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Water Resources in Pari Cay, Kepulauan Seribu, Jakarta, Indonesia

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Abstract. Pari Cay is the largest island in Kepulauan Seribu Archipelago. Population growth and tourism development in recent years have posed new challenges to its management, one of which concerns water resources. This research aimed to analyze the water resource condition in Pari Cay. The research scope included the analysis of meteorological water resources and groundwater resources. The meteorological water resource analysis employed the Thornthwaite-Mather method, while the groundwater resource was identified by analyzing groundwater quality and calculating static groundwater quantity. The results showed that meteorologically a deficit occurred in July and August. The groundwater quality analysis indicated the presence of highly dominant electrical conductivity, as well as magnesium and chloride enrichment, due to the influence of seawater intrusion. Furthermore, the amount of groundwater in Pari Cay was categorically in larger quantity and better condition compared to the other cays in Kepulauan Seribu Archipelago.

1. Introduction

Kepulauan Seribu is a group of islands in the capital city of Indonesia, Jakarta. This archipelago is located in the Java Sea off the north coast of Jakarta Bay and Banten Province with the coordinates of 106°19'30''-106°44'50''E and 5°10'00''-5°59'30''S. It consists of 110 cays [1], all of which are patch reefs with surface materials composed of bioclastic debris [2,3]. Based on the area, these cays are categorically very small islands, i.e., with an area of not larger than 100 km² and/or not wider than 3 km [4, 5]. Meanwhile, Pari Cay is located between 106°36'15''-106°37'34''E and 5°44'14''-5°45'09''S, or in Universal Transverse Mercator (UTM) projection it lies in 48M Zone between 678447-678935mE and 9364324 - 9365041 mN.

Pari is one of the cays in Kepulauan Seribu Archipelago. With an area of 41.32 hectares, it is the largest cay in the archipelago. Astronomically, it is located at 5°50'20''-5°50'25''S and 106°34'30''-106°38'20''E. It is administratively part of Pulau Koral Pari Subdistrict, Pulau Seribu Selatan District, Kepulauan Seribu Regency, Jakarta.

Pari Cay was initially used by the surrounding communities for stops when away for fishing. However, in its development, settlements started to occupy some parts of its area. The spatial plan of the Special Capital Region of Jakarta also proposes a scheme for transforming it into a residential area. There are currently 390 people or 265 families inhabiting the cay. This number continues to grow from year to year. At the same time, the rapid development of tourism increases the demand for resources, including water resources [6].



Like the other very small islands, Pari Cay faces problems related to water resources [7]. The relatively small rainfall, low groundwater recharge and the absence of one from other regions, high evapotranspiration, and the influence of seawater intrusion are the underlying factors of the limited amount of water resource in cays [8-10]. The highly permeable bioclastic debris also causes the groundwater in this cay to have high dynamics of groundwater quality [11,12]. Pollution by domestic wastes and seawater intrusion actively controls the changes in the groundwater quality.

This study aimed to analyze the condition of water resources in Pari Cay. In this case, it involved meteorological water resources, as reflected in rainfall and temperature (evapotranspiration), and groundwater quantity and quality. This research is expected to provide an overview of the water resources condition in Pari Cay as a contribution to future construction and development planning in the study area.

2. Method

2.1. Meteorological Water Resource Analysis

The data used in the meteorological water resource analysis consisted of rainfall, temperature, soil texture, land cover/use, and the astronomical coordinates of the study area. Both rainfall and temperature data were obtained from the climatology station in Pari Cay owned by the Indonesian Institute of Science (LIPI) [13] (Table 1). The astronomical location of the study area was plotted using a global positioning system receiver. The soil data were analyzed with a sand texture comparator, while the land cover/use data was interpreted from high-resolution satellite imagery (GeoEye). In this research, the meteorological water resource condition was identified using the Thornthwaite-Mather method.

Table 1. Rainfall, Temperature, and Evapotranspiration Data of Pari Cay

No.	Months	Rainfalls (mm)			Potential Evapotranspirations (Ep)	Actual Evapotranspirations (Ea)
		Minimum	Average	Maximum		
1	January	259	424	747	54	54
2	February	35	309	723	50	50
3	March	58	149	388	57	57
4	April	0	132	340	56	56
5	May	23	98	205	58	58
6	June	24	88	216	53	53
7	July	0	81	293	57	57
8	August	0	46	162	57	52
9	September	0	41	141	58	44
10	October	0	68	250	60	60
11	November	0	104	300	57	57
12	December	0	243	726	59	59

Source: The Meteorological Station of Pari Cay [13] and Data Analysis

2.2. Groundwater Resource Analysis

The groundwater resource analysis consisted of groundwater quality and quantity analyses. The groundwater samples for the water quality analysis were drawn from wells located in each imaginary grid with a dimension of 300 m x 100 m (Figure 1). When there was no well inside the grid, the data was obtained by drilling a hole until the groundwater table. These research parameters were sodium, potassium, calcium, magnesium, chloride, sulfate, bicarbonate, nitrite, nitrate, BOD, COD, and electrical conductivity. The water quality was analyzed by comparing the results of the laboratory analysis and measurement in the field with the standards for drinking water.

