design of RWHS in dwelling areas of Indonesia. The research found out that utilizing rainwater through RWHS can meet around 35% of domestic clean water needs [11]. Moreover, research team from Politeknik Negeri Bali (Bali State Polytechnic) in collaboration with Denpasar Regency and Yayasan Idep Selaras Alam (NGO) have been developed Rainwater Harvesting Model (RHM) since 2013. There 4 models have been developed, started with the Type 1, using the reinforced concrete pipe with a diameter of 1 m and a depth of 6 m (Figure 1) [12]. In implementing Type 1, there are field constraints where it is increasingly rare for workers to be able to manually excavate in about 1,5 wide and 6 meters depth of soil, while the use of mechanical tools cannot be done. Therefore, Type 2 was developed, consisting of 4 HDPe pipe with a diameter of 12" with and a depth of 4 m as presented in Figure 2. Type 2 can be done mechanically with a drilling machine so that the manufacturing process is easier and faster [13].

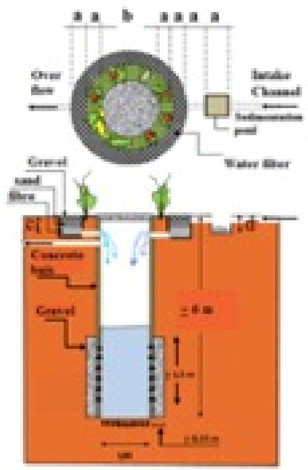


Fig 1. Rainwater Harvesting Wells Model 1 [12].

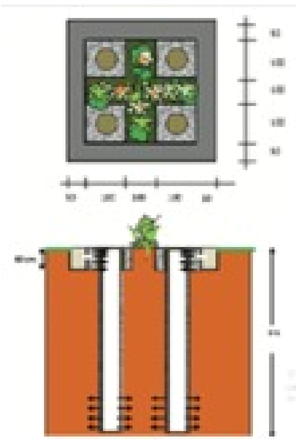


Fig 2. Rainwater Harvesting Wells Model 2 [13].

Type 1 and Type 2 were developed to offset domestic use of groundwater. Subsequently, Type 3 was developed with a larger capacity to offset groundwater use by industry. The increase in capacity of type 3 compared to types 1 and 2 is due to the addition of a rainwater storage tank before it is absorbed into the ground via drilled wells with a maximum depth of around 2 m above the initial groundwater level. As an effort to ensure the sustainability of the implementation of Rainwater Harvesting wells, in the socialization and implementation process, the Ergonomics SHIP approach with involving all stakeholders is used to produce a design that is flexible, affordable from an economic aspect, and its placement blends with the beauty of the existing landscape.

This continuing research was conducted to assess the harvesting capacity of Rainwater Harvesting Wells type 3 through direct empirical application and measurement in the field.

2 Material And Method

2.1 Research Design

This research was conducted in Munduk Vilage (8°15'47.6"S 115°05'10.3"E), Buleleng Regency, Bali Province. The Rainwater Harvesting Wells was built in the in the area of Tamblingan Bale Banjar where the local community gathers regularly to convey various information or village programs. This location was selected based on the results of previous research which showed that the Munduk Village area is a recharge area as shown in Figure 3. The location is very suitable for building rainwater harvesting wells. Besides, it is good location as the model to educate community about groundwater conservation.

Fig 3. The location of the research and the Rainwater Harvesting Wells type 3.

The light green area in the Fig. 3 is the main recharge area with the recharge value is > 33. The classification of the recharge area is determined based on the sum of the weights of each parameter and its ranking value as describes in Table 2. The total additive value for Munduk Village is 39 (>33). It means that the Munduk Village is as the main recharge area [14].

Table 2. Analysis of Additive value

Descriptions		Additive value	Score	Total Additive Value
Village	Munduk			
Regency	Buleleng			
Sample code	BLL 4 - 15 m			
Coordinate				
S	-8,26256			
E	115,065661			
Coefficient of permeability (m/day)	0,101892556	3	4	12
Rainfall (mm/yr.)	1559	2	3	6
Type of Soil Layer	Silty sand	3	3	9
Inclination (degrees)	Moderate	2	3	6
Water table (m below ground level	15	3	2	6
Total Additive Value				39

2.2 The Rainwater Harvesting Walls

The Rainwater Harvesting Wells type 3 was built with the dimension as describes in Figure 4.

