Determination of Pollutant Index (PI) for Assessing the Quality of Groundwater in the Area of Sidoarjo Mud (LUSI) Sidoarjo, East Java, Indonesia

Ilham Putra Adiyaksa*, Oleg G. Savichev
School of Earth Sciences and Engineering, National Research Tomsk Polytechnic University
Lenin Avenue 634050, Tomsk, Russia

*Correspondence email: ilhamadiyaksa@gmail.com

ABSTRACT

Sidoarjo mud (well known as LUSI) have been occurred since 2006 in Sidoarjo, East Java, Indonesia and gives many impacts to many aspects, as well as environment and water quality condition. One of the major concerns is water quality problem, especially in this current situation in 2022 since clean water still needed by local people and groundwater is the main water source for many local people in this area. Our previous study has carried out to assess the ecological and geochemical conditions of groundwater in the area around Sidoarjo mud in 2022. In this study, by using Pollutant Index (PI) calculation, the water quality classification will be determined from several samples and parameters in various places, including Tanggulangin, and Porong, Sidoarjo, East Java. From the calculation result, based on Pollution Index (PI) value, water in Tanggulangin is categorized as good water (clean water), while water in Porong is categorized as good water (clean) as well for sample B3, and the rest is categorized as lightly polluted water with sample B5 as the most contaminated. Groundwater in the area near to Sidoarjo mud is contaminated by NO_2^-, Mn, and Hg.

Keywords: groundwater, PI, Sidoarjo mud, water quality

INTRODUCTION

Since the Sidoarjo mudflow occurred in Porong, Sidoarjo, East Java, Indonesia which is known as LUSI (Lumpur Sidoarjo/Sidoarjo mud), many studies have been conducted, especially on understanding its impact on the environment. One of the major concerns is water quality problem. This is because people in that area (in Sidoarjo generally) utilize groundwater (through their respective wells) for various purposes, including for consumption/drinking. Thus, research on water quality in around Sidoarjo mud area is very actual and essential, considering the importance of using healthy clean water.

The center of Sidoarjo mud is in Porong, Sidoarjo. It has been occurred since Mei, 29th 2006 and already submerged 3 subregions of Sidoarjo, including Porong, Tanggulangin, and Jabon (Davies et al., 2007). The morphology of this area is composed mainly of surface deposits (alluvium) consisting of mud, silt, sand, and gravel. In addition, the Sidoarjo basin at the top is filled with alluvial deposits that grow from Upper Quaternary rocks. The bottom is covered by Lower Quaternary sediments and presumably bounded by lower clay units and the Pucangan formation (Rosadi, 2008). In this formation, it is predicted that it has big amount of groundwater.

The quality of groundwater can be determined by various parameters, including physical, chemical, as well as microbiological parameters. The standards of clean water for hygienic purposes (including for drinking) in Indonesia already being ruled in the regulation of Ministry of Health of Republic of Indonesia No. 32 2017 about "Environmental Health Quality Standards and Water Health Requirements for Sanitation Hygiene Purposes, Swimming Pools, Per Aqua Solutions, and Public Bathing" (Menteri Kesehatan RI, 2017).

Our previous study of determining the chemical content of groundwater in the area of Sidoarjo mud was carried out during 2022

(Adiyaksa et al., 2023). The result describes about ecological and geochemical condition of groundwater in the area of Sidoarjo mud in the current conditions in 2022. To understand the quality of water itself, the quality assessment is needed objectively. The importance of assessing water quality is to ensure that the water used is clean and healthy, because water consumption will have a direct impact on the health of consumers (Ashar, 2007; Behrooz & Burger, 2021; Castresana et al., 2019). Various chemical constituents in water will have a certain impact on health, thus the assessment of water quality is highly required.

Various method and calculation can be implemented for assessing the quality of water. One of the methods that can be utilized is Pollutant Index (PI) calculation. This method is widely implemented for determining the purpose of water use, since the method contains calculation that considering any chemical compounds. This method built based on two quality indices; first is the average index, that shows the average level of contamination in one time of observation, and second is the maximum index, that shows the biggest parameter of contamination that affect to the water quality decreasing.

Many research already carried out by implementing this method. This method widely used for assessing the quality of groundwater in Indonesia (Abadi et al., 2011; Agustina et al., 2021).

Based on the explanation above, the aim of this paper is to discuss about several chemical compounds of groundwater around Sidoarjo mud, especially in Tanggulangin and Porong, based on the parameters that being ruled in Permenkes No. 32 2017 as the newest geochemical condition of groundwater in the area of Sidoarjo mud in 2022, and to determine the water quality with using PI method.

