Assessment of the Effectiveness on Domestic Rainwater-harvesting Wells (SPAHUDO) in the Northern Area of Denpasar City – Bali Indonesia Through Ergo-Hydrogeology Approach

L Sudiajeng¹, I Wiraga¹, M Mudhina¹, I G N S Waisnawa², I M Sudiarsa¹
Civil Engineering Department, Bali State Polytechnic, Bali, Indonesia
Mechanical Engineering Department, Bali State Polytechnic, Bali, Indonesia

Correspondent author: sudiajeng@pnb.ac.id

Abstract. This research was conducted to assess the effectiveness on Domestic Recharge Wells that named (SPAHUDO). It’s designed as one of the output of long-term research (2013-2025) on the Model of Groundwater Conservation Program through Ergo-Hydrogeology approach. It synergized the hydrogeology approach, which is more focuses on the technical data of hydrogeology and geotechnical, while ergonomic approach is focuses on human aspect included in the research process, design, and product. The technical assessment of the effectiveness of SPAHUDO was conducted by using the basic formula of both hydrology and geotechnical, confirmed by user based ergonomic approach. The synergized between technically and human aspect is very important for sustainability of the implementation of SPAHUDO.

1. Introduction
Bali is a small island, but very well known as world tourism destination. Tourism industry becomes one of the important economic pillars in Bali and the source of the foreign exchange for Indonesia. The rapid growth of tourism increases the need of fresh water. Therefore, the withdrawal of fresh water through deep wells increased. In northeast Iran, most of water consumption met to groundwater and lead to the declining of water table from 1036.47 m to 1002.75 m from 1987 to 2006 with an annual rate of declining about 1.77 m [1]. Margat [2] reported that there is a huge fresh groundwater stores on earth; which is more than two thousand times the current annual withdrawal. Inline with this report, Asian Development Bank [3] declare that the total water availability in Indonesia is 690 × 10⁹ cubic meters (m³) per year, which is a lot more than the demand of 175 × 10⁹ m³/year. Moreover, the head of River Basin Department Bali-Penida addressed his speech on the celebration of World Water Day 2019 and reported that the total water potential is 7.57 billion m³, consisting of: Surface water / run-off 6.55 billion m³, Springs 0.73 billion m³, and Groundwater 0.29 billion m³. Total water demand of 1.37 billion m³, consisting of: Irrigation water 1,005 billion m³, Domestic 0.325 billion m³, and Non-Domestic 0.04 billion m³. This means that the availability of water sources in Bali is about six times the demand [4]. However, the global trend of water resources tends to decrease and becomes the strategic issue. Sunarta and As-Syakur reported that the analyses of water resources in Bali

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.
Published under licence by IOP Publishing Ltd
showed that the total water supply in 2009 was 4.71 billion m$^3$/year, decreased into 3.57 billion m$^3$/year in 2013. In the opposite, the total water demand increased from 5.46 billion m$^3$/year to 6.23 billion m$^3$/year in 2013 [5]. Water is life, water is a renewable resources, however, if the exploitation of water resources is far greater than the capacity of aquifers, then finally we cannot avoid water crisis that threatens the welfare of the community, especially future generations. Therefore, the water conservation program should be well maintained. All aspect should be considered, including technic, economic, ergonomic, socio-culture, preserve energy and friendly to environment, and finally create the humane program supported by all stake holders which guaranty the sustainability of the program [6]. This research is focuses on the water conservation program through domestic rainwater-harvesting wells (SPAHUDO) and it’s effectiveness in saving the water. Water is life, therefore it is very important to maintain its availability for future generations both the quantity and quality.

2. Material and Method
This research was conducted in Northern Denpasar City with Descriptive-Analytic design. The effectiveness of the SPAHUADO was measured by using basic formula of hydrology and geotechnical and confirmed by user/community based ergonomic approach as follows.

