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DOMESTIC RECHARGE WELLS FOR RAINWATER-HARVESTING IN DENPASAR CITY, BALI - INDONESIA

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ABSTRACT: This research is to create the design of shallow recharge wells for harvesting rainwater in Denpasar City, Bali-Indonesia. The growth of the tourism industry is increasing rapidly. It has been able to accelerate the economic growth, but also followed by some negative effects, including rapid growth of population, changes in land use, reduced the catchment area and groundwater exploitation for tourism infrastructure development. The result showed that in several strategic areas have shown an indicator of water crisis, especially in North and East Denpasar. Based on the permeability analyses, the recharge area was in the north and a little part of west Denpasar. The rainfall was between 1500 - 1750 mm/year with 4 wet months a year. The shallow groundwater level reaches 16.10 m below ground level in the North, while in the West was 18.2 m with the maximum infiltration rate was 0.00000054 mm/sec. Based on those data, it has been designed the ergonomics shallow recharge wells for rainwater harvesting to offset the domestic water usage. The analyses showed that if all 220.150 households make at least one shallow recharge wells, it can harvest rainwater about 222.40 l/sec, and is able to return about 63.87% of water which should be recharge to the ground. In conclusion, making one-recharge wells for each household has not been able to recover the domestic water usage. It is recommended to create another innovation for water conservation program such as building the recharge wells along the drainage tunnel.

Keywords: Recharge wells, Rainwater harvesting, Denpasar City-Indonesia.

1. INTRODUCTION

In a few decades, Bali with it's unique culture has changed from an agricultural area became very famous tourist areas. The growth of the tourism industry are increasing rapidly been able to accelerate economic growth, but also followed by some negative impacts, including the rapid increasing of population growth, changes in land use, reduces catchment areas, and the exploitation of natural resources with less consideration to preserve environment, including the exploitation of groundwater usage.

Strategic environmental assessment in 2010 at the province of Bali has produced a map that shows the high level of groundwater usage and there were 13 points area experienced seawater intrusion [1]. Following up the assessment in 2010, Denpasar government, in cooperation with Politeknik Negeri Bali (Bali State Polytechnic) has built research collaboration on Groundwater in Denpasar City (2013-2014). As the result, it was identified that there were indicators of water crisis in some strategic area, especially in Panjer, Peguyangan village (North Denpasar), and Penatih Village (East Denpasar). The pumping test of 15 deep wells showed that 5 wells (33%) indicated in a good design and well developed (well loss value <0.5), 13% suffered minor damage (well loss value between 0.5 - 1), 33% suffered severe damage with some blockage (well loss value between 1-4), and the rest was experienced heavy damage and difficult to be restored (well loss values > 4). This is consistent with the statement of the Bouwer [3] that the main cause of the global water crisis is partly due to increased water demand, global climate change, and lack of catchment areas. Wang et al. [4] reported that the exploitation of groundwater during the years 1985 to 2010 led to a decrease in the depth of groundwater in Linze County. Meanwhile, Adham at all [5] reported that the numerical simulation showed the effect of climatic change on the decreasing of groundwater quality. Liu et al. [6] reported that the land conversion in China Alagan the period 1980-2000 has led to changes in flow and groundwater levels.

Water is essential for life. Abundant water resources with good quality will lead all living beings to a better life as well. Therefore all efforts for the conservation of water resources must be fully supported. Changes in land use must be done carefully so the deterioration in the green land area can be avoided. Deforestation must be avoided so that the sustainable rainwater harvesting is naturally guaranteed as well as the sustainability of other living creatures. For example, the research done by Ma, Le [7] has demonstrated that woodland has potential positive effects on *Margaritifera*. Therefore, the protection of riparian woodland is important for the conservation and management of freshwater pearl mussels.

Ground water is renewable natural resource, but un-controlled exploitation with lack awareness to preserve; it will lead to the water crisis as well as the decreasing of the quality of life. Therefore, it is important to undertake a program of conservation of groundwater and building awareness of society, especially in urban areas such as Denpasar City. There are some ways for ground water conservation; one simple program that can be done is harvesting rainwater through recharge wells.