MATERIALS AND METHODS

The material that is used in this research was groundwater from several different points of wells. The A1-A5 samples were taken in the Kedensari village, Tanggulangin, Sidoarjo, in around January 11th, 2022, and February 1st, 2022, while the B1-B5 samples were taken from Porong, Sidoarjo, closer to the area of Sidoarjo mud in 2nd of October 2022. Water was taken in the depth of 5-10 m from the surface of land. Fig 1 and Table 1 are showing the sampling points scheme and coordinate.

The A1-A5 samples were analyzed in the Environmental Laboratory, Jasa Tirta I, Malang, Indonesia with several parameters; pH was using potentiometric method; turbidity was using nephelometry; Cl^- was using argentometry; Na^+ was using atomic absorption spectrometry with flame atomization, and SO_4^{2-} was using turbidimetric method (Adiyaksa et al., 2022).

Table 1. Coordinate of sampling points in Tangulangin and Porong, Sidoarjo, East Java

Samples	Coordinate
A1	-7.50489, 112.69266
A2	-7.50463, 112.692719
A3	-7.50454, 112.692795
A4	-7.50482, 112.692541
A5	-7.50509, 112.692431
B1	-7.5403788, 112.7002897
B2	-7.541071, 112.7045007
B3	-7.5349055, 112.699067
B4	-7.5279536, 112.7032352
B5	-7.5119828, 112.706591

The B1-B5 samples were analyzed in Hidrogeochemistry laboratory, School of Earth Sciences and Engineering, National Research Tomsk Polytechnic University (TPU), Tomsk, Russia. The analysis was taken for several chemical compounds; pH was using potentiometric method; specific electrical conductivity EC was using conductometric; permanganate oxidizability (PO), Ca^{2+}, Mg^{2+}, HCO_3^-, Cl^-, CO_2 were using titrimetric; SO_4^{2-} was using turbidimetric, NH_4^+, NO_2^-, NO_3^-, phosphates, Fe were using photocolorimetry; Na^+, K^+ were using flame emission spectrometric; more than 30 trace elements were using inductively coupled plasma mass spectrometric (NexION 300D mass spectrometer); and organic, inorganic, total carbon, and total nitrogen were using high temperature catalytic oxidation (Adiyaksa et al., 2023).

The chemical analysis results will be compared with the regulation of Ministry of

Health of Republic of Indonesia No. 32 2017 about "Environmental Health Quality Standards and Water Health Requirements for Sanitation Hygiene Purposes, Swimming Pools, Per Aqua Solutions, and Public Bathing" to understand which parameter that has higher value than the standard, which means as the source of contamination.

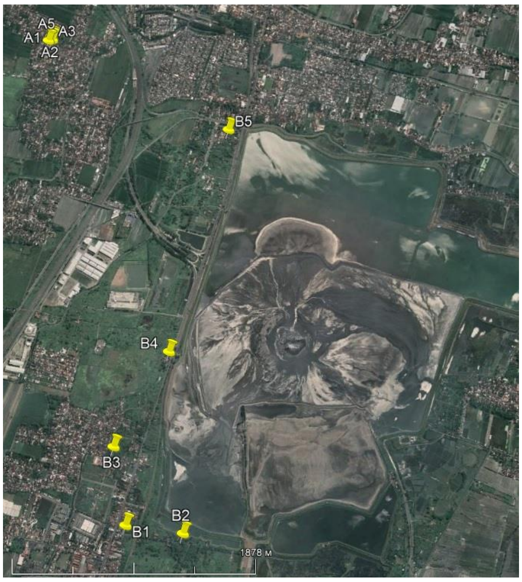

Figure 1. Sampling points scheme of groundwater around Sidoarjo mud, Sidoarjo, East Java, Indonesia
(Source : Google Earth image at 22.06.2022)

Pollutant Index (PI) calculation

Water quality management based on contamination index has a big role to give some inputs for making decisions on overcoming water quality decreasing. The calculation is carried out by following these steps (Angelina, 2021):

1. To calculate C value of each parameter, for example Fe, Hg, Cr contains. This calculation is understanding the correlation between standard and the laboratory result. The calculation is carried out by using the equation (1).

$$C = \frac{C_i}{L_{ij}} \quad (1)$$

Where :

C : comparison of chemical concentration from laboratory analysis and the standard