B.1. Top view

1) a cover made of reinforced concrete plate measuring 1300 mm x 2300 mm which is divided into 4 parts, each measuring 1300 mm x 575 mm, functioning as a cover for the rainwater reservoir. The reinforced concrete plate cover is provided with ½” diameter holes with a distance of approximately 300 mm which functions as an intake for rainwater which falls directly on the wells;

2) Gravel backfill around the water tank with a width of 250 mm as part of the filtration system to filter rainwater that falls on the yard to ensure that the quality of rainwater entering the intake pipe and filling the water tank meets groundwater quality standards;

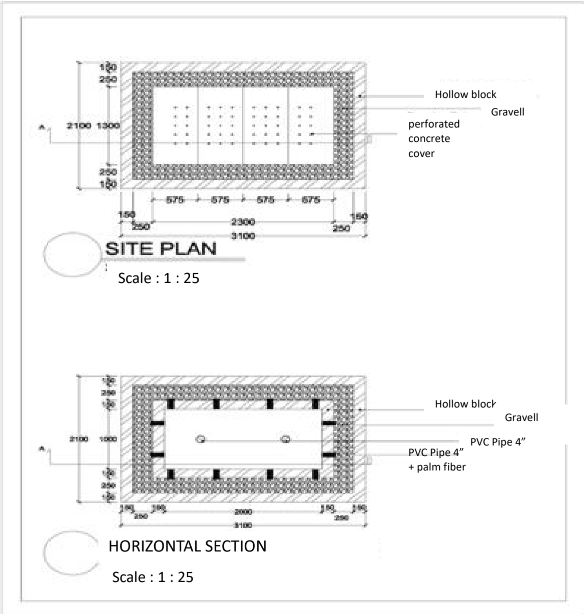
3) Hollow block 300 mm x 100 mm x 150 mm installed around the gravel pile in a sleeping position, which functions as a barrier so that the gravel does not scatter beyond the boundaries of the filtration system.

B.2. Horizontal Section

1) Two drilled wells with a diameter of 4" installed on the base of the reservoir which function to absorb rainwater into the ground and replenish groundwater sources by gravity;

2) Intake pipe with a diameter of 4" 200 mm long, filled with fiber inside, installed on the wall of the reservoir with a distance of about 40 cm, which functions as an intake

for rainwater that falls on the yard, enters the gravel backfill, flows through the intake pipe and fills the basin container.



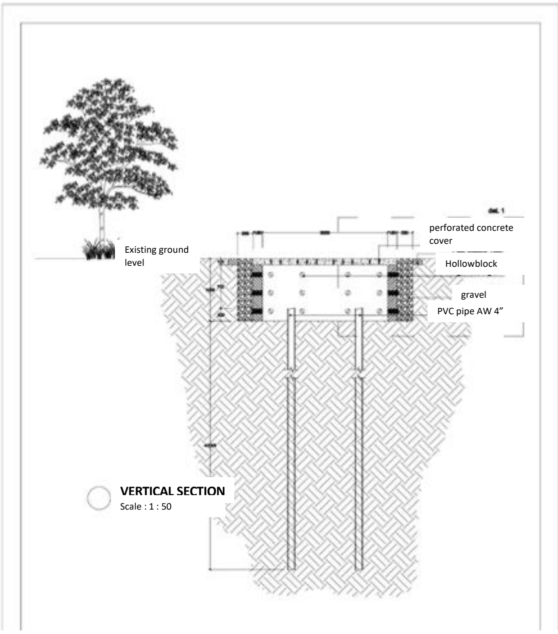


Fig 4. Rain Water Harvesting Wells with the Natural Filtration System, Simple Patent No. IDS000004756 (Granted).