2.1. Water Discharge
Water discharge is the volumetric flow rate of water that is transported through a given cross-sectional area [7].

$$Q = V \times A$$ ................................. (1)

In which  
- $Q$ = Quantity of water discharge (m$^3$/s)  
- $V$ = average flow velocity (m/s)  
- $A$ = cross-sectional area of the portion

2.2. Soil Permeability
The soil permeability is a measure indicating the capacity of the soil or rock to allow fluids to pass through it. It is often represented by the permeability coefficient ($k$) through the Darcy’s equation [8]

$$V = k \times i$$ ................................. (2)

In which  
- $V$ = Fluid velocity (m/s)  
- $i$ = Hydraulic gradient  
- $k$ = Coefficient of permeability (m/s)

In this research, $k$ value was assessed through empirical test directly in the area where the wells built.

2.3. Effectiveness of SPAHUADO
The effectiveness of SPAHUADO is influenced by several factors: 1) the dimensions of the rainwater wells; 2) soil characteristics; 3) absorption area. In this study, the wells was built with 4 points of HDPe pipes with 12” diameter, to be able to accommodate a catchment area of about 200 m$^2$. Soil characteristic was performed by the value of soil permeability, and absorption area is determined through the end surface area of the pipes and holes made along the pipe surface (approximately 40% of the pipe area).

2.4. Community Perception of Effectiveness of SPAHUADO
User Perception of Effectiveness of SPAHUADO was assessed through ergonomic approach by using questionnaire with 120 subjects as representative of all stakeholders, which includes elements of government, village officials, teachers, students, religious leaders, and the community. Elements of the questionnaire included program socialization, site selection and structuring of the SPAHUADO landscape, the effectiveness of the SPAHUADO function, and the sustainability of the groundwater conservation program. Subject’s perception was given in the form of scores using 5 likert scales with categories as follows: strongly disagree (score = 1); disagree (score = 2); quite agree (score = 3); agree
(score = 4); strongly agree (score = 5). The results of the questionnaire were tabulated as presented in Table 2

3. Result and Discussion

3.1. Effectiveness of SPAHUDO

The effectiveness of SPAHUDO was calculated based on (A) and coefficient of soil permeability. The cross-sectional area (A) includes the area of the pipes base and the 40% of the area around the four pipes. The coefficient K was assessed in the recharge area as shown in Figure 1.

![Figure 1. Map of soil permeability/Infiltration Rates (K)](image)

Figure 1 shows that the recharge area is in the northern part of Denpasar city where the recharge wells (SPAHUDO) were built, with the coefficient K is 1.10 to 2.81 mm/hour or the average is 1.9550 mm/hour = 0.0326 mm/minute. The capacity of SPAHUDO was calculated based on the average of K as shown in Table 1.

| Descriptions                              | Data          | Unit         |
|-------------------------------------------|---------------|--------------|
| π                                          | 3.14          |              |
| Diameter of pipe                          | 0.30          | m            |
| Length of pipe                            | 4             | m            |
| Number of pipes                           | 4             |              |
| Pipes base area                           | 0.28260       | m²           |
| Length of pipe circle                     | 0.94200       | m           |
| Hole area along the pipe (40% pipe side area) | 6.02880       | m²           |
| Recharge area                             | 6.31140       | m²           |
| Coefficient K                             | 0.0326        | mm/minute    |
| Water recharge volume                     | 108.08777     | m³/year      |