2. MATERIAL AND METHOD

2.1 Times and Location

The research was started on 2013 and now is still ongoing. It was conducted in Denpasar City, one of the strategic tourism destinations in Bali (Fig. 1).

Fig.1 The map of Denpasar City

Denpasar city is located between 08 ° 35 "31'- 08 ° 44 '49' south latitude and 115 ° 10" 23'-115 ° 16 "27 'east longitude. Denpasar City area is 12 778 ha, 2.18% of the total land area of Bali province. It is divided into four sub-districts, North, East, South, and West Denpasar. The largest of sub-districts is South Denpasar, followed successively by the Northern, West and East Denpasar. The land use is consisting of wetland covering 2,717 ha. and dry land 10 051 ha. Dry land consists of 7,831 ha. yard land, dry land 396 ha, pond/pool 10 ha, not cultivated 81 ha., 613 ha of forest, 35 ha of plantation and others is 1,162 ha. The topography of the city of Denpasar is generally skewed towards the south with a height ranging from 0-75m above sea level. Morphology ramps with a slope of land mostly range between 0-5% however on cut slope can reach 15% [8]

2.2 Research Approach

This paper reported part of the research with focused on the innovation design of recharge wells for harvesting rainwater for domestic usage through ergo-hydrogeology approach. One of the factors contributed on the changing of the groundwater condition is the human activity. Therefore, in designing the conservation program should put a man with all the activities, behavior and socio-cultural background as a primary consideration in accordance with the basic principles of ergonomics SHIP approach as shown in Fig. 2.

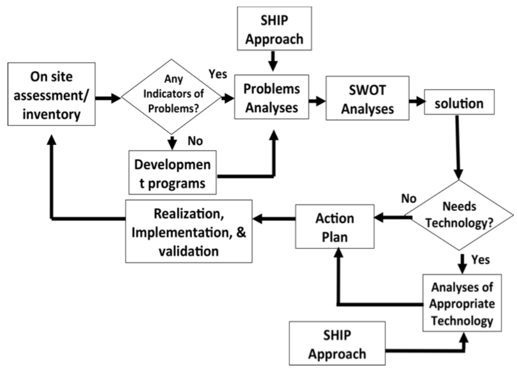

Fig. 2 The Model of Ergonomics SHIP Approach [9]

The design process was involved all parties through Focus Group Discussion (FGD) which has been held on July 31, 2015. The FGD brought together all participants from local governments, state companies, the private sector, and local communities. The FGD participants were divided into four groups - each consisting of representatives of every stakeholder. The result of FGD presented lists of prioritized issues related to the existing water resources management, expectations of the future, as well as challenges and constraints in meeting those expectations.

The hydrological approach was done to analyze the capacity of the recharge wells based on the basic formula of rainfall (R), permeability (K), infiltration rate (I), and water discharge (Q).

2.3 Data Collecting

General data on groundwater obtained from the Public Works Department of Denpasar City, included data of geography, hydrology, topography, hydrogeology, and the list of licensed deep bore wells.

The primary quantitative data was collected through assessments, included data of permeability (K) and infiltration rate (I), while the subjective data was collected through questionnaire.
The technical data analyses were conducted by using the basic formula of hydrology.

3. DATA ANALYSES

3.1 Descriptive Analyses

The results of questionnaire analysis, which is reinforced by the results of FGD, show some strategic issues as follows:

1. Prioritized of strategic issues on technical aspects:
   a. Excessive exploitation of ground water by industry
   b. Decreased groundwater quality and resources
   c. Increased seawater intrusion
   d. Lack of monitoring wells
   e. Many buildings on the watershed
   f. Decreased green spaces

2. Prioritized of strategic issues on Management aspect
   a. Ground water drilling permits are easy to obtain, but many groundwater drilling unlicensed
   b. Monitoring system for groundwater exploitation and quality is still weak
   c. The data series on groundwater characteristics are not yet available
   d. Taxes groundwater utilization is too low
   e. There are no regional regulations governing the use of groundwater
   f. Efforts to control the destructive force of groundwater resources is still weak
   g. Ground water conservation programs that have been implemented less on target
   h. There are many overlaps in the tasks and functions related agencies in the conservation of water resources
   i. There are no clear SOPs for ground water conservation activities
   j. Less of public awareness

