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Changes in the Configuration of the Fresh Water Lens due to ASRRG, Western Part of The tiny Pari Island, Seribu Islands, Jakarta, Indonesia

Perubahan Konfigurasi Lensa Air Tawar Karena Konstruksi Simbat, di Bagian Barat Pulau Sangat Kecil Pulau Pari, Kepulauan Seribu, Jakarta, Indonesia

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Abstract - Pari Island (*Pulau Pari*) is a small coral island in the Seribu Islands group off the north coast of the Jakarta Capital Special Region. The government has planned to develop this island into a tourist attraction because of its beautiful environment. However, the government development plans have not included facilities to meet the demand for groundwater, which represent the essential resource to meet the demand for freshwater. The Pari Island has limited resources of groundwater due to the small size of the area where recharge of groundwater from rainfall can take place. A problem will arise that with the increase of visitors to the island the demand for freshwater will increase, while groundwater resources of the island are very limited and dominated by brackish and saline groundwater. The objective of this research was to explore the possibility to increase the resources of fresh groundwater of the Pari Island to support the increasing demand of fresh water. The method employed in the research is the application of ASRRG (Artificial Storage Recharge and Recovery for Groundwater) technology by the injection of the largest possible volume of rainwater and monitor changes of electrical conductivity and geoelectrical resistivity. Installation of an ASRRG network proved effective in lowering the salinity of groundwater in small islands. By increasing pore volume from 30 to 60% salinity decreases by 77%, which is reflected by the effect that the fresh groundwater lens which before comprised brackish water became fresh water with a thickness of 2.5 meters. The gain in pore volume equalled the decrease in salinity.

Keywords - Artificial recharge, Small island hydrology, pore volume, Seribu Islands

Abstrak - *Pulau Pari adalah pulau kecil dan termasuk grup Kepulauan Seribu. Terletak di utara pantai Jakarta. Pemerintah DKI berencana mengembangkan pulau ini menjadi kawasan wisata, karena mempunyai lingkungan indah dan menarik. Namun rencana pemerintah ini tidak diikuti dengan pemenuhan kebutuhan airtanah dimana merupakan sumberdaya yang esensial untuk memenuhi permintaan air bersih. Pulau Pari mempunyai keterbatasan airtanah karena ukurannya yang kecil sehingga pengisian airtanah dari air hujan sangat kecil/kurang. Permasalahan akan muncul jika penambahan jumlah wisatawan ke pulau ini semakin banyak sehingga permintaan air bersih semakin besar. Pada saat yang sama persediaan air tawar/bersih sangat terbatas dan didominasi oleh air asin dan payau.*
Tujuan penelitian ini adalah untuk melakukan eksplorasi kemungkinan menambah sumberdaya airtanah tawar di Pulau Pari dalam rangka mendukung memenuhi permintaan air bersih. Metoda riset yang digunakan adalah menerapkan teknologi SIMBAT (Simpanan dan Imbuhan Buatan Airtanah), yaitu dengan melakukan penginjeksian air hujan ke dalam tanah sebanyak-banyaknya. Kemudian melakukan pemonitoran konduktivitas airtanah dan pengukuran geolistrik-resistiviti.
Pemasangan jaringan SIMBAT membuktikan efektivitas yang baik dalam menurunkan tingkat salinitas airtanah di pulau kecil. Dengan menambah volume pori bawah tanah dari 30% ke 60%, maka salinitas turun menjadi 77% lebih, dimana hal ini dicerminkan oleh terbentuknya lensa air tawar yang sebelumnya merupakan air payau dan berubah menjadi air bersih dan berketebalan 2.5 m. Penambahan volume pori sebanding dengan penurunan salinitas.

Kata kunci - *SIMBAT, hidrologi pulau kecil, volume pori, Kepulauan Seribu*

INTRODUCTION

Background

As an archipelagic state, the policy of the Government of Indonesia to emphasise the development of the maritime sector is a correct decision. The vast maritime resources, the coastal regions, and the small islands have not yet been adequately explored. The development of maritime resources, coastal areas, and small islands will open up new economic areas. The fishing industry and tourism will experience rapid development which in turn could result in growing social welfare. However, this effort will face some limitations as coastal areas, and small islands primarily depend on limited fresh groundwater resources to meet the demand for fresh water. The limited fresh groundwater resources in the small islands are caused by its size, and geological setting. Meanwhile, human activity including industry and tourism will diminish the availability of fresh groundwater.

Pari Island is one of the Seribu Islands group of islands located in the Bay of Jakarta. The island is classified as a very small island with an area of 41.32 Ha (Ministry of Ocean and Fishery, 2012), with a length of 2.5 km, and an average width of 200 meters. The broadest part of the island is in the centre of the islands, while its width tapers off towards the ends of the island. Although a small island, around 800 people live on the island. The provincial government of Jakarta aims to developing the island into a marine tourism destination. Based on the data from the tourism management office on the Pari Island, the monthly number of tourists visiting the island is around 3,000, peaking during holidays. This fact gives rise to a new problem, which is that of clean water supply is needed. Up till now meeting the demand for freshwater for domestic purposes was met by groundwater, while bottled water brought from Java Island served as drinking-water. Desalination technology has been employed on the island, but with no success because the product was too expensive and could not be successfully introduced and accepted by the local community.

However, over-exploitation of groundwater could cause increasing salinity of the groundwater due to seawater intrusion. Originally, fresh groundwater could change to brackish and ever become saltwater during the dry season. According to Falkland (1991), the occurrence and geometry of the groundwater body in small islands are very much influenced by the geological conditions, tidal fluctuation and variation in rainfall. In very small islands, fresh groundwater is replenished exclusively from precipitation while significant groundwater uptake through evapotranspiration can occur in low-lying and/or vegetation covered areas (Falkland and Custodio, 1991; Vacher and Wallis, 1992; White, 1996; White *et al*.,2007; Comte *et al*., 2010).