C_i : chemical concentration based on laboratory result (mg. L^{-1})

L_{ij} : chemical concentration based on standard (mg. L^{-1})

2. Recalculate every parameter that has *C* value more than 1 (C>1) as *Cn*. The calculation is using equation (2).

$$C_n = 1 + P \log C \quad (2)$$

Where :

C_n : new comparison of chemical concentration from laboratory standard and the standard

P : constant value of 5

C : the result from equation (1)

3. Calculate the Pollution Index (PI) by using equation (3).

$$PI = \sqrt{\frac{C_{n\,(max)}{}^2 + C_{n\,(avg)}^2}{2}} \quad (3)$$

Where :

$C_{n\ (max)}$: the maximum Cn value from 1 sample

$C_{n\ (avg)}$: the average Cn value from 1 sample

The PI value is used to determine in which level the water contaminated is. The water classification, based on the regulation of Ministry of Health of Republic of Indonesia No. 32 2017, are divided into 4 groups (Table 2).

RESULT AND DISCUSSION

Physico-chemical Characteristics in the Area of Sidoarjo Mud

The A1-A5 samples are located about 3.3 km to the northwest from the center of Sidoarjo mud in Porong, preciously in Kedensari village, Tanggulangin, Sidoarjo, East Java. All physico-chemical parameters in this location are met the standard of the regulation by Indonesian Ministry of Health (Table 3). Data analysis were taken, as well as risk analysis calculation from the chemical exposure (chloride and sodium) to human health (Adiyaksa et al., 2022). Near from this area, especially in Taman Budaya Tanggulangin (Tanggulangin Cultural Park), were obtained observation for several parameters. The result shows that in that area water hardness and total coliform are met the standard as well (Adiyaksa, 2022). Thus, by comparing with

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the standard, all parameters are fit as the source of water use, in this case, for drinking purposes. Although all tested parameters show a good result, it should be noted that there was a significant increasing of Na^+ in A4 and A5, that might be caused by local contamination from household disposal.

Table 2. Classification of water contamination based on PI value

No.	PI value	Condition
1	0-1.0	Good
2	1.1-5.0	Lightly polluted
3	5.1-10	Moderately polluted
4	>10	Heavily polluted

Source: the regulation of Ministry of Health of Republic of Indonesia No. 32 2017 about "Environmental Health Quality Standards and Water Health Requirements for Sanitation Hygiene Purposes, Swimming Pools, Per Aqua Solutions, and Public Bathing"

While the B1-B5 samples are located about 1-2 km from the center of Sidoarjo mud and in the same region of the Sidoarjo mud itself, which is in Porong. The result of geochemical analysis is presented in Table 5. The completed result of analysis with more than 30 chemical compounds is presented in (Adiyaksa et al., 2023). Our previous analysis to conclude the ecological and geochemical condition of groundwater in this area in current condition in 2022. In general, water is classified into 2 (Table 6, Fig. 2); first is fresh water with high mineralization (bicarbonate calcium) for B1-B3, and second is brackish with the contamination of Hg, I, Br, and B (sodium chloride) for B4 and B5. The water in this area is not suitable for consumption purposes, since it contains increased chemical compounds (and especially the heavy metals).

Table 3. Physico-chemical characteristic of well water in A1-A5 samples, Kedensari, Tanggulangin, Sidoarjo, East Java (January to February, 2022)

Indicators	Unit	Standard	Input data				
			A1	A2	A3	A4	A5
Sampling time	-		11.01.22	11.01.22	11.01.22	01.02.22	01.02.22
Latitude	◦		-7.505	-7.505	-7.505	-7.505	-7.505
Longitude	◦		112.693	112.693	112.693	112.693	112.692
Ta	C	±3	28.0	28.8	28.6	30.0	29.0
Tw	C		26.7	28.5	28.3	29.2	28.7
pH	-	6.5-8.5	7.76	7.53	6.69	8.20	7.82
Turbidity	NTU	5	1.00	1.10	0.90	0.80	1.50
Na^+	mg. L^{-1}	200	1.70	1.40	1.60	29.7	17.4
Cl^-	mg. L^{-1}	250	62.9	56.1	57.5	62.5	42.3
SO_4^{2-}	mg. L^{-1}	250	32.6	26.3	25.2	26.6	17.0

Note: Ta (temperature of air), Tw (temperature of water)
Standard is following the Regulation of the Minister of Health of the Republic of Indonesia No. 492/Menkes/Per/IV/2010 concerning Requirements for Drinking Water Quality

The result show that several chemical compounds are exceeding the standard, including Fe, Mn, NO_2^-, Hg, as well as Se. Other studies show that water around Sidoarjo mud contaminated by those chemicals as well, Mn, SO_4^-, as well as PO_4 and NH_3 (Auvaria & Munfarida, 2020; Purwaningsih & Notosiswoyo, 2013).