The data used for the groundwater quantity analysis were aquifer conditions, groundwater quality, and material's hydraulic conductivity [14,15]. To identify the volume of the potential aquifer (materials with the capacity to store groundwater), this study relied on relevant data provided by the previous research in the study area. The water quality analysis, which in this case was represented by groundwater salinity, aimed to determine the thickness of the fresh groundwater in Pari Cay. The

thickness was identified with the Ghyben-Herzberg method [16]. The hydraulic conductivity of the aquifers was measured using the inverse auger hole method for deep groundwater table (deeper than 2 m) and the auger hole method for shallow groundwater table. Since the measurements were performed in 8 points, the K values used in the analysis was the average of the hydraulic conductivity values in these eight points. The hydraulic conductivity was then used to determine the specific yield (S_y) based on the results of the previous studies. The static groundwater quantity was calculated using Equation 1.

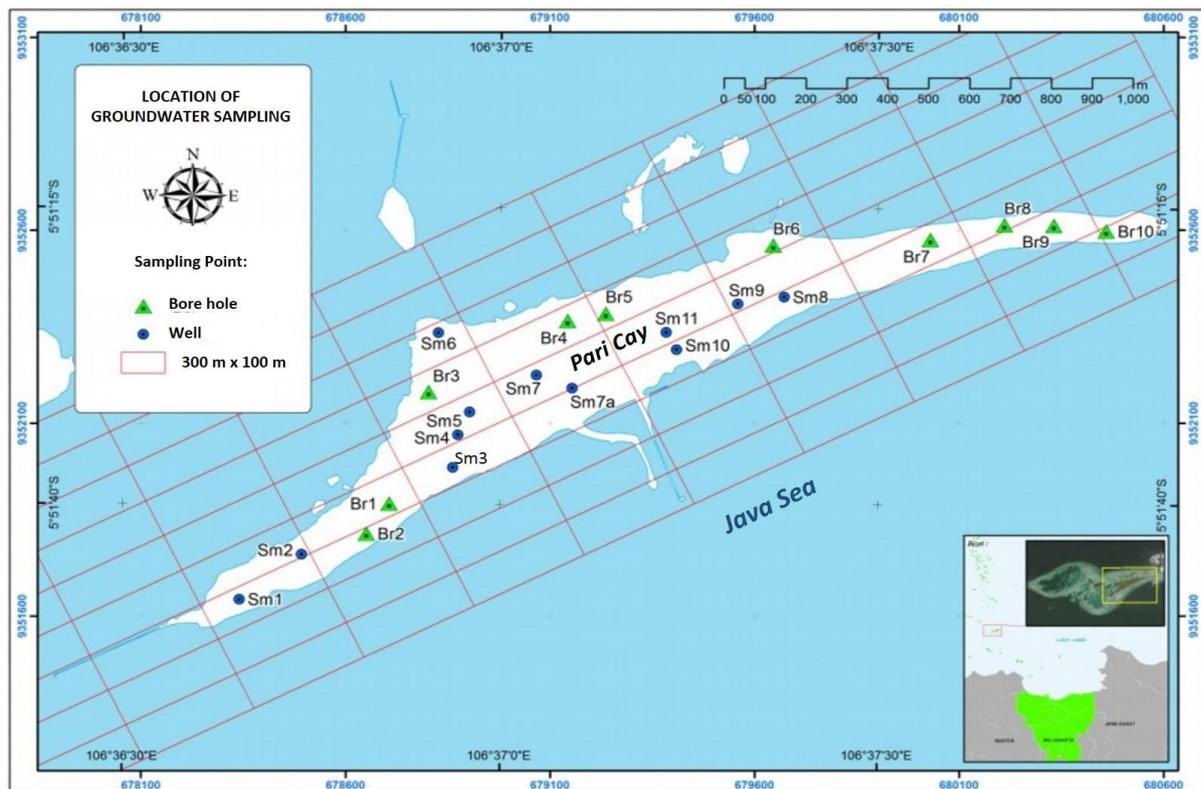


Figure 1. The Groundwater Location Sampling in Pari Cay.

