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Development of Water Quality Index of Island Wells in Makassar City

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Abstract. Several types of research have shown that the household waste and septic tank have polluted the water of the wells in several small islands in the world and therefore requiring water well quality measurement. The research aims at measuring the water quality index of water well in small islands using the parameters of Coliform bacteria concentration, salinity, pH, and temperature. The research used survey analytics method with point time approach and combined with water quality index (WQI) formulation. There are 18 samples taken from the water well of Lae-Lae island, Barrang Lompo, and Barrang Caddi. The results have shown that the highest bacteria concentration of Coliform found was 2400 coliny/100 ml. The highest salinity is 0.007. The average temperature in well water was 20.5°C to 29.1 °C. The average pH was 7.6 to 8.9. Based on the water quality index (WQI) the calculation, the condition of 11 well water was moderately polluted, 3 well water was mildly polluted, and 4 well water was categorized as good. The results of the research showed that the development of water quality index (WQI) using Coliform parameters, salinity, pH and temperature enables identification of well water conditions in small islands and therefore informed the public regarding the quality of their well water.

1. Introduction

Healthy water becomes a necessity for the people on this planet. This includes for the people who live in the small islands. People on the small islands, however, find healthy water difficult to find because of limited water resources. Additionally, available surface water apparently has also been polluted by household water waste. Many small islands in a different part of the worlds need to monitor the quality of their groundwater to fulfill the sanitation requirements of the people in these islands, for example, Mediterranean [1] and Montréal [2].

The people living on small islands continue to use the well water for their basic sanitation needs, i.e., bathing and washing, some even use it for drinking water. The well water in these small islands is susceptible to contamination, particularly in small and densely populated islands where limited availability of land prevents the people from building standard septic tanks. The very close proximity of toilets greatly affects the water quality of the wells nearby [3]. According to Borchardt, due to the very short spacing of the toilets (the distance is not up to the standard) with the septic tanks, bacteria and virus contaminate the well water [4]. The bacteria can contaminate the water from septic tanks and in this case is thermotolerant coliform (TTC) [5]. In addition to bacteria and viruses, hazardous chemicals can also contaminate well water and may pose the risk of diseases such as herbicides [6].

The limited availability of water reserves and the risk of bacteria and chemicals contamination in the islands' well water means that that the communities in the small islands face a healthy water crisis. Moreover, high salinity concentrations also affect the water quality in the coastal areas and small islands.

As reported in a study, people are living in coastal areas of Bangladesh use tube well water (groundwater) as a source of drinking water. But the water has a high level of salinity because of the seawater intrusion [7].

To support the availability of water according to the health standard, regular monitoring of the well water in the islands is required. Different water quality measurement methods have been developed in various parts of the world. One of the methods available is water quality index (WQI), a water quality measurement method that can provide a more accurate water quality information through a combination of different parameters. WQI method has been used to measure the quality of water in the Aksu river located in Antalyam City, Turkey. As a result, WQI can provide the information that the quality of the water in the Aksu river was good [8].

The water quality measurement with the WQI method has also been used to measure the level of pollution in the Kuantan River, Malaysia. Modification of WQI using receptor model and the introduction of 13 water quality parameters have shown that it can detect the level of pollution in the Kuantan river. For that reason, river water quality monitoring with WQI is highly recommended to solve the water pollution-related environmental issues [9]. It can be used not only to determine the river water quality but also to evaluate the water quality produced from waste processing. Using the Canadian Water Quality Index (CWQA) a wastewater processing plant in Shiraz, Iran can accurately provide the information on the quality of the water from the waste processing facility for irrigation purpose [10].

Every country has developed their own method of WQI. For example, Iran has conducted research to develop a specific WQI to monitor the water quality in the country [11]. That explains why every country has a different parameter to measure their WQI. The purpose of water quality measurement will usually define the parameters used.

From several studies that have been conducted, WQI is rarely used to measure the well water quality in the small islands despite the fact that the main issue faced by people living in the small island is the lack of safe water for drink, bath, and wash. The lack of water issue is not only in term of its quantity but also the quality. It needs to be urgently resolved to improve the well being of the people living in the small islands.

Based on these issues, this research aims to develop a WQI for the well water of the islands in Makassar City. These islands are the Barrang Lompo, Barrang Caddi, and Lee-last island. These islands are densely populated and therefore suitable for the research samples to develop WQI for the well water. As the benefit, the WQI can be used as a reference to measure the quality of well water in small islands around the world.