It is found that Fe has the biggest amount in sample B4 with the content of 1.48 mg. L^{-1} (the standard is 1.0 mg. L^{-1}), Mn has the biggest amount in sample B4 as well with the content of 4.11 mg. L^{-1} (the standard is only 0.5 mg. L^{-1}), NO_2^- has biggest amount in sample B1 with the content of 7.70 mg. L^{-1} (the standard is only 1 mg. L^{-1}), Hg has the biggest amount in sample B5 with the content of 0.0264 mg. L^{-1} (the standard is 0.001 mg. L^{-1}), and Se has the biggest amount in sample B5 with the content of 0.0143 mg. L^{-1} (the standard is 0.01 mg. L^{-1}).

Table 4. Result of Pollution Index (PI) calculation for A1-A5 samples

Indicators	Unit	C				
		A1	A2	A3	A4	A5
Sampling time	-	11.01.22	11.01.22	11.01.22	01.02.22	01.02.22
Latitude	◦	-7.540277	-7.54089	-7.534902	-7.528039	-7.5121
Longitude	◦	112.7002	112.7043	112.6991	112.7027	112.7063
Ta	C	1.30	-0.50	-0.30	-1.20	-0.70
Tw	C					
pH	-	-0.26	-0.03	0.81	-0.70	-0.32
Turbidity	NTU	0.20	0.22	0.18	0.16	0.30
Na+	mg. L^{-1}	0.09	0.01	0.01	0.15	0.09
Cl-	mg. L^{-1}	0.25	0.22	0.23	0.25	0.17
SO_4^{2-}	mg. L^{-1}	0.13	0.11	0.10	0.11	0.07
C max		1.30	0.22	0.81	0.25	0.30
C avg		0.27	0.004	0.17	-0.21	-0.07
PI		0.94	0.159	0.59	0.23	0.22

Table 5. Geochemical characteristics of groundwater in the area of Sidoarjo mud, Porong, Sidoarjo, East Java (October 2nd, 2022) (Adiyaksa et al., 2023)

Indicators	Unit	Standard	Input data				
			B1	B2	B3	B4	B5
Sampling time	-		02.10.22	02.10.22	02.10.22	02.10.22	02.10.22
Latitude	◦		-7.540	-7.541	-7.535	-7.528	-7.512
Longitude	◦		112.700	112.704	112.699	112.703	112.706
Ta	C	±3	29.3	28.9	30.2	30.7	30.6
Tw	C		28.0	27.6	28.5	29.2	29.3
pH	-	6.5-8.5	6.52	6.63	6.59	6.47	6.39
Fe	mg. L^{-1}	1	0.07	0.42	0.09	1.48*	0.20
Mn	mg. L^{-1}	0.5	1.48*	0.71*	0.29	4.11*	0.62*
NO_3-	mg. L^{-1}	10	3.40	4.00	0.88	8.90	8.70
NO_2-	mg. L^{-1}	1	7.70*	5.30*	0.36	1.73*	0.70
Hg	mg. L^{-1}	0.001	0.0007	0.0010*	0.0005	0.0013*	0.0264*
As	mg. L^{-1}	0.05	0.0002	0.0006	0.0064	0.0162	0.0031
Cd	mg. L^{-1}	0.005	0.0000	0.0000	0.0000	0.0000	0.0001
Cr	mg. L^{-1}	0.05	0.0020	0.0018	0.0020	0.0025	0.0016
Se	mg. L^{-1}	0.01	0.0002	0.0009	0.0005	0.0022	0.0143*
Zn	mg. L^{-1}	15	0.0080	0.0647	0.0009	0.0015	0.0075
SO_4^{2-}	mg. L^{-1}	400	29.00	26.00	14.00	18.00	35.00
Pb	mg. L^{-1}	0.05	0.0000	0.0010	0.0000	0.0001	0.0003

Note: Ta (temperature of air), Tw (temperature of water)
* Exceeding the standard

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Table 6. The type of water in B1-B5 samples based on the main ions