Geology/Stratigraphical Setting

The lithology of Pari Island can be observed in dug-wells and along the coastline (Figure 1 and Figure 2) dominated by coral limestone. The sand layer on the top of coral with a thickness between 0.5-1 meters. The sand interval is thicker at the central part of the island and tapers off towards to the island edge. The sand not only acts as a reservoir but also as a recharge agent. The sea tides effect the water contained in the sand reservoir. In the case of this very small island where groundwater is intensely exploited, the quality of most of the groundwater varies from brackish to saline with electrical conductivity (EC) varying between 0,08-0,4 mS/cm (Figure 3).

Figure 1. Pari Island lithology consisting of coral limestones and sands.

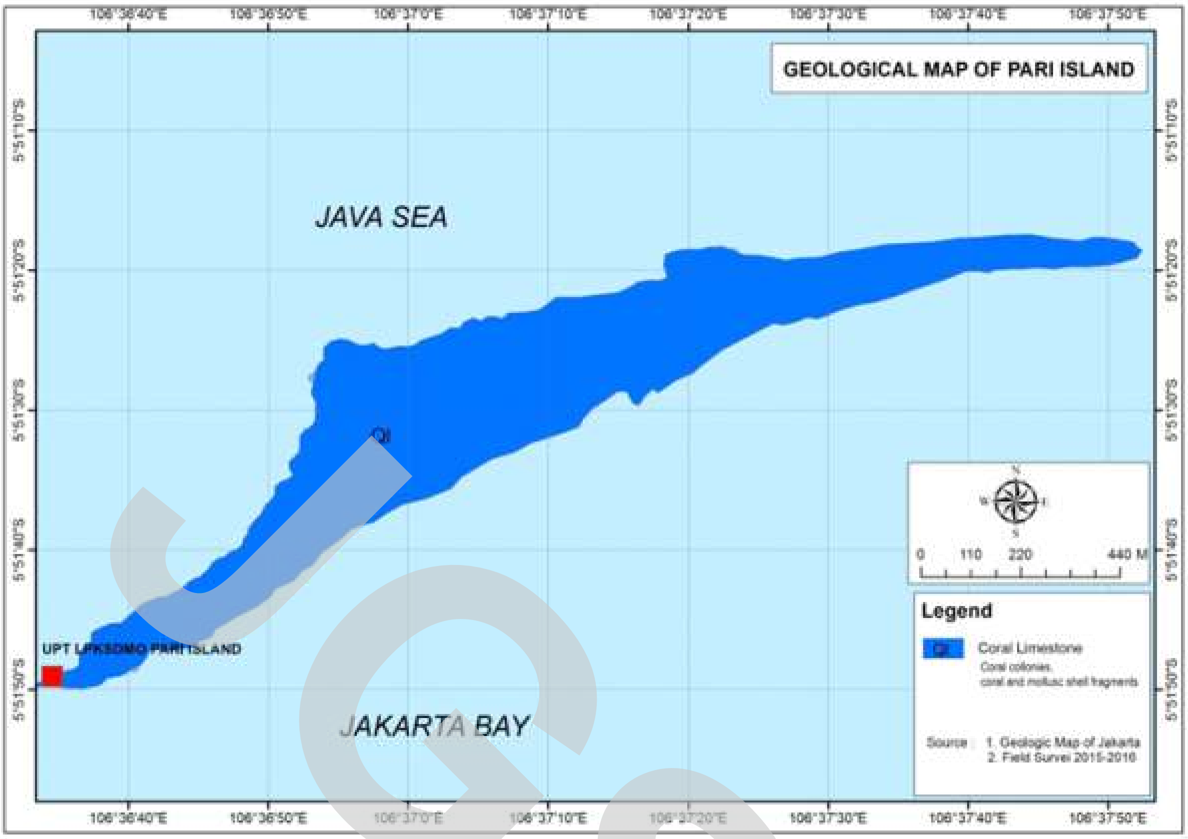


Figure 2. The Geologic Map of Pari Island

Figure 3. Map showing the distribution of groundwater electrical conductivity values

From the above discourse it was decided that to increase the capacity of the groundwater to meet the demand for freshwater, an ASRRG system construction aimed to enhance the capacity of the fresh groundwater by the injection of rainwater. ASR-wells (aquifer storage and recovery) can infiltrate water into an aquifer and to extract water later according to the demand (Dillon *et al*., 1997; Pyne, 2005; Holländer *et al*., 2009). The ASRRG system was installed at the western end of Pari Island where land was available. To observe and monitor the increase in the volume of freshwater, a geoelectrical survey and direct EC measurements were carried out. These observations were executed before and after the installation of the ASRRG system.