B.3. Vertical Section

1) 60 mm thick reinforced concrete plate cover, with ½” diameter holes at a distance of approximately 300 mm, installed overlapping the storage tank wall;

2) The walls of the storage tank are 100 mm thick made of hollow block with a depth of 900 mm;

3) Intake pipe with a diameter of 4” 200 mm long, filled with palm fiber, installed on the wall of the reservoir;

4) Gravel backfill 250 mm wide with a depth of 1000 mm around the reservoir;

5) Pair of hollow block measuring 300 mm x 100 mm x 150 mm, installed in a sleeping position with a thickness of 100 mm, installed at the top around the gravel pile;

6) Two well points drilled from PVC pipe with a diameter of 4", installed at the bottom of the storage tank, with a depth of 32,000 mm.

B.4. Main component

1) A filtration system consisting of gravel backfill around 250 mm wide reservoir with a depth of 1000 mm, a 2" diameter PVC pipe installed on the wall of the rainwater reservoir, and palm fiber filled into the intake pipe, which functions to filter the rainwater falls on the yard so that the quality of rainwater entering the intake pipe and filling the reservoir meets groundwater quality standards;

2) Water storage tank with internal dimensions 1000 mm wide, 2000 mm long, 900 mm deep. The size and capacity can be adjusted to the area of the target rainwater catchment area and local rainfall, with a minimum capacity of 20% of the estimated volume of rainwater that falls in the rainwater catchment area.

3) Two wells drilled from PVC pipes with a diameter of 4” with a depth of 32,000 or around 2 (two) meters above the groundwater level where the wells are built, function to absorb rainwater into the ground by gravity.

B.5. Data Collecting

Empiric data was collected through the experiment by measuring the increase in water level during filling and the decrease in water level during infiltration, using an electric water level sensor instrument. The measurement time starts with a measurement time interval of about 0 – 10 minutes every 1 minute, 10 – 30 minutes every 5 minutes, 30 – 60 minutes every 10 minutes, and 1 – 2 hours every 20-40 minutes.

B.6. Ergonomics Approach for Sustainable Development

Ergonomics is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data, and methods to design in order to optimize human well-being and overall system performance [15]. The implementation of ergonomics in the Saving Water Program started form the problem analysis to enlargement and enrichment is for sustainability as describes in Figure 5.

Macro-ergonomics is an ergonomics approach with a broader perspective carried out through the application of Systemic, Holistic, Interdisciplinary, and Participatory (SHIP) concepts in designing, implementing, evaluating and developing sustainable work systems and/or technology by placing human capacity, limitations and abilities as the main consideration [17]. Systemic means that one sub-system should be considered as a part of the whole system; Holistic means in designing work system or product, should be analyzed holistically for the long-term objective, although in the implementation program it done partially; Interdisciplinary means all aspect should be involve related discipline; and Participatory means started from the socialization, preparation to implementation should be involved all stakeholders as per step of process.

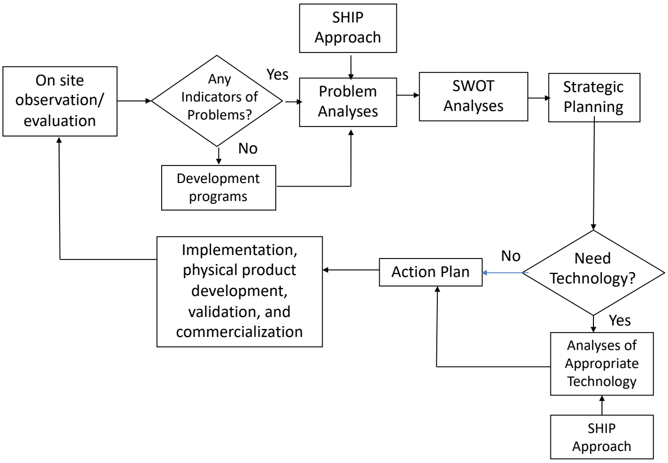


Fig 5. Ergonomics SHIP Approach [16].

3 Results And Discussion

3.1 Sieve Analysis

The result of sieve analysis showed that the land in Munduk is silty sand as describes in Table 3.

Table 3. Soil Gradations Test in Munduk Village.

No.	Description	gradation (mm)	Proportion
1	Clay	< 0.002	1.44%
2	Silt	0.002 < d < 0.075	5.18%
3	Fine sand	0.075 < d < 0.42	48.60%
4	Medium sand	0.42 < d < 2	19.58%
5	Coarse Sand	2 < d < 4.75	26.64%
6	Fine Gravel	4.75 < d < 19.1	1.96%
7	Coarse gravel	19.1 < d < 76.20	0%

Table 3 presented that the soil in Munduk Village is silty sand.