2. Materials and methods
2.1 Material
The research was conducted on Barrang Caddi, Barrang Lompo, and Lae-lae island. There are 1532 people living in the Barrang Caddi island, 4,594 people in Barrang Lompo and 1,487 people in Lae-lae island. A total of 18 public wells will be examined on the three islands. Purposive sampling was used as the sampling technique with most widely used public wells by the community as the criteria. The total wells selected as samples were 5 wells on Barrang Caddi Island, 8 wells on Barrang Lompo Island, and 5 wells on Lae-lae Island.

Point time approach was employed as the research design through measurement of Coliform's bacteria concentration, temperature, pH, and salinity simultaneously in one go. The four parameters were used based on the physical, chemical, and water microbiology references collected by the researcher that may cause diseases. MPN Coliform test was used to measure the concentration of Coliform. Digital measuring devices was used to measure the temperature, pH, and salinity.

2.2 Methods

The result of Coliform bacteria concentration, temperature, pH, and salinity measurements was analyzed using *water quality index* (WQI) measurement. Water quality index was the tool used to predict the water quality and help the decision maker to categorize and analyze the parameters using a single numeric system [12]. The WQI from the Ministry of Environment of Indonesia number 115 of 2003 concerning the Water Quality Status Guideline was used as the reference for the WQI.

It can be used as a reference by the decision makers to enable them in assessing the quality of the water source and its use as well as to take action to improve its quality if the pollutants are found. To obtain the WQI value, the following formula was used:

$$Pij = Ci / Lij$$

If Lij represents the concentration of water quality parameters as specified in the water standard for use (j), and Ci represents the concentration of water quality parameters (i) obtained from the water samples analysis at a sampling location, then Pij will represent the WQI for use (j) which is the function of Ci/Lij.

Any Ci/Lij value indicates relative pollution caused by water quality parameters. Ci/Lij value = 1.0 is a critical value, as it is expected to be the value to be met as the standard water quality for use. Additionally, if the value (Ci/Lij) is greater than 1.0 then the new (Ci/Lij) will be used with the following formula:

$$New (Ci/Lij) = 1,0 + P.log (Ci/Lij) \text{ of the measurement result}$$

P represents a constant and its value can be determined freely based on the result of observations made to the environment and or required for specific use (usually 5 is used).

In Pi model, several water quality parameters are used. Therefore the use of the parameters requires an overall average of Ci/Lij as the benchmark of pollution ((Ci/Lij)R) and the maximum Ci/Lij value ((Ci/Lij) M) Waters will be increasingly polluted for a use (j) if the values of (Ci/Lij)R and or (Ci/Lij) Mare are greater than 1.0. The bigger the maximum value of Ci/Lij and/or average value of Ci/Lij, the bigger the pollution level of the water. Therefore to obtain IP in water, the following formula is used:

$$Pij = \sqrt{\frac{(C_i/L_{ij})^2{}_M + (C_i/L_{ij})^2{}_R}{2}}$$

After new Ci/Lij value is obtained from the overall parameters analyzed, the maximum Ci/Lij value and the average Ci/Lij are then obtained, WQI is then can be obtained using the above equation. As for water quality, it is categorized according to the following table:

Table 1 WQI of the Ministry of Environment of the Republic of Indonesia

WQI	Description
$0 \leq Pij \leq 1.0$	Meets the Quality Standard (Good Condition)
$1.0 < Pij \leq 5.0$	Lightly Polluted
$5.0 < Pij \leq 10$	Mildly Polluted
$Pij > 10$	Highly Polluted

3. Results and discussion

3.1 The concentration of MPN Coliform, Temperature, pH, and Salinity

The results of the research conducted on Barrang Caddi island, Barrang Lompo and Lae-lae island shown that there were 13 wells did not meet the requirements and only 5 drinking water sources had the Coliform bacteria concentration according to of PERMENKES NO.416/Menkes/Per/IX/1990 concerning the Quality of Clean Water for maximum piping of 50/100 ml sample. All qualified drinking water sources are protected vertical wells. However, there are also 5 unqualified protected man-made wells.

For temperature, it was found that from 18 wells measured for its temperature, only one well that was not qualified according to PERMENKES No.416/Menkes/PER/IX/1990 concerning clean water

quality (air temperature (30 ℃) ± 3℃). As for pH, all well water pH on Barrang Caddi island, Barrang Lompo and Lae-lae Island met PERMENKES No.416/Menkes/PER/IX/1990 standards concerning Clean Water Quality (6.5-9.0).