$$V_{fw} = S_y \times V_{aq} \quad (1)$$

where:

V_{fw} = The volume of usable fresh groundwater

S_y = Specific Yield

V_{aq} = The volume of freshwater aquifer

3. Results and Discussion

3.1. The Meteorological Water Resource Condition in Pari Cay

The data analysis results showed that the average annual rainfall of Pari Cay was 1,783 mm/year. Even though the cay is located in the tropics, the rainfall is categorically low. Nevertheless, this condition is typical in very small islands due to the absence of elevation factor that inhibits cloud movement. In this case, the rain clouds pass through the cays. However, this condition does not apply to volcanic islands where the elevation allows for the formation of orographic rain. Therefore, volcanic islands and large islands with high altitude receive higher precipitation.

The air temperature in Pari Cay has a fairly high daily fluctuation. It can reach 32°C during the day and decrease to 22°C at night. The average daily temperature is 27°C with 80% air humidity. The high temperatures during the day affect the amount of potential evaporation (E_p) and actual evapotranspiration (E_a) in the cay. The meteorological water balance created with the Thornthwaite-

Mather method (Figure 1) shows that the E_a and E_p range from 50 mm to 60 mm. Furthermore, the surplus appears to dominate the water balance for ten months, whereas the deficit only occurs in the remaining two months, i.e., in July and August. In these two months, the threat of seawater intrusion is higher because the water availability in the soil moisture is depleted to the minimum point of exhaustion. From a meteorological point of view, the water resources in the study area are in good condition.

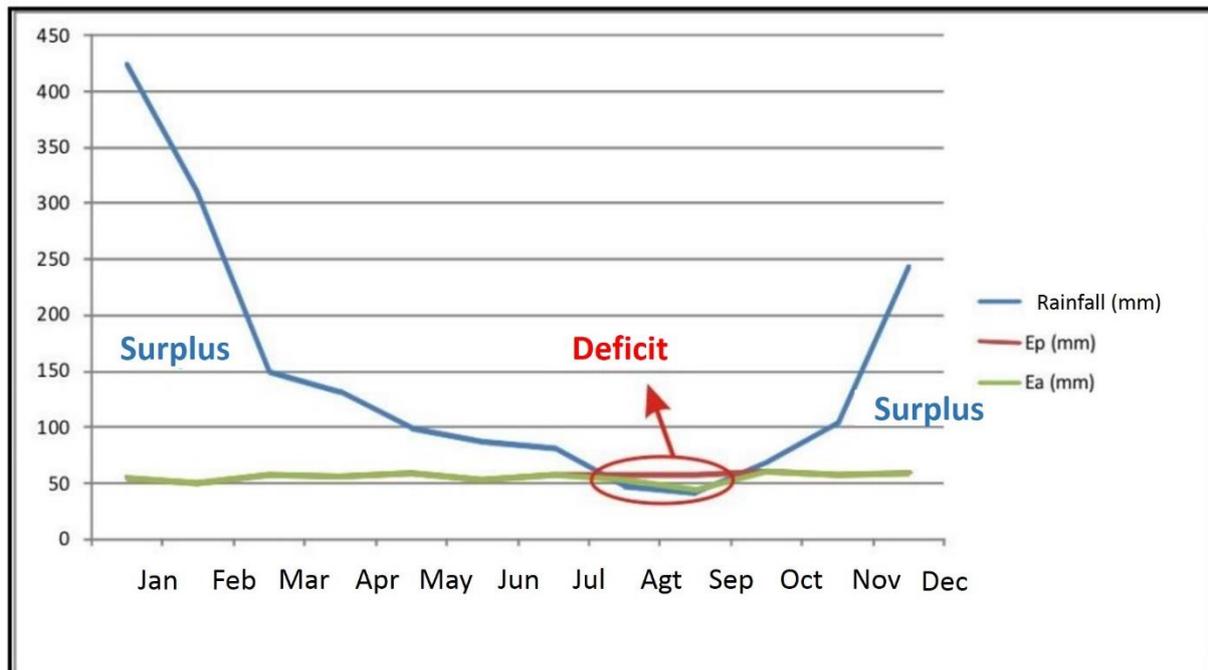


Figure 2. The Meteorological Water Balance of Pari Cay.