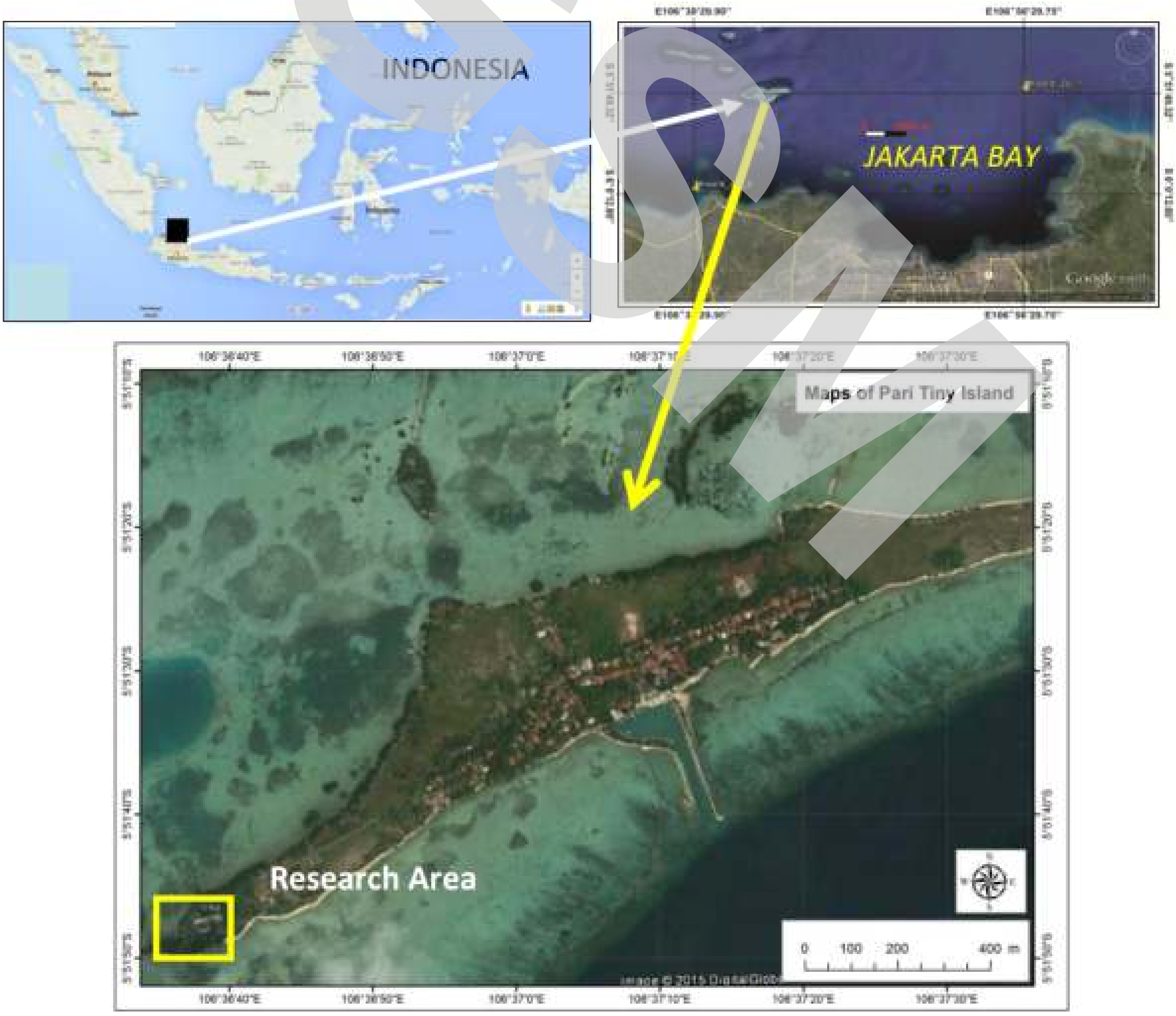
METHODS AND MATERIAL

Research Area

The Pari Island is one of the Seribu Islands group, Jakarta DKI (Capital Special Area), its geographical coordinates being 5°52'50" - 5°54'50" S.Lat and 106°34'00" - 106°38'00" W.Long (Figure 4). The area of Pari Island is 41.32 Ha. Its topography being flat 0-3 meters *a.s.l.*, with a white sandy beach with mangrove vegetation covering the northern and southern part of the island (Ministry of Ocean and Fishery, 2012).The beautiful nature of Pari Island attracts many tourists, which on the other hand, puts stress on the groundwater resources, being the sole local source of fresh water.

Methods

The Ghyben-Herzberg relation between fresh and saline groundwater in which fresh groundwater is lighter than saline groundwater is the main principle of this research method. ASRRG is a technology of collecting rainwater, and through recharge wells store to increase the (fresh) groundwater capacity and to restore the lowered groundwater level. This technology has been applied on the mainland to overcome some problems such as drought and flooding.



Source: Google Maps

Figure 4. Location of the research area on the Pari Island

Design and management of artificial recharge systems involve geological, geochemical, hydrological, biological, and engineering aspects (Bouwer, 2002).

The main problem facing small islands is the limited availability of fresh groundwater and saltwater intrusion/coning as a result of overexploitation and sea-level rise. This technology aims in preventing sea-level rise from negatively affecting groundwater quality and to inject rainwater as much as possible into the ground. The rainwater was collected from the run-off from the roof of the office of the Pari Island Technical Executing Unit (UPT) of the Loka Pengembangan Kompetensi Sumberdaya Manusia Oseanografi (LPKSDMO) LIPI and through a gutter piped to the perforated infiltration wells. A system of 12 infiltration wells is connected by a perforated pipe which is called the gallery pipe. The components of the ASRRG include the rainwater gutter, gallery pipes and recharge wells. The material used for the rainwater gutter and the various types are PVC tubular of 10, 8, and 4-inch sizes (Figure 5).

Before installation of the ASRRG (Indonesian: SIMBAT) system, a survey of the EC of groundwater at the ASRRG site has to be carried out to act as a baseline input. The ASRRG system comprises 13 recharge wells. One is located outside the well configuration, while the remaining 12 wells are connected by a network of gallery pipes (Figure 6). A protective wall surrounds the ASRRG wells to prevent tidal influence. Observations on the increase in the volume of the freshwater resources are carried out before and after the installation of the ASRRG. The observations comprise the change in electrical conductivity and geoelectric investigation. The change in Electrical Conductivity/EC is conducted at every ASRRG well while the geoelectric investigation is carried out along traverses around the ASRRG system (Figure 7).