3.2 On-site Permeability Test

Permeability test was conducted directly in the field and the result is presented in Table 4 that showed the existing soil permeability in the location of rainwater harvesting wells is in the moderate category with the permeability value is 5.73 (2 – 6.5).

Table 4. On-site Permeability Test.

Number of observation	Time		Duration	water level in the pipe	Different water levels in the pipe	pipe Diameter	The flow of water to the pipe	Permeability
	minute	second	second	(m)	(m)	(m)	(m3/sec)	(m/sec)
1	0,60	36		3,40				
2	1,14	68,4	32,40	4,00	0,60	0,1016	0,0002501	0,002462
3	1,39	83,4	15,00	4,26	0,26	0,1016	0,0005402	0,005317
4	2,10	126	42,60	4,36	0,10	0,1016	0,0001902	0,001872
5	2,37	142,2	16,20	4,42	0,06	0,1016	0,0005002	0,004923
6	3,04	182,4	40,20	4,51	0,09	0,1016	0,0002016	0,001984
7	3,26	195,6	13,20	4,59	0,08	0,1016	0,0006139	0,006042
8	4,05	243	47,40	4,72	0,13	0,1016	0,0001710	0,001683
9	4,32	259,2	16,20	4,82	0,10	0,1016	0,0005002	0,004923
10	4,51	270,6	11,40	4,89	0,07	0,1016	0,0007108	0,006996
11	5,30	318	47,40	5,00	0,11	0,1016	0,0001710	0,001683
12	6,00	360	42,00	5,13	0,13	0,1016	0,0001929	0,001899
13	7,49	449,4	89,40	5,39	0,26	0,1016	0,0000906	0,000892
14	10,00	600	150,60	5,80	0,41	0,1016	0,0000538	0,000530
15	14,22	853,2	253,20	6,40	0,60	0,1016	0,0000320	0,000315
16	20,29	1217,4	364,20	7,46	1,06	0,1016	0,0000222	0,000219
17	25,26	1515,6	298,20	8,14	0,68	0,1016	0,0000272	0,000267
18	30,25	1815	299,40	8,82	0,68	0,1016	0,0000271	0,000266
19	40,28	2416,8	601,80	10,59	1,77	0,1016	0,0000135	0,000133
20	50,43	3025,8	609,00	11,19	0,60	0,1016	0,0000133	0,000131
21	60,00	3600	574,20	12,28	1,09	0,1016	0,0000141	0,000139
22	80,00	4800	1.200,00	14,20	1,92	0,1016	0,0000068	0,000066
23	100,00	6000	1.200,00	15,54	1,34	0,1016	0,0000068	0,000066
24	120,00	7200	1.200,00	16,61	1,07	0,1016	0,0000068	0,000066
25	150,00	9000	1.800,00	18,00	1,39	0,1016	0,0000045	0,000044
26	180,00	10800	1.800,00	19,41	1,41	0,1016	0,0000045	0,000044
27	240,00	14400	3.600,00	21,30	1,89	0,1016	0,0000023	0,000022
Total								0,042986
Average (m/sec)								0,001592
Average (m/min)								0,095524
Average (m/hr)								5,731442

3.3 On-site Assessment of Rainwater Harvesting Capacity

The assessment of rainwater harvesting wells capacity is carried out by measuring the decrease in water level both in the pipe and in the water storage tank. The result describes in table 5.

Table 5. Capacity for rainwater harvesting.

Description	Harvesting
Harvesting capacity through the bore pipe (2 pipes , 32 m dept) (m3/hr)	1.209
Harvesting capacity through the bottom of the water reservoir (m3/hr)	39.878
Total harvesting capacity (m3/hr)	41.087

Table 5 shows the rainwater harvesting through the bottom of the water reservoir is much bigger the through the pipes. However, the rainwater harvesting through pipes is directly go to the aquiver (32 m dept), while the rainwater harvesting through the bottom of the water reservoir needs more time to achieve the aquiver.