3. Expectations on Technical Aspect
   a. Engineering effort required to overcome the problem of groundwater
   b. Drilling groundwater should be accompanied by building a recharge well
   c. Recharge shallow wells need to be made in every yard
   d. Need to build reservoirs / artificial lake to accommodate / rainwater harvesting
   e. Need to develop green areas

4. Expectations on Managements Aspect
   a. Necessary organizational restructuring related efforts to conserve water resources
   b. Required Groundwater Management Model that able to synergize all sustainable water resource conservation programs
   c. Required a clear vision and mission related to the preservation of water resources
   d. Monitoring and control the utilization of ground water must be carried out periodically and continuously
   e. Need strict sanctions for those who violate the rule of water resources
   f. Need to build an IT data base systems
   g. Need to improve the quality of human resources
   h. Keep in groundwater conservation efforts
   i. Need enacted progressive tariff system, the more water utilization, higher tariffs
   j. Need to be coordination between the relevant agencies in the implementation of groundwater conservation program
   k. The role of communities in groundwater conservation needs to be improved
   l. Need to be controlling and regulating the use of groundwater

3.2 Quantitative Analyses

3.2.1 Characteristic of shallow wells

Analyses were conducted to identify the characteristics of shallow wells spread out over four districts in Denpasar City as presented in Table 1. It can be seen that the maximum depth of the water table wells was in west Denpasar, it achieved about 18.2 m below the ground level (bgl), then followed by the North Denpasar: 16.10 m bgl; East Denpasar: 11.55 m bgl, and South Denpasar: 4.50 m bgl. These data will be used as a basis for determining the depth of recharge wells. The depth of recharge wells should be at least one m above the water table level, so there is space for the recharge water to be absorbed following the gravity and increase the water table level surrounding.

Table 1. Characteristic of Shallow Wells

Sub-District		Groundwater table (m-bgl)	Debt of wells (m-bgl)
North	Span	0.80 – 16.10	2.60 – 24.10
Denpasar	Average	5.63	10.24
East	Span	0.40 – 11.55	1.90 – 20.55
Denpasar	Average	4.06	7.22
South	Span	0.45 – 4.50	2.00 – 6.40
Denpasar	Average	1.53	3.54
West	Span	2.40 – 18.20	8.90 – 21.20
Denpasar	Average	7.41	12.41

3.2.2 Recharge area

The results of the analysis and mapping of soil permeability indicate that the recharge area is in the north of Denpasar area with a maximum permeability (K) of 0.0434 m / day (Fig. 3)

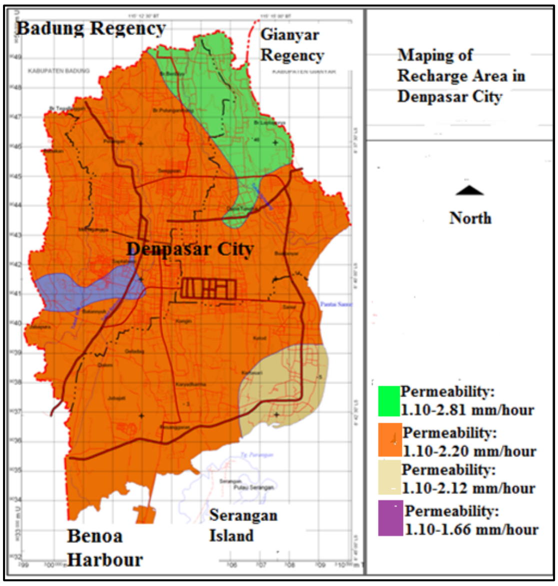

Fig. 3. Map of Recharge Area in Denpasar Regency

Based on the recommended recharge area, then the design of recharge wells was based on the characteristics of the groundwater in the area of North Denpasar.