The equipment used for the geoelectric survey was a SuperSting R8/1P with 56 swift electrodes. In geoelectric surveying, everything depends on the desired depth of penetration, the shallower the target, the more detailed the results (data). Because the Pari Island is relatively flat and groundwater level is at shallow depth (< 1 meter), geoelectric measurements were carried out to a maximum depth of 10 meters. The specific resistivity of various lithologies is shown in Figure 8.

RESULT AND ANALYSIS

The freshwater lense on the Pari Island is very limited extent (volume) because the strong influence of the seawater resulting in the fact that groundwater in area is mostly brackish to salty. The ASRRG technology employed on this island is expected to increase the size/volume of the freshwater lens by lowering the salinity of the groundwater as the ASRRG principle is to catch rainwater and inject it as much as possible through recharge wells. According to the Ghyben-Herzberg principle, as the specific gravity of fresh water is smaller than of saltwater. It follows that if sufficient large amounts of freshwater, except for some lesser influence of sea tides, the freshwater will lower the freshwater-saltwater boundary resulting in an increased volume of fresh groundwater.

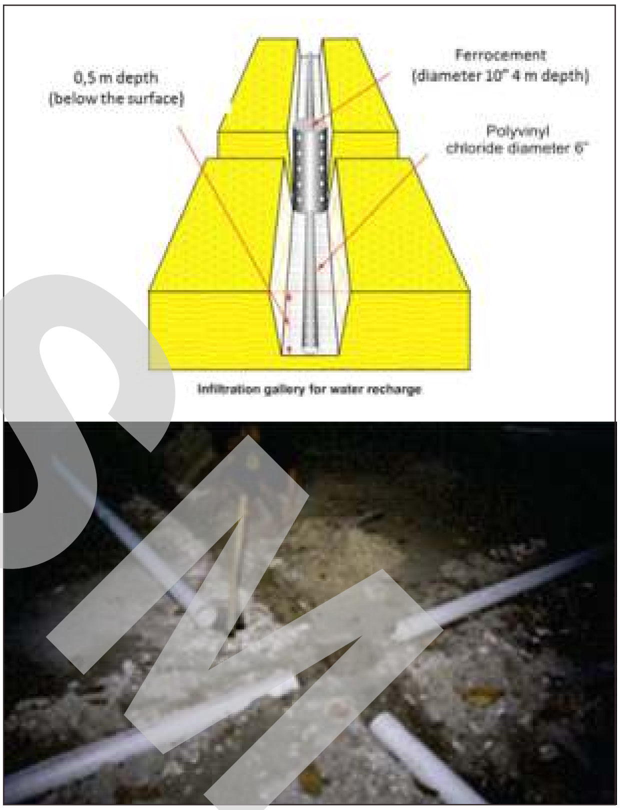


Figure 5. ASRRG Construction

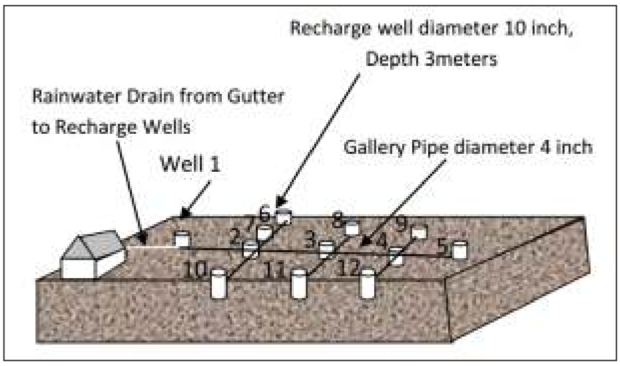


Figure 6. Lay-out of the ASRRG system on Pari Island

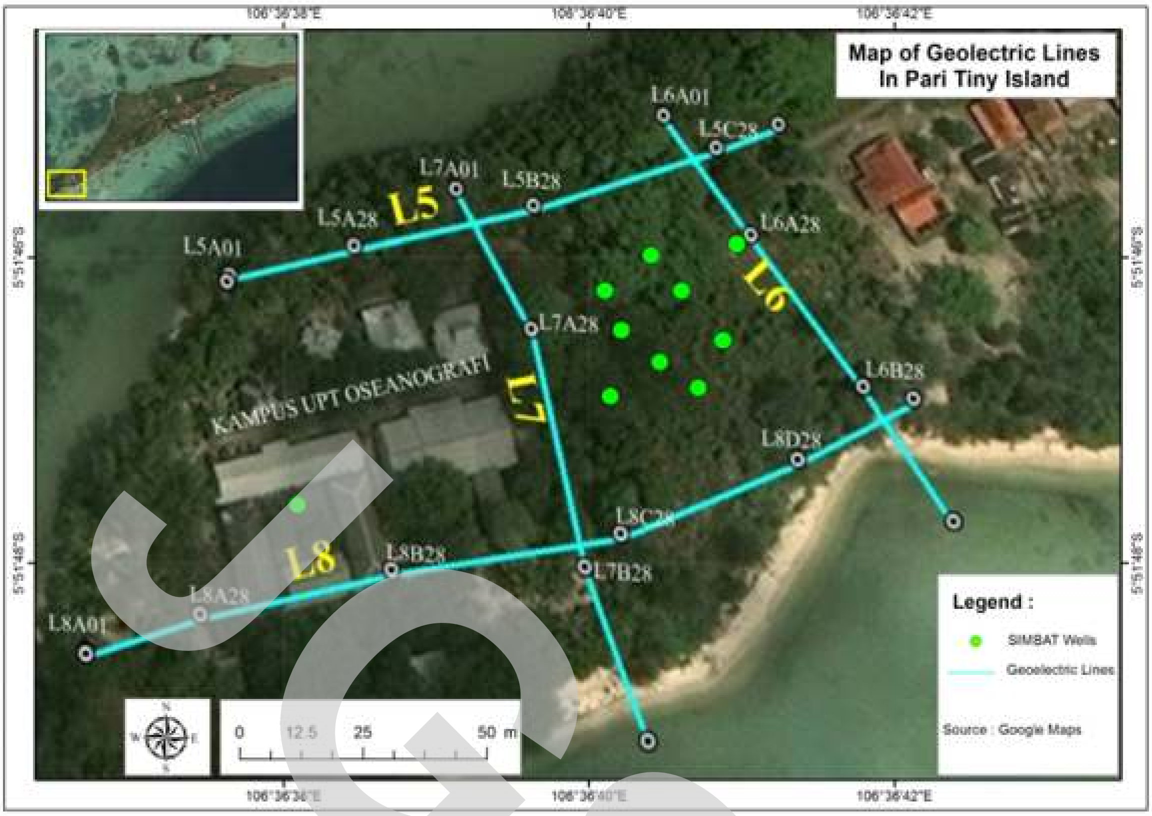
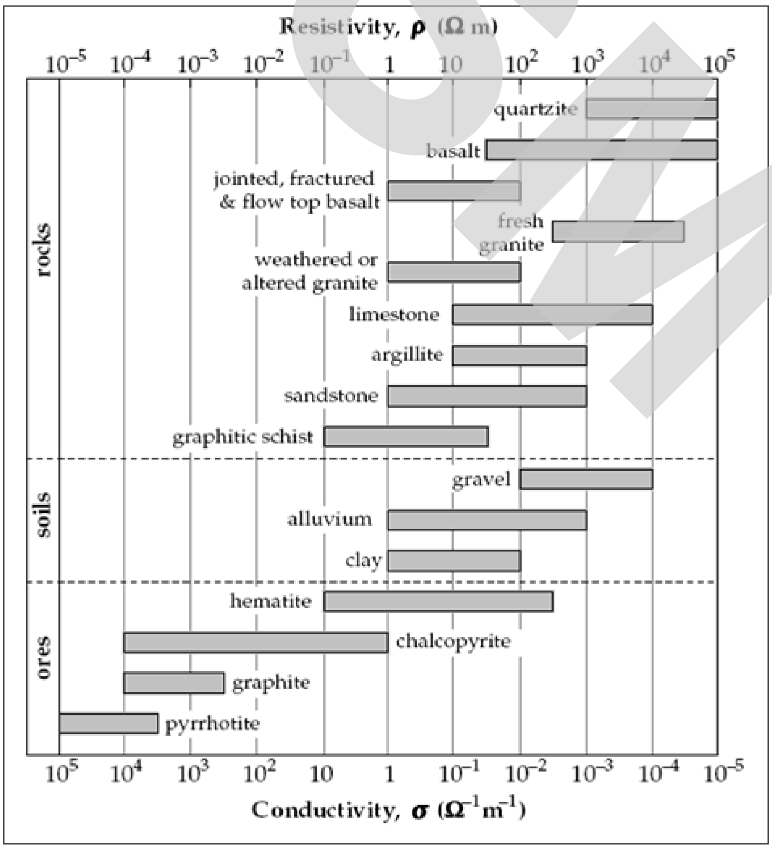


Figure 7. Geoelectric survey lines at ASRRG construction in the Pari Island



Sources : Telford et al. (1990)

Figure 8. Value range of specific resistivity

Before ASRRG rainwater runoff dispersed in all directions and mixed with seawater to become brackish or even salty groundwater. As explained earlier, changes in groundwater salinity in the Pari Island are monitored by measuring electrical conductivity in the ASRRG wells, and by geoelectric surveys around the ASRRG installation area.