3.4 Ergonomics Approach

The final appearance of the rainwater harvesting wells is shown in Figure 5.

Fig 6. Final view of Rainwater Harvesting Wells types 1, 2, and 3 with various forms of placement according to available land.

Figure 5 shows that the design and placement of the Rainwater Harvesting Well is not rigid, flexible, adapts to the availability of land and the surrounding landscape and looks beautiful. This final appearance is the result of an ergonomic SHIP (Systemic, Holistic, Interdisciplinary, and Participatory) approach that prioritizes safety, health and comfort of users/visitors as an effort to ensure the sustainability and maintenance of wells, as well as being able to be used as an object of Edu-conservation tourism. To build the impression that the wells can look beautiful and blend in with the surrounding landscape, ornamental plants can be added above and around the wells which are arranged in such a way as not to interfere with the flow of rainwater that falls on the yard and enters the filtration system.

3.5 Discussion

Rainwater harvesting system has been developed in some countries as an effort to save the water and preserve groundwater resources. This result found out that one rainwater harvesting wells type 3 can harvest and absorb the rainwater for about 41.087 m3/hr. or 986.10/day. Bali has 4 wet months/yr. (120 days). It means 1 wells can harvest about 118,331.78 m3/yr. Type 3 rainwater harvesting wells are designed to balance the use of groundwater by industry, especially the tourism industry. Based on Bali statistical data, in 2022 there were 498-star hotels (excluding tourism supporting industries). If every star hotel is required to build at least 1 rainwater harvesting well, 58,929,224.81 m3/year of rainwater can be saved. If the movement to save water through rainwater harvesting wells is socialized and implemented well, then Bali will not face the water crisis that many parties have been worried about. The addition of water through rainwater harvesting can at least preserve groundwater, and can even meet some domestic and industrial clean water needs.

Lahore city India has a great Rain Water Harvesting system. Hussain et all reported the groundwater level can rise to 3.54 ft after every monsoon period if the recharge wells structure with maximum capacity about 29.32 m3/h are used, which is a key to groundwater sustainability [18].

Roba et al conducted the research in various places in Ethiopia to assess the country's achievements and opportunities when it comes to Rain Water Harvesting (RWH). They describe the actual findings that the community faces the financial inadequacies, historical and political instability, lack of understanding among farmers, and resistance to new technologies, therefore, country has opportunities and has made some progress on RWH systems [19]. Pandey et al did a review article about rainwater harvesting and concluded that rainwater harvesting in South Asia remain continuous practice for at least the last 8000 years. The antiquity of rainwater harvesting as an adaptation to climate change in India is deep. In a fluctuating Holocane climate, rainwater harvesting by early farmers may have been pivotal for emergence and diversification of food production [20].

From these various references, it can be seen that rainwater harvesting is still being considered for development and implementation as a simple way to save water and overcome the water crisis problem, especially in the rural area during dry season.

4 Conclusion

The water crisis problem has become a global issue and occurs almost all over the world. Various water management methods are applied to overcome this water crisis problem, starting from the simplest methods to those using high technology. One simple method that has been used for hundreds of years now is a rainwater harvesting system. Saving water through rainwater harvesting does not seem to provide significant benefits, but in fact in the long term saving water through rainwater harvesting wells can increase groundwater levels, and can even meet both domestic and industrial needs, especially in the dry season. However, the implementation and development of this rainwater harvesting system requires strengthening policies from the government.

The Bali State Polytechnic research team has been developing rainwater harvesting wells since 2013, in collaboration with the Idep Selaras Alam Foundation (NGO) and the local government of Denpasar City, starting from the domestic scale to the industrial scale. However, its implementation in the field is still based on limited awareness, has not been structured and there has been no policy strengthening. The results of research on type 3 rainwater harvesting wells, which are designed to offset groundwater use by industry, are proven to be able to harvest rainwater and seep it back into the ground. 1 rainwater harvesting well can save 41,087 m3/hour of water if built in the main recharge area. If there is a policy where there are around 498 star hotels in Bali, it can be estimated that Bali will be able to save around 58,929,224.81 in water per year. The results of this research need to continue to be developed and require strengthening local government policies so that they can be generalized to various regions in Bali.

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