3.2.3 Rain water harvesting analyses

1. Effective Rainfall (R (Ef))
   Rainfall (R)
   R = 1500 mm/year
   = 375 mm/month
   = 0.0001447 mm/sec

   Wet months (Wm)
   = 4 month/year
   = 10.368.000 second

   Effective rainfall :
   R (Ef) = R/Wm
   = 375 mm/month
   = 0.0001447 mm/second
   = 0,00000015 m/second

2. Rainwater Harvesting (Q1)
   Rainwater harvesting was analyzed for 100 m2 of catchment area (estimation of covered land/household)

   Q1 = A * R(Ef)
   = 100 * 0,00000015
   = 0.000015 m3/sec.
   = 1,296 m3/day

   Statistic data of Denpasar City showed that there are 220,150 households with 4 person average in each household.

   If each household harvest at least 20% of rainwater, it means that the effective rainwater harvesting = 0.20 * 1,296 m3/day
   = 259.2 m3/day/household

3. Domestic ground water usage

   The water needs of each person (N)

   N = 165 l/person/day

   Water needs = 165*4 l/day/household
   = 660 l/day/household
   = 0.66 m3/day/household
   Total water needs = 0.66 * 220.150
   = 145.299 m3/day

The analyses of effective rainfall harvesting and total water needs/household showed that Denpasar will never meets the water crisis, but the fact showed in contrary. Therefore, the water conservation program is still needed.

3.2.4 Recharge wells design

Based on the results of technical analysis that includes data characteristic of shallow groundwater, soil permeability, infiltration rates, and the result of FGD, produced designs of recharge wells (Fig. 4) with technical specification as followed:

1. It made from concrete pipes with 1 m diameter
2. The debt is at least 1 m above the groundwater table, in this research, it was assigned 9 m

3. The filtration pond was constructed around the top of wells to ensure the quality of incoming water to the wells meet eligibility standards
4. To facilitate operations and maintenance, as well as the safety and health considerations, recharge wells equipped with a ladder made of galvanized pipe diameter of 1 ".
5. From the socio-cultural aspects of Bali, the wells designed and positioned to blend with the surrounding beauty and fulfilling aspects of asta-Kosala-Kosali, ie the spatial arrangement based on the culture of Bali.
6. The charging process are as follows:
   - Rainwater that falls directly on the filtration pond will be filtered and fed into the well through pipes that installed in the bottom of the pond
   - Rainwater that fell in the courtyard flows through the intake tunnel into the sedimentation pond, the mud will be settled to the bottom of the pond, the water flows to the filtration pond, filtered and fed into the recharge wells

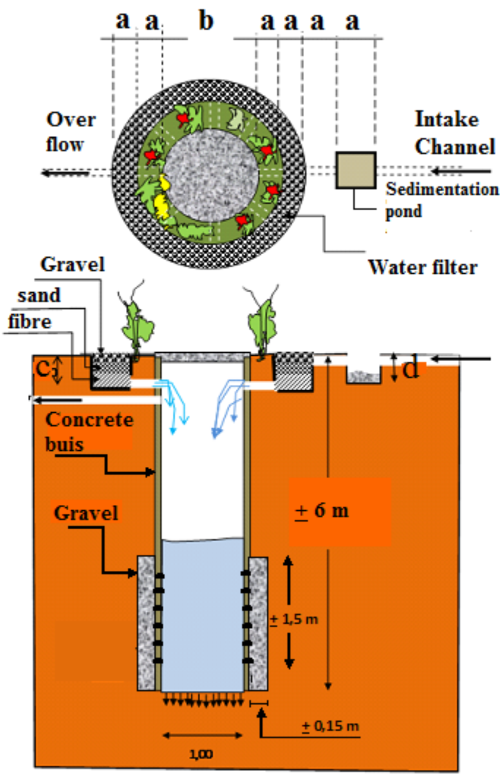

Fig.4 The design of concrete recharge wells

Note :
a = 40 cm
b = 100 cm

3.2.5 Capacity of rechrge wells

Data :
Diameter (d) = 1 m
Debt of recharge wells (L) = 9 m
The water volume in the recharge wells (V)

$$V = 1/4\ \pi\ d^2 * 9\ \text{m}$$

$$= \mathbf{¼\ \pi * 1\ m^2 * 9\ m}$$

$$= 7{,}07\ \text{m}^3$$

Rainwater harvesting (Q1) = 1,296 m3/day

The estimate effective that will fulfill the recharge wells is 70%

The period needs to fulfill the recharge wells (T1)