Pore Volume

The increase in pore volume will result in an increase in rainwater infiltrating in the ground, which will increase the amount of freshwater as expressed in the increased thickness of the freshwater containing part of the aquifer. As such the design of the ASRRG system aims to increase the pore volume to maximise infiltration of fresh water. Pore volume increases by achievement in the ASRRG technology through the volume of the recharge wells and the volume of the gallery pipes.

Pore volume increases through ASRRG = Recharge well volume + Gallery pipes volume (1)

Calculation of this volume is achieved using the pipe volume calculation, as follows:

Pipe Volume = ¼ x πx diameter2 x pipe length (2)

Well Pipe = Diameter 10 inch = 25,4 cm, Length 3 m = 300 cm, number of wells: 12

Gallery Pipe = Diameter 4 inch = 10,16 cm, Length 10 m = 1000 cm, number of pipes: 11

Well Volume = ¼ x 3.14 x 25,42 x 300
= ¼ x 3.14 x 645,16 x 300
= 151,935.18 cm3
= 0.1519 m3

Volume of 12 Wells = 12 x 0.1519
= 1,8228 m3

Volume gallery pipes = ¼ x 3.14 x 10,162 x 1000
= ¼ x 3,14 x 103,2256 x 1000
= 81032,096 cm3
= 0.81 m3

For 11 gallery pipes = 11 x 0,81
= 0.89 m3

Total ASRRG Volume = Well Volume + Gallery Volume
= 2.71 m3

The result will be the increasing of the pore volume for recharging of 2.17 m^3, while previous calculation based on a sand porosity of 30% (before ASRRG) resulted in a pore volume of 0.81 m^3.

Electric Conductivity

Measurement of electric conductivity in ASRRG wells is carried out using an EC meter. Instantaneous measurements were carried out without considering sea tidal movements or depth of the well. All ASRRG wells have the same depth which is 0.5 m below sea-level. Monitoring has been carried out with the same equipment and method except that it was done at varying times, namely in September 2015 and March 2016. The results of measurement are shown in Table 1.