Ions	B1		B2		B3		B4		B5	
	mg-eq. L^{-1}	%	mg-eq. L^{-1}	%	mg-eq. L^{-1}	%	mg-eq. L^{-1}	%	mg-eq. L^{-1}	%
Ca^{2+}	3.40	47.35	3.40	49.61	2.88	54.48	3.52	27.24	11.90	36.62
Mg^{2+}	0.22	3.09	0.43	6.31	0.59	11.25	0.63	4.89	1.20	3.68
Na+	2.17	30.27	2.65	38.70	1.39	26.32	8.35	64.61	17.91	55.12
K+	1.38	19.28	0.37	5.39	0.42	7.95	0.42	3.25	1.49	4.58
Sum	7.18	100	6.85	100	5.29	100	12.92	100	32.50	100
HCO_3-	5.84	81.61	4.75	66.47	4.72	84.96	5.64	47.46	3.61	7.41
Cl-	0.71	9.94	1.86	25.95	0.54	9.80	5.87	49.38	44.34	91.09
SO_4^{2-}	0.60	8.45	0.54	7.57	0.29	5.25	0.38	3.16	0.73	1.50
Sum	7.15	100	7.15	100	5.56	100	11.88	100	48.68	100
Kurlov	HCO_3-, Ca^{2+}		HCO_3-, Ca^{2+}		HCO_3-, Ca^{2+}		Cl-, Na^+		Cl-, Na^+	
Type	Calcium bicarbonate		Calcium bicarbonate		Calcium bicarbonate		Sodium chloride		Sodium chloride	

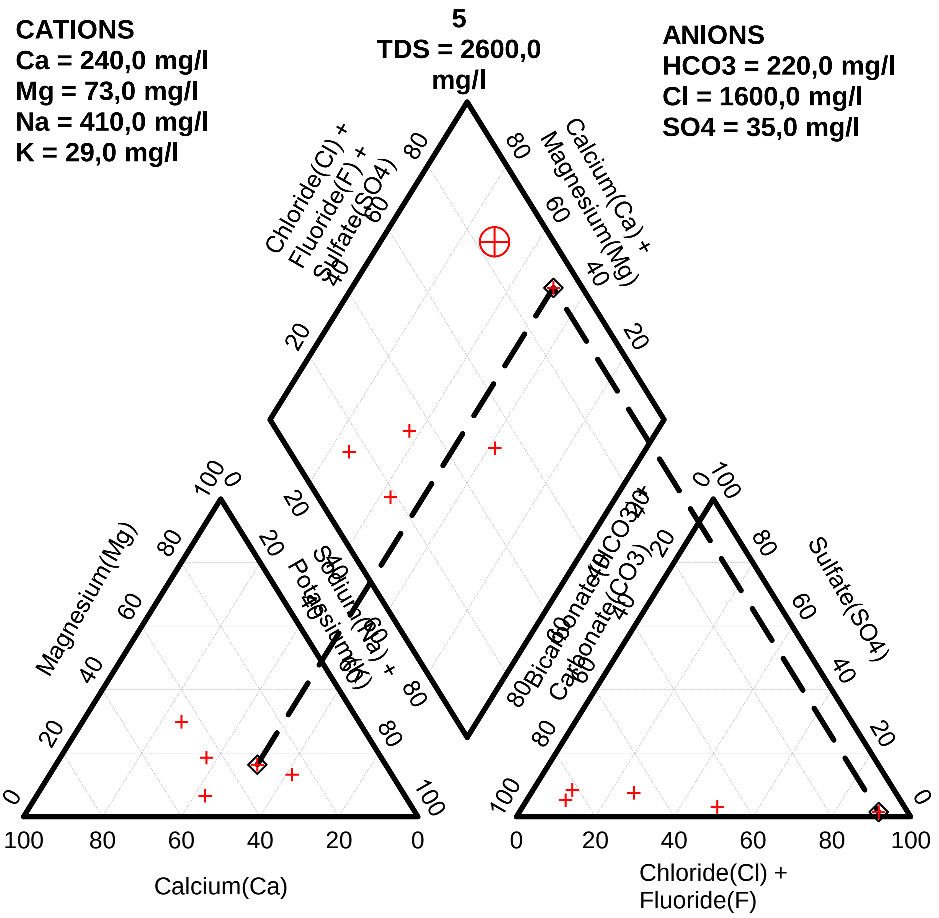

Figure 2. Trilinear piper diagram of B1-B5 samples

Pollutant Index (PI) Analysis

To assess the water quality, PI can be used since it has good approach to consider every pollution that contains in water and is one of comprehensive method (Novita et al., 2020).