T1 = 70% * V / Q1 = 7.79 days

Analyses showed that the average infiltration rate in the region of North Denpasar is:

If = 0.00000054 mm/sec.
= 0.001944 m/hour

The water infiltration volume (Q2)

Q2 = ¼ π x 1 * 1 * 0.001944
= 0.0110322 m3/hour
= 0.2647728 m3/day ~ 0,265 m3/day

Thus, the time required absorbing water until all the water in the recharge wells entirely permeated (T2)

T2 = 7,07/0.265 = 26,68 day ~ 27 day

If each household makes 1-recharge wells, the total volume of water infiltration (Q3) during wet month (4 months = 120 days)

Q3 = Total household*Wm/T2*V
= 220.150 * 4/27) * 7.07
= 6.917.602 m3/year
= 18.952,33 m3/day = 222,40 l / sec

3.2.6 Deficit of recharge water

The average of daily needs in Denpasar City is 165 l/day/person.

The wet months (Wm) is 4 months/year

Total water needs

Q4 = Total household*Wm*Dn

= 220.150 x 4 x 165
= 150.552.600 l/day = 1.742 l/sec

The daily needs that supplied by local government company is 478 l/sec. Thus, the ground water usage (Q5)

Q5 = 1.742 l/sec - 478 l/sec
= 1.264 l/sec

The obligation to restore ground water is at least 20% of usage (Qr) = 0.2 * 1.264 l/sec = 252,8 l/sec

Rainwater harvesting Q3 = 222,40 lt/dt (87.975% Qr)

Then the groundwater deficit that has not been recovered is:

Q6 = 252 l/sec - 222,40 l/sec
= 30.4 l/sec
= 12.025% Qr.

4. DISCUSSION

Groundwater comes from rainwater infiltration through pores or cracks in rock formations as well as of the flow of surface water such as rivers, lakes, and reservoirs that seep through the soil into the lane saturated through hydrological processes [10]. Arimitsu at all [11] found out that hydraulic gradients between 100 cm depth and the soil-bedrock interface were indicating that subsurface water flowed from the upper area to the lower end of the slope at all times. These results indicate that the saturation occurred after very small amounts of rainfall, regardless of soil moisture conditions. Under ideal conditions, the hydrological cycle will naturally maintain a balance between inputs, savings and output, but the development of the industry as well as changes in activity/human behavior disturbing the balance so that there arises the issue of global water crisis. The main cause of the global water crisis is partly due to increased water demand, global climate change, the lack of catchment areas or the lack of surface water storage [3] [4] [5]. The main problem in the management of groundwater, especially in developing countries is the limited supply of water from surface water sources due to land conversion, exploitation of groundwater due to industrial development, the behavior of people who are less concerned about the preservation of the environment which ultimately led to the decline of groundwater, sea water intrusion, groundwater pollution, and land subsidence. This is similar to the results of research by Tirtomihardjo and Setiawan [12]. It was reported that the changing in land use in Bali have led to a decline in groundwater levels up to 60-73 m below ground surface (bgs). Meanwhile, Sudiajeng et all. [13] reported that the exploitation of groundwater through deep bore wells by the hotel and supporting industries in Denpasar reached depths between 70-200 m bgs and caused the critical potencies of groundwater resources. Exploitation of groundwater on a large scale through the deep bore wells can cause the seawater intrusion and degrade groundwater quality. Sudiajeng [2] reported that in the whole area of Denpasar has been experienced of seawater intrusion. Based on the 134 wells tested, 89.06% had Electrical Conductivity (EC) <1000 μ mhos/cm and 10.94% between 1000-2079 μ mhos/cm (Figure 2. & Figure 3.). Moreover, Sukaarsana et al. (2015) [14] reported that in the region of North Kuta - Badung Bali, an EC of 60 samples had reached 1,677 μ mhos/cm. those data showed that the EC in most of area in Bali, including Denpasar regency had already in the upper limit, even exceeding the threshold limit (EC <2000 μ mhos/cm). One of the simple programs to increase the water level as well as the quality of groundwater is by building domestic recharge wells.