Table 1. Results of electric conductivity measurements (from Analyses 2016)

No	Wells	EC Before ASRRG Sept 2015 (µS/cm)	EC After ASRRG March 2016 (µS/cm)	Percentage Decline (%)
1.	Well 1	47,800	1,700	96.4
2.	Well 2	Not measured	4,400	-
3.	Well 3	Not measured	6,780	-
4.	Well 4	41,600	14,000	66.3
5.	Well 5	22,000	8,380	61.9
6.	Well 6	56,300	5,080	91.0
7.	Well 7	41,200	4,640	88.7
8.	Well 8	51,650	3,550	93.1
9.	Well 9	53,600	32,700	39.0
10.	Well 10	Not measured	24,900	-
11.	Well 11	50,500	11,300	77.6
12.	Well 12	Not measured	18.000	-

Geolectric Investigations

Geoelectric measurements were carried out before and after the construction of the ASRRG system, the measurements before construction were carried out in September 2015, while those carried out after construction were executed in February 2016. The measurements carried out at different times were along the same traverses and using similar methods. Measurements were conducted along 4 (four) traverses before setting up the ASRRG system, and along 5 traverses after setting up the system was set up, with a target depth of 12 meters. All of the line measurements were located in out of injection well except traverse 9. The following is a description of the geoelectric measurement results.

Traverse 5

This traverse is located along the northern side of the ASRRG and the Pari Island. The traverse has a length of 120 meters with a penetration/target depth of 12 meters, as shown in Figure 9. The figure shows 2 (two) resistivity sections along the traverse, the upper one showing the results of the pre-ASRRG survey (2015), the lower one the results of the post-ASRRG survey (2016).

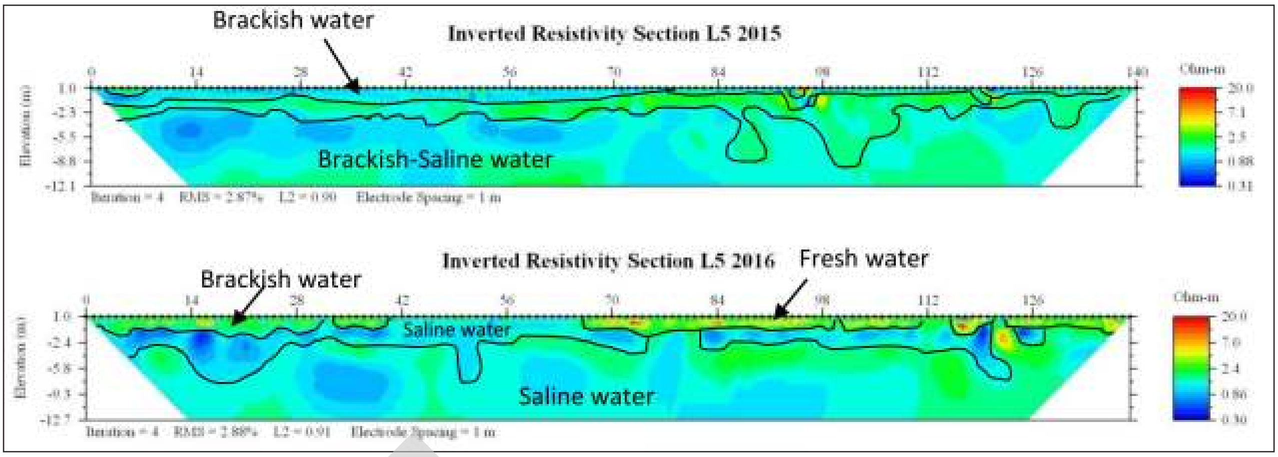


Figure 9. Geoelectric Traverse 5

The pre-ASRRG geoelectric measurements show that the groundwater along the traverse is brackish to saline with resistivity values between 0-1 ohm-meter. In the pre-ASRRG geoelectric measurements show no indication of fresh water. On the other hand, the results of the measurements after the installation of the ASRRG observation points where resistivity values indicated the presence of freshwater were more widespread. Thus, the change in the fresh groundwater interval between the measurements in 2015 and 2006 is around 1 m.

Traverse 6

This traverse cuts the Pari Island in a North-South direction with the length of the traverse being 100 meters (Figure 10). The 2015 resistivity measurements showed values of less than 2 (two) ohm-meters. This value indicated that the lithology comprises brackish to saline groundwater filled fine sand to mud. The measurements of 2016, however, indicated an increase in resistivity values showing that the groundwater in the area along the traverse was fresh to brackish. The thickness of the freshwater interval varies from 0.5-1 m.. This indicates a positive change in groundwater quality which initially was dominated by brackish to saline into fresh to brackish groundwater.

Traverse 7

This traverse runs parallel to Traverse 6, which cut across the Pari Island with a length of 105 meters (Figure 11). Measurements carried out in 2015 indicated that most of groundwater in the area along the traverse was saline, and only in some locations, for example at location 50, indications of freshwater were encountered and probably brackish. On the other hand,