Table 4 shows the calculation of pollution index (PI) for A1-A5 samples, that located in Kedensari village, Tanggulangin, Sidoarjo. The PI value respectively from A1-A5 is 0.93, 0.15, 0.59, 0.23, and 0.22. Based on the classification in Table 1, all the water in this samples are classified as 'good' water, which means clean, since the PI value is less than 1 (PI<1). Based on that score as well, the best water (cleanest) is in the sample of A2.

While Table 7 shows the PI value for the sample B1-B5, which is located closer to Sidoarjo mud. The PI value respectively from B1-B5 is 3.89, 3.31, 0.66, 3,99, and 5.77. Based on the classification in Table 1, only sample B3 that categorized as 'good' water, and the rest is categorized as 'lightly polluted' water. B5 is the only location that has the highest PI value, which means that samples in B5 have the biggest contamination compared with other locations. These calculation has similarity result with our previous finding in (Adiyaksa et al., 2023) that B5 is the most contaminated water that contaminated not only by Hg, but also, I and Br, while B3 is the cleanest water, with the lowest PI value.

The biggest contamination in sample B1 is NO_2^-, as well as in B2. While in B4, the biggest contamination is Mn, and in B5 is Hg. With this contamination, water is not suitable for consumption purposes. These contaminations will have a negative impact to human health as the consumer (Febrina & Ayuna, 2015; Putranto, 2011).

From the equation (1) to (3) we understand that the concentration of chemical compounds itself has big role to increase the PI value. Since we could classify the quality of water by calculating PI value, we can understand that higher concentration of chemical exceeding the standard, will increase the value of PI, means that will decrease the quality of water.

Table 7. Result of Pollution Index (PI) calculation for B1-B5 samples

Indicators	Unit	Standard	Cn				
			B1	B2	B3	B4	B5
Latitude	°		-7.540277	-7.54089	-7.534902	-7.528039	-7.5121
Longitude	°		112.7002	112.7043	112.6991	112.7027	112.7063
Ta	C	±3	0.529	1.00	-0.059	-0.88	-1.00
Tw	C						
pH	-	6.5-8.5	0.980	0.870	0.910	1.030	1.110
Fe	mg. L^{-1}	1	0.074	0.417	0.087	1.855	0.200
Mn	mg. L^{-1}	0.5	3.351	1.772	0.582	<u>5.576</u>	1.463
NO_3-	mg. L^{-1}	10	0.340	0.400	0.088	0.890	0.870
NO_2-	mg. L^{-1}	1	<u>5.432</u>	<u>4.621</u>	0.360	2.190	0.700
Hg	mg. L^{-1}	0.001	0.712	1.001	0.509	1.582	<u>8.107</u>
As	mg. L^{-1}	0.05	0.003	0.012	0.127	0.325	0.062
Cd	mg. L^{-1}	0.005	0.000	0.000	0.000	0.000	0.014
Cr	mg. L^{-1}	0.05	0.041	0.036	0.040	0.049	0.032
Se	mg. L^{-1}	0.01	0.017	0.086	0.052	0.224	1.778
Zn	mg. L^{-1}	15	0.001	0.004	0.000	0.000	0.001
SO_4^{2-}	mg. L^{-1}	400	0.073	0.065	0.035	0.045	0.088
Pb	mg. L^{-1}	0.05	0.001	0.020	0.001	0.002	0.006
	Cn max		5.432	4.621	0.910	5.576	8.107
	Cn avg		0.825	0.736	0.195	0.920	0.959
	PI		3.885	3.309	0.658	3.996	5.773

From the discussion above, it can be concluded as follows,

1. From samples of A1-A5, water in the area of Tanggulangin, Sidoarjo, East Java is categorized as 'good' water, which is clean water since the water samples in this area have a PI value less than 1.0.
2. From samples of B1-B5, water in the area of Porong, Sidoarjo, East Java (near to Sidoarjo mud) is categorized as 'good' water only in sample B3, and the rest is lightly polluted water. The most contaminated water is in B5 with PI value more than 5.
3. Water in the area of Kedensari, Tanggulangin (A1-A5) in general is suitable to utilize for any purposes, including drinking, while water in the area of LUSI (B1-B5) is not suitable since it contains several contaminants, including Hg, Mn, as well as NO_2^-, which will cause desease for its consumer.
4. An adequate water system should be installed in this city to provide clean and healthy water for its people. Water management should be carried out considering the chemical compunds and contaminants in the groundwater.

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