Table 1. The effectiveness of SPAHUDO
The analysis of the SPAHUDO, which was built of 4 HDPe pipes and 4 m debt, shows that 1 SPAHUDO saves about 30.88% of rainwater in about 200 m² catchment area as shown in Table 1. Physically, SPAHUDO has successfully overcome the presence of rainwater in the vicinity of the yard where SPAHUDO was built as shown in Figure 2. Normally; rainwater that can be absorbed into the soil in urban areas is from 30 to 35%. If every house built on 200 m² of land is equipped with one SPAHUDO, then rainwater that can be absorbed and recharge into ground water sources can be doubled and it will increase the water level of ground water. Central Ground Water Board Ministry Of Water Resources India reported that experiments carried out in the form of water recharge for 250 days with average of 225 cubic meters per day. The results showed an increase in water level as high as 5 meters in the wells which are about 11 m and 0.6 to 1.0 m in wells which are 150 meters away from the observed recharge wells in Mehsana Area And Coastal Saurashtra – Gujarat. Similar experiment was done using a recharge pit (1.7 m x 1.7 m x 0.75 m). During the recharge process which was conducted in 60 days at the rate of 17.3 cubic meters per day and an infiltration of 0.5 m/day. The result showed that it was effectively increased the water level of 4.13 m in the distance of 5 meters from the recharge pit. [9]. Referring to the success of the research in India, the SPAHUDO as an effort to conserve groundwater will be able to raise the level of groundwater optimistically and in the long term be able to preserve groundwater, so the water crisis can be avoided. The current research has only reached the creation of recharge wells and has not been accompanied by the monitoring of wells to ensure that the development of SPAHUDO is really able to increase groundwater levels.

3.2. **User/Community Perception of Effectiveness of SPAHUDO**

To ensure that the community accepted the application of this research; as well as its sustainability is maintained, it is very important to know how the community thinks about the groundwater conservation program, specifically regarding the application of SPAHUDO as an effort to conserve ground water. The failure of various development programs in several countries is caused by the community's ignorance of the program. Therefore, recently developed various community-based programs and the results are very encouraging. Community based wildlife management schemes succeed in protecting some of the larger mammals only by virtue of their increased enforcement levels, not their ability to distribute socioeconomic benefits [10]. Moreover, the Community-based Natural Resource Management Model (CBNRM) showed the potential to increase citizen participation in decisions that impact natural systems [11]. This model is inline with the Total Ergonomics SHIP approach model. In developing the water conservation program, not only focused on the technical and economic aspect, but also considered the community or the user as the first priority consideration. SHIP means Systemic, Holistic, Interdisciplinary, and Participatory. Ergonomic SHIP approach model succeed the programs to achieve the goals. The community involve started from the problem analysis, creating some alternative of solutions and decided the possible one, planning, executing, and implementing. The ergonomic SHIP approach increases sense of belonging and awareness and finally lead the self will to maintain the sustainability of the program [12].

The implementation of the SPAHUDO was conducted through ergonomic SHIP approach and the result is describes in Table 2. The assessment was conducted through distributing questioner with four variables: 1) Program socialization (5 Statements); 2) Site selection and structuring of the SPAHUDO landscape (5 statements); 3) Effectiveness of the SPAHUDO function (4 statements); 4) Sustainability of the groundwater conservation program (5 statements). Variable 1 described that program socialization of water conservation program through SPAHUDO was well known, followed, understood, and supported by the community. Variable 2 described that the site selection and structuring of the SPAHUDO landscape was conducted together with village officials and community representatives.
does not interfere with activities, become part and beautify of the house. Variable 3 described the existing condition before and after the SPAHUDO was built and the effectiveness of SPAHUDO in harvesting the rainwater and overcome the rain puddles that disrupt community activities. Variable 4 described the awareness of community maintaining the SPAHUDO and saving water, awareness of the government in continuing the sustainably water conservation program.

Figure 2a. Existing conditions before SPAHUO type 1 was built

Figure 2b. Existing conditions after SPAHUO type 1 was built

Figure 2c. Existing conditions before SPAHUO type 2 was built

Figure 2d. Existing conditions after SPAHUO type 2 was built

Figure 2. Existing condition before and after SPAHUO was built.

Table 2. User/Community Perception of the Effectiveness of SPAHUO

| No. | Elements of questionnaire                                      | No of Subject | Total score | Average score | Category     |
|-----|----------------------------------------------------------------|--------------|-------------|---------------|--------------|
| 1   | Program socialization (5 Statements)                          | 97           | 22.81       | 4.56          | Strongly agree |
| 2   | Site selection and structuring of the SPAHUO landscape (5 statements) | 97           | 23.10       | 4.62          | Strongly agree |
| 3   | Effectiveness of the SPAHUO function (4 statements)           | 97           | 17.76       | 4.44          | agree         |
| 4   | Sustainability of the groundwater conservation program (5 statements) | 97           | 22.16       | 4.43          | agree         |
|     | **Average Score**                                             | **4.51**     | **Strongly agree** |