The result of Salinity measurement in Barrang Caddi, Barrang Lompo, and Lae-lae Island shown that there are 4 brackish wells found in Barrang Caddi Island. For the water sources measured in Barrang Lompo and Lae-lae Island all were fresh water.

Table 2 MPN Coliform Concentration, Temperature, pH, and Salinity

Water Well Sample	MPN Coliform	Temperature (℃)	pH	Salinity	Islands
1	150	27.3	8.1	0.07	Barrang Caddi (1-5)
2	2,400	27.5	8.3	0.07	
3	2,400	27.1	8.2	0.07	
4	0	28.3	8.9	0.00	
5	23	27.8	7.6	0.07	
6	2,400	28.7	8.0	0.04	Barrang Lompo (6-13)
7	0	27.9	8.2	0.02	
8	0	28.7	8.1	0.05	
9	1,100	29.1	8.2	0.05	
10	1,100	28.0	8.1	0.03	
11	1,100	27.7	8.3	0.02	
12	2,400	28	8.3	0.02	
13	120	27.7	7.9	0.04	
14	2,400	28,7	8,8	0,02	Lae-lae (14-18)
15	4	20,5	8,2	0,03	
16	2,400	28,7	8,1	0,03	
17	2,400	28,7	8,3	0,03	
18	2,400	28,3	8,1	0,03	

3.2 Water Quality Index

Based on the water quality index (WQI) the calculation there was 12 well water was moderately polluted, 3 well water was mildly polluted, and 3 well water were categorized as good. The characteristics of most wells categorized as mildly polluted were that the wells that were not protected or without covers, making it easily contaminated with Coliform bacteria. Additionally, there are also protected wells categorized as mildly polluted. The reason is that the well was not maintained and the well distance from the septic tank or other pollutant sources is very close.

The most significant Coliform bacteria in the WQI of the wells were the Wells in Barrang Caddi, Barrang Lompo, and Lae-lae island. Based on observations at the study site, the main contributing factor to the WQI causing Coliform bacteria to be the dominant parameter is the septic tank's distance with the well that failed to meet the standards. The risk of pollution is even higher as the density of the houses in these islands is increased.

The characteristics of most wells in as mildly polluted category are those not protected or without covers, making it easily contaminated with Coliform bacteria or other pollutants. As for good well, it is usually protected or has cover. Moreover, the well is usually deep and pipes are used to collect the water and therefore minimize the possibility of contamination.

The concentration of measurement (Coliform MPN, temperature, pH and salinity) was symbolized by C_i while the symbol for maximum concentration standard is L_{iij}. The value of L_{ij} from MPN Coliform concentration was 50 colony per 100 ml, temperature was 33 degree Celcius, pH 9, and salinity was 0.05 ppt. Multiplication of these values will result in C_i/L_{ij} value.If C_i/L_{ij} is more than 1, new

calculation must be repeated to obtain a new Ci/Lij.After calculation using the formula (Ci/Lij) new = 1.0 + P.log (Ci/Lij), the next step is to determine the maximum (Ci/Lij) and average (Ci/Lij). Finally, all maximum (Ci/Lij) and average (Ci/Lij) were calculated by Pij formula and WQI was then determined by referring the value with the value in Table 1.

Table 3 Ci/Lij Calculation of Water Quality Index

Islands	Water Sample	Ci/Lij				Description
		MPN	°C	pH	Salinity	
Barrang Caddi	1	3	0.83	0.90	1.4	(Ci/Lij) new
	2	48	0.83	0.92	1.4	(Ci/Lij) new
	3	48	0.82	0.91	1.4	(Ci/Lij) new
	4	0	0.86	0.99	0	
	5	0.46	0.84	0.84	1.4	(Ci/Lij) new
Barrang Lompo	1	48	0.87	0.89	0.80	(Ci/Lij) new
	2	0	0.84	0.91	0.40	
	3	0	0.87	0.90	1	
	4	22	0.88	0.91	1	(Ci/Lij) new
	5	22	0.85	0.90	0.60	(Ci/Lij) new
	6	22	0.84	0.92	0.40	(Ci/Lij) new
	7	48	0.85	0.92	0.40	(Ci/Lij) new
	8	2.4	0.84	0.88	0.80	(Ci/Lij) new
Lae-lae	1	48	0.87	0.98	0.40	(Ci/Lij) new
	2	0.08	0.62	0.91	0.60	
	3	48	0.87	0.90	0.60	(Ci/Lij) new
	4	48	0.87	0.92	0.60	(Ci/Lij) new
	5	48	0.86	0.90	0.60	(Ci/Lij) new