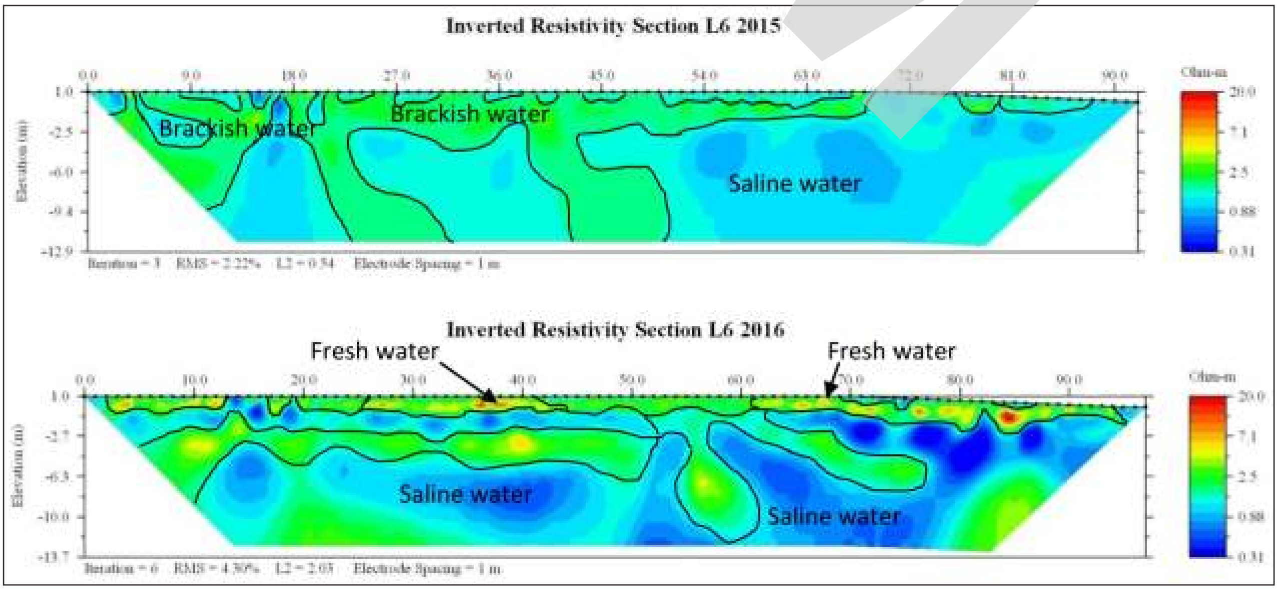


Figure 10. Geoelectric Traverse 6

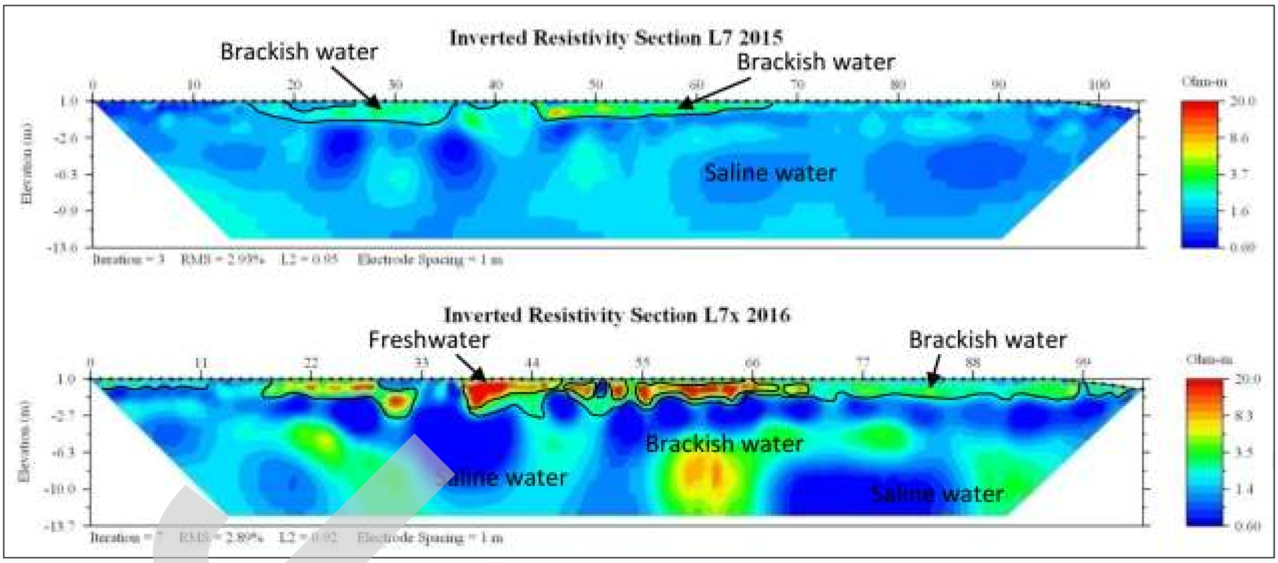


Figure 11. Geoelectric Traverse 7

the measurements in 2016 indicated significant changes where from the surface to a depth of 2 (two) meters fresh groundwater was indicated by resistivity values between 8-20 ohm-meters.

Traverse 8

This traverse is located at the southern side of the ASRRG paralleling the southern coastline. The length of the traverse is 180 meters with a target depth of 13 meters. The measurements of 2015 and 2016 indicated a salinity change of the groundwater. During the 2015 survey, the area along the traverse indicated that the groundwater was predominantly brackish to saline, while the measurements of 2016 indicated the existence of a fresh groundwater lens indicated by the red colour in Figure 12, with a thickness of up to 2 meters.

Traverse 9

This traverse is located at the middle side of the ASRRG construction. The length of the traverse is 55 meters with a target depth of 13 meters. The measurements is conducted only in 2016 after construction. During the 2015 salinity survey, this area indicated that groundwater was predominantly brackish to saline, while the geoelectric measurements after construction in 2016 resulted in the existence of a fresh groundwater lens.It was indicated by the red colour in Figure 13, with a thickness of up to 2 (two) meters. Some area near the injection well has a high resistivity that indicated fresh water. However, in others area has a low resistivity that indicated brackish until saline water.