Table 2 shows that most of the subjects strongly agreed that Program socialization of water conservation through SPAHUO was involved all stake holders and the SPAHUO was built properly. Most of the subjects were also agree-strongly agreeing that the SPAHUO was effective in harvesting the rainwater and overcome the rain puddles and it needs the government’s commitment for sustainability of the water conservation programs.
4. Conclusion
The research showed that the SPAHUDO is effective in rainwater harvesting and overcome the rain puddles both from the hydro-geological analysis and the perception of the community through Ergonomic SHIP Approach. The SPAHUDO with four points of HDPe pipes, 12” of diameter, and 4 m of debt can harvest about 30.88 % of rainwater volume in about 200 m2 of catchment area. It is emphasized by the user/community that the SPAHUDO is very effective in rainwater harvesting with average score is 4.51 (strongly agree).

5. References
Caplar R and Kulisic P 1973 Proc. Int. Conf. on Nuclear Physics (Munich) vol 1 (Amsterdam: North-Holland/American Elsevier) p 517
[1] Gholam Reza Lashkaripour and Mohammad Ghafoori 2011 The Effects of Water Table Decline on the Groundwater Quality in Aquifer of Torbat Jam Plain, Northeast Iran Int. J. Emerg. Sci. Vol 1(2), p 153-163
[2] Fred A.O. Otieno2 and George M. Ochieng 2012 Review Groundwater: Characteristics, qualities, pollutions and treatments: An overview. International Journal of Water Resources and Environmental Engineering Vol 4(6), p 162-170
[3] Asian Development Bank 2016 Indonesia Country Water Assessment (Manila: Mandaluyong City Asian Development Bank) p 22
[4] Margat J 2008 Les eaux souterraines dans le monde [Groundwaters of the world] (UNESCO, New York and BRGM, Orléans, France) p 187
[5] I Nyoman Sunarta and Abd. Rahman As-syakur 2015 Study on the Development of Water Crisis In Bali Island in 2009 and 2013 (E Journal of Tourism Vol 2. No.1) p 33-42.
[6] Sudiajeng L, IW Wiraga, M Mudhina, IGNs Waisnawa 2018 Ergonomics for Sustainable Groundwater Conservation Program (Atlantis Highlights in Engineering) p 447-451
[7] Buchanan, T.J. and Somers, W.P. 1969 Discharge Measurements at Gaging Stations: U.S. Geological Survey Techniques of Water-Resources Investigations (Book 3, Chapter A8) p 1
[8] Guerriero, Vincenzo et al 2013 A Permeability Model for Naturally Fractured Carbonate Reservoirs (Marine and Petroleum Geology 40) p 115–34.
[9] Central Ground Water Board Ministry Of Water Resources. Guide On Artificial Recharge To Ground Water. 2000.
[10] Clark C Gibson, Stuart A Marks 1995 Transforming Rural Hunters into Conservationists: An Assessment of Community-Based Wildlife Management Programs in Africa (Great Britain Workl De–el---rue,rr, Elsevier Science Ltd Vol 23 No 6) p 941-957, 1995
[11] Becky L. Jacobs 2016 The Role of Law in Reducing Barrier to Citizens Participation in Community-Based Natural Resource Management Model (United States: Internationale des Gouvernements Ouverts Vol 3) p 6
[12] Sudiajeng L, IGL Parwita, IW Wiraga, M Mudhina. Community Based Educational Model on Water Conservation Program (IOP Publishing Journal of Physics: Conference Series. Vol. 953 issue 1) p 012055

6. Acknowledgment
This research paper is made possible through the help and support from everyone, especially the Director of Research and Community Service, Ministry of Research, Technology and Higher Education Republic of Indonesia, Bali State Polytechnic, Public Work Denpasar City for the research grant. Thanks also to colleagues and students of the Civil engineering Bali State Polytechnic who have assisted in conducting this research.