3.2. The Groundwater Resource Condition in Pari Cay

The groundwater was sampled from several wells and drill holes in the vicinity of the settlements to describe the quality of the groundwater currently used by the population in Pari Cay. Based on the laboratory analysis results of the groundwater samples, all groundwater sources in the study area have exceeded the standards for drinking water quality. The exceeded standards are those of magnesium and BOD. Magnesium enrichment is the indicator of seawater intrusion [17-19]. The previous studies also found the same conditions in two cays in Kepulauan Seribu, Jakarta, namely Panggang Cay and Pramuka Cay. Chloride enrichment in nearly all groundwater samples also confirms the influence of seawater intrusion in the study area. Table 2 shows that 4 out of the 6 groundwater samples have chemical parameters that exceed the standards for drinking water quality.

The electrical conductivity map shows that the groundwater in Pari Cay has low to high salinity (fresh to saline water). The freshwater is concentrated in the middle of the cay (Figure 3) and areas covered by shrub and vacant land. The groundwater availability at the center of the cay is caused by the lowest influence of seawater intrusion in this zone. At the same time, since there are no groundwater extraction activities in shrub and vacant land, the groundwater in these two land covers is slightly or even not affected by seawater intrusion.

Compared to the other cays in Kepulauan Seribu Archipelago, the groundwater resources in Pari Cay are considerably better [11,20,21]. Three reasons underlie this condition, namely (1) larger terrestrial area, (2) lower population number and density, and (3) wider distribution of shrub and vacant land in Pari Cay. However, with the trend of population growth and the increase in tourist number, this condition can worsen if managed improperly.

Table2. Groundwater Quality in Pari Cay.

No	Parameters	Units	Sample Numbers						Standards	Test Methods
			Sm3	Sm4	Sm5	Sm6	Sm10	Br2		
1	K ⁺	mg/l	9.0	16.0	20.0	29.0	1.0	6.0	10.0	APHA 2012
2	Na ⁺	mg/l	45.0	472.0	493.0	1,680.0	69.0	378.0	200.0	APHA 2012
3	Ca ²⁺	mg/l	38.2	111.4	58.1	184.67	39.8	80.0	100.0	SNI 06-6989.12-2004
4	Mg ²⁺	mg/l	51.7	89.0	93.3	183.8	53.68	83.2	50.0	SNI 06-6989.12-2004
5	Cl ⁻	mg/l	17.4	632.8	610.4	2,134.1	115.1	625.4	250.0	SNI 6989.19.2009
6	HCO ₃ ⁻	mg/l	392.0	491.5	367.1	398.2	304.9	454.2	500.0	APHA 2012
7	SO ₄ ⁻	mg/l	6.0	40.0	63.0	272.0	7.0	55.0	250.0	SNI 6989.20.2009
8	NO ₂	mg/l	0.20	0.04	0.04	0.11	0.05	0.14	3.0	SNI 06-6989.12-2004
9	NO ₃	mg/l	0.27	0.61	28.19	5.43	0.44	2.55	50.0	APHA 2012
10	BOD	mg/l	3.0	5.4	2.8	3.0	2.4	2.7	6.0	SNI 6989.72.2009
11	COD	mg/l	19.4	24.6	12.5	15.7	10.4	15.7	10.0	SNI 6989.2.2009

Source: Laboratory Analysis Results

Note: Red-colored cells mark parameters that exceed the standards

Based on groundwater salinity and electrical conductivity (Figure 3), the fresh groundwater is distributed over an area of 93.239,13 m² or approximately 9.3 ha. As estimated using the Ghyben-Herzberg method, the aquifer has an average thickness of 29.2 meters. The measurement value of hydraulic conductivity (K) with inverse auger hole method shows the number of 7.6 m / day up to 15.2 m / day. The value is the same as the K value for medium sand material [14]. This means the value of the specific yield (Sy) is 27% (corresponding to the Sy value for medium sand material. Therefore, the freshwater potential in Pari Cay is 154,370.43 m³. With the assumption that every region in Pari Cay has the same thickness and aquifer response, this figure represents a gross groundwater potential.

The freshwater potentials identified in this study are mostly located in the middle of the cay. This condition is common in very small islands [22]. The shape of the freshwater lens symmetrically follows the topography of the surface and thickens in the middle of the cay only when the material and the geological structure are homogeneous.

In general, Pari Cay has shallow groundwater with a maximum depth of 1.4 meters. The average groundwater table is not higher than 0.9 m. The south and north sides of the cay have somewhat different groundwater depths. The groundwater table in the south is deeper than in the north because of the erosion process by seawater is more intensive in the south. The dominant process in the north is sedimentation; therefore, the land elevation in this part of the cay is higher and the groundwater is deeper than in the south. Materials with high hydraulic conductivity and very shallow water table make the groundwater in Pari Cay highly vulnerable to pollution.