Table 4 The Calculation Result of Ci/Lij new

Island	Water Sample	Ci/Lij new			
		MPN	Temperature	pH	Salinity
Barrang Caddi	Ci/Lij1 new	3.38	0.83	0.90	1.73
	Ci/Lij2 new	9.41	0.83	0.92	1.73
	Ci/Lij3 new	9.41	0.82	0.91	1.73
	Ci/Lij4	0	0.86	0.99	0
	Ci/Lij5 new	0.46	0.84	0.84	1.73
Barrang Lompo	Ci/Lij1 new	9.41	0.87	0.89	0.80
	Ci/Lij2	0	0.84	0.91	0.40
	Ci/Lij3	0	0.87	0.90	1
	Ci/Lij4 new	7.71	0.88	0.91	1
	Ci/Lij5 new	7.71	0.85	0.90	0.60
	Ci/Lij6 new	7.71	0.84	0.92	0.40
	Ci/Lij7 new	9.41	0.85	0.92	0.40
	Ci/Lij8 new	2.90	0.84	0.88	0.80
Lae-lae	Ci/Lij1 new	9.41	0.87	0.98	0.40
	Ci/Lij2	0.08	0.62	0.91	0.60
	Ci/Lij3 new	9.41	0.87	0.90	0.60
	Ci/Lij4 new	9.41	0.87	0.92	0.60
	Ci/Lij5 new	9.41	0.86	0.90	0.60

Ci/Lij value = 1.0 is a critical value, as it is expected to be the value to be met as the standard water quality for use. Additionally, if the value (Ci/Lij) is greater than 1.0 then the new (Ci/Lij) will be used

with the following formula: New $(C_i/L_{ij}) = 1,0 + P.\log (C_i/L_{ij})$ of the measurement result, P usually 5 is used.

Table 5 Categorization of Water Quality with WQI

Islands	Water Sample	(Ci/Lij) Max	(Ci/Lij) Average	Pij	Category
Barrang Caddi	Ci/Lij1 new	3.38	1.71	2.68	Lightly Polluted
	Ci/Lij2 new	9.41	3.22	7.03	Mildly Polluted
	Ci/Lij3 new	9.41	3.22	7.03	Mildly Polluted
	Ci/Lij4	0.99	0.46	0.77	Good Condition
	Ci/Lij5 new	1.73	0.97	1.40	Lightly Polluted
Barrang Lompo	Ci/Lij1 new	9.41	2.99	6.98	Mildly Polluted
	Ci/Lij2	0.91	0.54	0.75	Good Condition
	Ci/Lij3	1	0.69	0.86	Good Condition
	Ci/Lij4 new	7.71	2.62	5.76	Mildly Polluted
	Ci/Lij5 new	7.71	2.51	5.73	Mildly Polluted
	Ci/Lij6 new	7.71	2.47	5.72	Mildly Polluted
	Ci/Lij7 new	9.41	2.89	6.96	Mildly Polluted
	Ci/Lij8 new	2.90	1.36	2.26	Lightly Polluted
Lae-lae	Ci/Lij1 new	9.41	2.91	6.96	Mildly Polluted
	Ci/Lij2	0.91	0,55	0.75	Good Condition
	Ci/Lij3 new	9.41	2.94	6.97	Mildly Polluted
	Ci/Lij4 new	9.41	2.95	6.97	Mildly Polluted
	Ci/Lij5 new	9.41	2.94	6.97	Mildly Polluted

3.3 Development of WQI in Island Wells
The results of WQI development on well water located in small islands shown that the coliform, temperature, pH, and salinity parameters are accurate parameters in WQI-oriented measurement of well water quality in the islands. Coliform parameter greatly influence the WQI calculation to determine the quality of well water in the island. These four parameters however, tend to be similar in each island. For instance, in terms of salinity, Barrang Caddi, Barrang Lompo and Lea-lae Island tend to show that their well water is categorized as brackish water. The same condition occurs in other continent, i.e. Canary Island, Spain. The results of the research shown that the shallow wells on the island tend to be brackish while deep wells tend to be salty. The groundwater in deep wells on the island is caused by the remnants of old sea water trapped in isolation of the intrusive rocks with very low intrusive permeability [13].