Building the domestic recharge wells is simple and easy, but one of the obstacles is the lack of awareness of people. This could happen because people did not know how important is the water conservation program and they were not directly involve both in the identification of problems, building plan and implementation for solutions. Therefore, this research used the ergonomics approach that puts all stakeholders to participate in the planning process as well as the implementation programs so the sustainable implementation of the domestic recharge wells for harvesting rainwater can be assured. All the stakeholders contributed their opinion in the FGD through Systemic, **H**olistic, **I**nterdisciplinary, and **P**articipatory (**SHIP**) approach. Systemic means that the plan should be analyze through a system; Holistic means that each teamwork should interrelate with other team works; Interdisciplinary means that the analyses should be utilized by all related discipline; and Participatory means that all relevant stakeholders should be involved. The main goal of ergonomics SHIP approach is to attain the humane and sustainable work system [15][16]. By synergizing the principle of ergonomics approach with the science of hydrology, is expected to have a domestic recharge wells in which emphasizes the advantages, limitations, and the permissibility of human as a subject in each phase of the design and implementation. As the result, it can be designed an appropriate technology which is humane, fit with the local socio-culture, friendly to environment, and preserve energy. Through the ergonomic SHIP approach, this research has changed the mind-set that the wells are not always there in the back yard with slum condition, but it can be placed in the front yard, together with the beauty of the house. With this mind-set, people will have self-motivation to build the domestic recharge well in their yard and finally increasing the awareness to the environment.

The application of ergonomics in various aspects began to grow rapidly. This is emphasized by some implementation of ergonomics in the working system that has been shown the increasing awareness of stakeholders on the sustainable development programs [7][17][18].

Hydrogeological analyses showed that the domestic recharge wells could harvest the rainwater about 1,296 m3/day or recovered about 87.975% of the obligation of recharge water for domestic usage with assumption that each household build about 100 m2 of the house. It is expected to increase the groundwater level as well as the water quality. Refers to the Stiefel and Melles [19], rainwater harvesting was improve the water quality through the dilution of chemical constituents in groundwater. In addition, the rainwater harvesting is still safe to drink and can be a potential alternative source of water supply [20].

Currently, in the ongoing research is being built two prototype domestic recharge wells and will be measured empirically about its effectiveness in recharging water into the ground. It is expected that rainwater harvesting through the domestic recharge wells will reduces the effect of seawater intrusion as well as increases the groundwater level in Denpasar Regency. The previous research showed that all area in Denpasar regency experienced of seawater intrusion, although some of area were still under threshold limit, but some others were already in the upper limit, even out of the limit, especially in South Denpasar, which is directly adjacent to the sea.

Water is life. Groundwater is a renewable resource, but it is not infinite. If the sustainability of groundwater resource is threatened, our lives will be in danger. Therefore, groundwater conservation programs are very important ranging from the simplest things such as domestic recharge wells to injection wells in high technology.

5. CONCLUSSION

1. Ergonomic SHIP approach has changed the mind-set that the wells are not always there in the back yard with slum condition, but it can be placed in the front yard, together with the beauty of the house.
2. Hydrogeological analyses showed that the domestic recharge wells could harvest the rainwater about 1,296 m3/day or recovered about 87.975% of the obligation of recharge water for domestic usage.
3. Law-reinforcement is needed to build awareness of people on the conservation program.
4. People that build more than 100 m2 should build more than one recharge wells or bigger dimension of recharge wells.
5. It is needed water conservation to meet the groundwater exploitation by industry, especially tourism industry.
6. Socialization about "saving water" should be done started from the early age.

6. ACKNOLEDGMENT

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