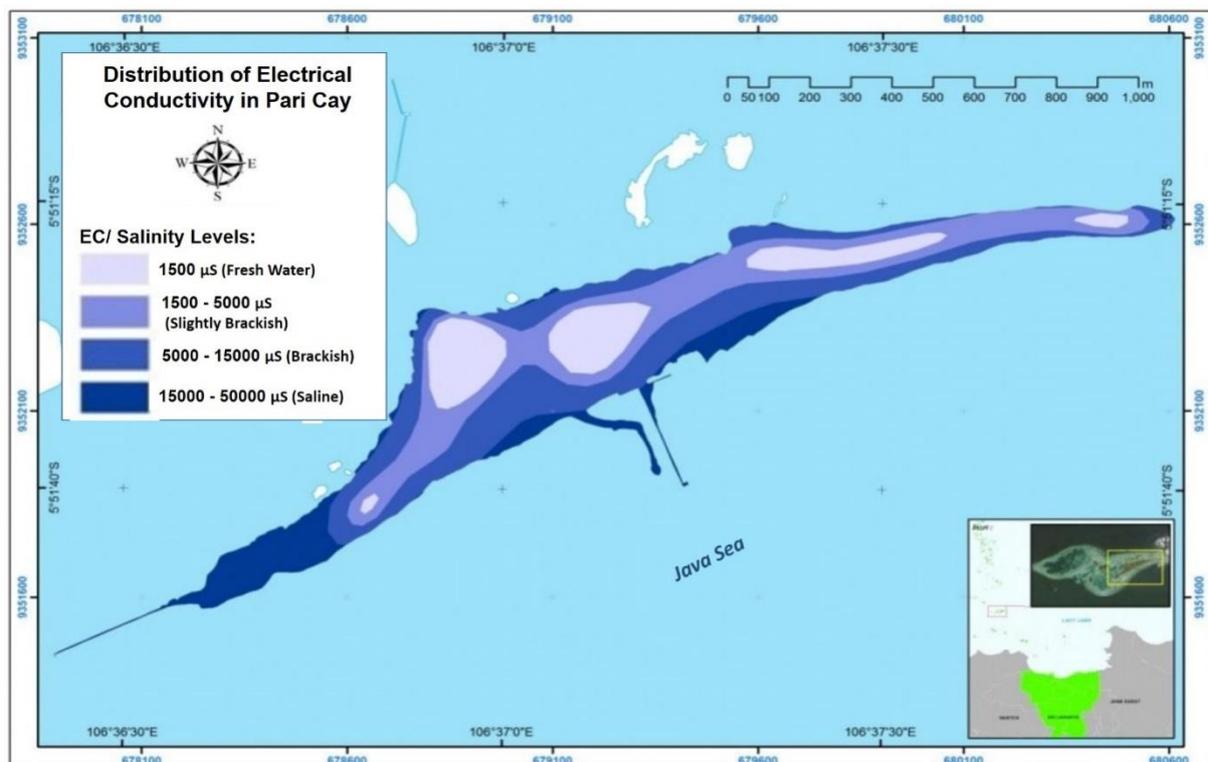


Figure3. The Spatial Distribution of Groundwater Salinity and Electrical Conductivity in Pari Cay.

Based on the interviews and field observations, the groundwater table in Pari Cay is also affected by the fluctuation of the sea level. This influence is evident in the change of the groundwater table. When the sea water level rises, the groundwater table in the wells near the coast moves upward. On the contrary, when the sea water level recedes, the groundwater table falls.

The groundwater potential in Pari Cay can deplete rapidly due to any changes in the condition of the cay. The aquifer is not thick, making the groundwater storage in the cay highly vulnerable to quantity decline and quality deterioration. Moreover, not all of the groundwater potential in Pari Cay can be directly extracted and utilized. Excessive withdrawals can accelerate the adverse effect of seawater intrusion and, consequently, decrease the groundwater quantity faster [23-25].

4. Conclusions

Pari Cay has low rainfall because of its low elevation and flat morphology. However, based on the meteorological water balance, a deficit only occurs in July and August. Compared to the other cays in Kepulauan Seribu Archipelago, the groundwater condition in Pari Cay is better because it has the largest area, more extensive non-built-upland (shrub and vacant land), and relatively lower population and density. Nevertheless, the water quality analysis found the influence of seawater intrusion, as characterized by magnesium and chloride enrichment in the groundwater, as well as high electrical conductivity that reflected the presence of saline groundwater.

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