Complete parameters of physics, chemistry and biology is required to develop WQI based on the the Island's water quality measurement. Different from most other WQI research used to measure the water quality of the river and irrigation, only physical-chemical parameters were used. Even to measure the well waters located in big islands or land, all researchers used only physical-chemical parameters. This is the case for the quality of ten well water samples taken in Mexico City. It showed that no significant differences in physicochemical concentration (pH; temperature; dissolved oxygen concentration) in every well that was measured [14].

WQI should not only be used to measure water quality that disregards the human health aspect. The reason is that water is a medium where disease agents may enter the human body (waterborne disease). For instance, the pollutants from the well water may come from waste water located near the well and seeps into the soil. It is highly possible that the well water polluted with waste water particularly contain pathogen bacteria and even virus. The research of Espinosa shown that the well water for irrigation and drinking water in the south of Mexico contained Total Coliform, Faecal Coliform, and Faecal Entrococci [14]. Even rotavirus (RV), enterovirus (EV) and astrovirus (AST) were found there. Moreover, Borchardt's research also revealed that four wells located in the vicinity of feces processing facilities had been contaminated with the virus [15].

The introduction of WQI as a method to measure water quality has long been used by the researchers or agencies focusing on environmental sanitation. The research conducted by Debels on the quality of Chilan river loicated in Central Chile used WQI with nine variables of DO, BOD, Ammonia, Nitrite, Nitrate, Orthophosphate, Temperature, pH, conductivity, and COD. WQI developed by Debels was originated from the development of Martınez de Bascaran's research in 1979 [16].

WQI has also been used in Mexico in the research performed by Orozco and the parameter used was physical chemistry [12]. The variables include pH, dissolved oxygen (DO), total dissolved solids (TDS), electrical conductivity (EC), alkalinity (Alk), total hardness (TH), total phosphorous (TP), Cl, Ca, Zn, K, B , As, SO4, Cu, NO_3, and Mg. These parameters were the standard parameter established by the Mexican National Water Commission (CNA). WQI was used to measure the water quality of La Vega dam/reservoir in Teuchitlan, Jalisco, Mexico. WQI developed by Orosco is a development of the research by Conesa in 1995 and León-Vizcaíno in 1991. Furthermore, the measurement of Bagmati river's water quality in Nepal by Kannel were almost identical with previous research using physical-chemical parameters [17].

The WQI method developed in several countries were almost entirely different, i.e. National Sanitation Foundation Water Quality Index (NSFWQI) [18], WQI of Mexican National Water Commission [12] , etc. The parameters used in WQI were also different. For that reason, the selection of WQI parameters were based on the objectives of WQI calculation results. The WQI method that has been developed produce three water quality measurement class, i.e. very bad (0–25), bad (26-50), medium (51–70), good (71–90), and excellent (91–100). Therefore, WQI and XX was essential to regular monitoring program [17,18,19]. All water quality measurements using WQI method can be used as an accurate reference to warn health impacts that may be caused by water.

Well water measurement-based WQI in small islands developed in this research provides new parameter in WQI for specific measurements in the island. The parameters are Coliform, temperature, pH, and salinity. Consequently, the WQI with the specific parameters can predict the incidence of waterborne disease in small islands.

Water quality measurement with WQI must be used as a tool to monitor water quality in coastal and small island areas as it is closely related with waterborne disease caused by fecal bacteria. A research shown that there are strong relationship between gastrointestinal disease with the presence of fecal bacteria entering the body through water [20]. The impact was not just waterborne disease but also diseases caused by chemical waste, if the island is in the vicinity of industrial or mining area. This is exactly the case with Farwa Island in Libya where from waste coming industry located not far from the island have caused the pollution [21].

In the future, WQI to measure the quality of drinking water in the islands must be developed. If no regular examination/monitoring on the quality of drinking water source are carried out, people who consumed the contaminated water for years will be exposed to diseases. The drinking water source in Rhode Island has been recorded to have contaminated with tetrachloretilen and affect the pregnant women [22].

4. Conclusions

The development of measurement-based WQI on well water quality on the island can provide accurate information on the quality of well water used by the community. The result of WQI calculations in the islands around Makassar City have produced the following water quality category; they are mildly polluted, lightly polluted and in good condition. The four parameters (Coliform, suhu, pH, and salinity) developed in the research can produce accurate parameters to measure the water quality in small densely populated islands.

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