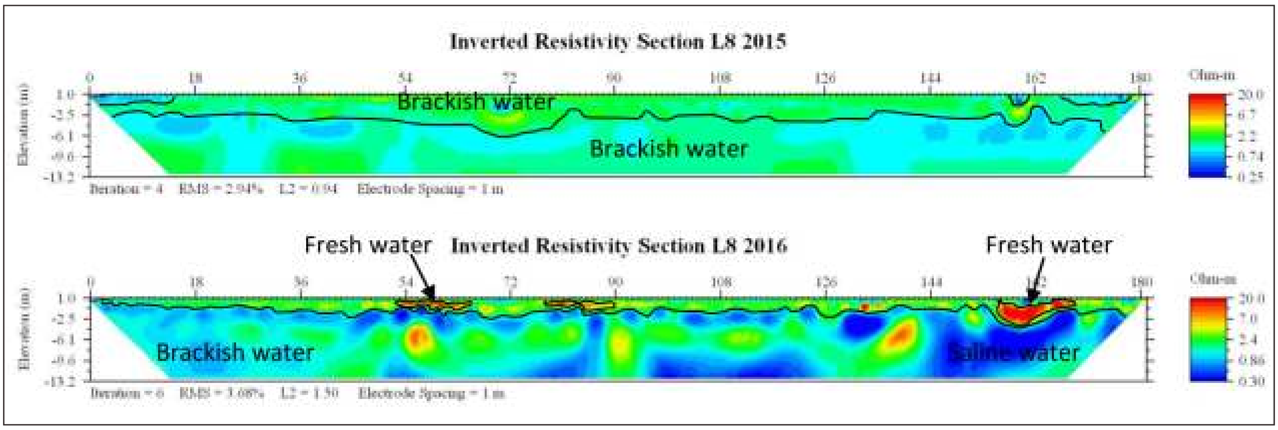


Figure 12. Geoelectric Traverse 8

J.G.S.M. Vol. 18 No. 1 Februari 2017 hal. 1 - 11

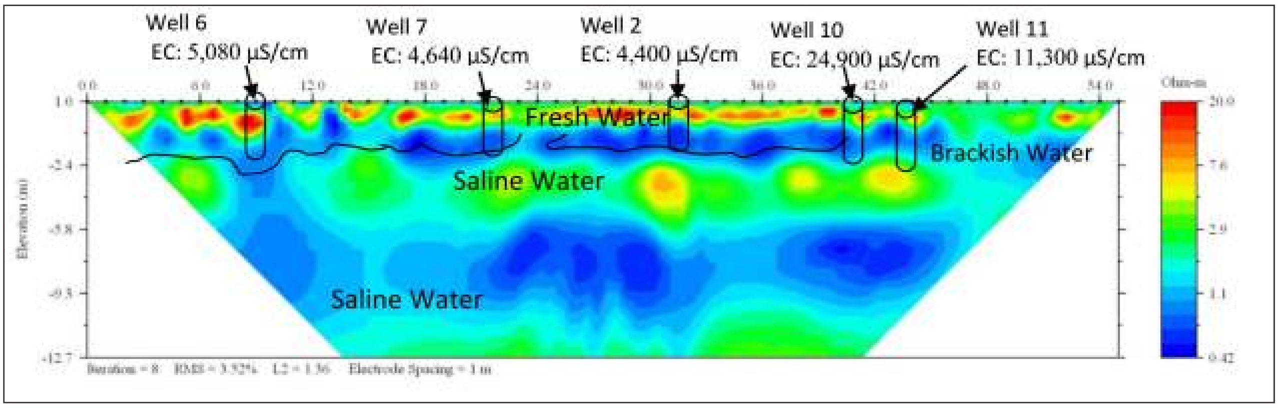


Figure 13. Geoelectric Traverse 9

DISCUSSION

Lowering of groundwater salinity in the Pari Island has been achieved through the injection of fresh water in the ground after the application of ASRRG. Installation of an ASRRG set-up was by the construction of some recharge wells. It was connected by gallery pipes. The objective of the construction of an ASRRG system was to increase the recharging pore volume, to be able to inject fresh water as large as possible in the ground. Perforations were made with a diameter of 0.2 mm at a distance of 10 cm in the recharge wells and the gallery pipes. The perforations objected to enable the water in the recharge wells and gallery pipes to force out the saltwater in the area of the ASRRG and its vicinity.

The success rate of the installation of the ASRRG system can be concluded through the monitoring of the salinity of the groundwater before and after the employment of the ASRRG system. The monitoring is to be carried out by measuring the EC, and Geolectric measurements. EC measurements indicate a reduction of salinity of 77%. It indicates a significant decrease in salinity. The geoelectric measurements before and after ASRRG instalations also shows the increasing of resistivity. The thickness of the freshwater lens varies with a maximum thickness of 2.5 meters. The amount of rainfall injected and captured in the ASRRG is considered sufficient to lower the salinity.

Increasing pore volume from 30 to 60% is capable to decrease salinity until 77% or fresh water thickness until 2.5 m (in rainy season). The increase in pore volume is comparable to the decrease in salinity. Increasing pore volume for groundwater recharge can be achieved either by increasing diameter size of the ASRRG or through the extensification of the ASRRG network.

CONCLUSIONS

The conclusions which can be drawn from this research are as follows :

The greater the pore size/volume for recharging the groundwater the greater the thickness of the freshwater lens. The percentage increase of pore size/volume for recharging is in linear comparison to the reduction percentage of decrease in groundwater salinity on small islands. Increasing of the recharged pore size can be achieved by modification of the construction of the ASRRG system. The construction of ASRRG with a network system proves to be very effective approach to increase the groundwater resource potential in small islands.

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