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MULTIVARIATE STATISTICAL ANALYSIS FOR THE ASSESSMENT OF GROUNDWATER QUALITY IN SEMARANG LOWLAND AREA

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ABSTRACT: Groundwater is the primary water resources for the human activities in Semarang lowland area. Serious threats against sustainable development concerning groundwater are inevitable. Therefore, it is essential to assess groundwater quality. The primary objective of the research is assessing groundwater quality using the multivariate statistical analysis using Principal Component Analysis (PCA) and Hierarchical Component Analysis (HCA) to evaluate 30 groundwater samples which are collected from dug wells. The results show the concentration of pH, Fe^{3+}, Cl^-, Mn^{2+}, SO_4^{2-}, NO_2^-, exceeding the Indonesian water drinking standard. Cluster and factorial analysis showed three primary factors in groundwater. Factor 1 explained that 63.5% from total variant with EC, $CaCO_3$, Mg^{2+}, K^+, Na^+, Cl^- and TDS show a potential contamination source from seawater intrusion. Factor 2 explained that 13.5% from total variant with pH and NO_3^- show a potential contamination source from household waste. Factor 3 explained that 10.4% from total variant with Fe^{3+} is assumed to be contaminants from rocks around Semarang.

Keywords: Groundwater, Multivariate, PCA, HCA, Semarang

1. INTRODUCTION

Human activities play a dominant role in transforming the biosphere and influencing the function of the Earth system [1,2]. The act of fulfilling water necessities can trigger the rising pressure towards the environment and causing a trade of water necessity and environmental sustainability. As stated in the first sentence of World Water Development Report 2015, "water is the core of sustainable development"[3]. A serious threat against sustainability in relation to water. About 1.4 billion people live in waterbeds where the usage level of water exceeds its replenishment. [4]. In developing countries, close to 90% of waste is disposed of without prior treatment [5]. There is an increase of nitrogen in global rivers due to the combination of fertilizers deployment with the rise of water waste [6]. Globally, 1.8 billion people have consumed water contaminated with waste [7].

Water quality control is becoming paramount [8]. Groundwater quality is equally important as the quantity due to its versatility for various needs [9,10]. Hydrochemical evaluation of groundwater system usually is based on the availability of information regarding groundwater chemical contents [11]. This research is in the Semarang lowland area in the Central Java Province, Indonesia. Semarang, as one of the coastal cities on the northern shores of Java Island, has fastly grown especially in industries and commercial sector [12]. The use of land on shorelines and lowlands are dominated by residences, pools, and trade and service areas [13]. Groundwater contamination due to industrial, household, and agricultural waste has caused the decline of groundwater quality [14]. This research is focused on groundwater abstraction from the unconfined aquifer. The objective of this research is evaluating groundwater quality using the multivariate statistical analysis, which are Principal Component Analysis (PCA) and Hierarchical Component Analysis (HCA) as well as deploying spatial analysis method. Several researchers have analyzed various statistical methods to determine the quality of groundwater [15,16,17,18]. Multivariate statistical analysis is applied in this research to assess the quality of groundwater and to identify the most dominant chemical parameter affecting the decline of groundwater quality.

2. METHODS

The hydrogeological field campaign was conducted in months as the lowest precipitation rate. It was in July 2017 by collecting 30 groundwater samples from dug wells (Figure 1). Groundwater samples were tested through 16 parameters: EC, pH, $CaCO_3$, Mg^{2+}, Fe^{3+}, K^+, Na^+, Cl^-, Ca^{2+}, Mn^{2+}, NH_4^+, HCO_3^-, SO_4^{2-}, NO_2^-, NO_3^- and TDS. EC and pH were tested in the field using WtW Conductivity portable meter ProfiLine Cond 3110 and WtW pH portable meter ProfiLine 3110. The chemical parameters were analysed in the hydrogeochemistry laboratory of the Indonesian Geological Agency in Bandung.

The research area has a volcanic product such as breccia in Damar Formation in the south and Alluvium consist of unconsolidated material such as sand to clay material in the centre to the north (Figure 2). Land usage is mostly residential on the northern, city centre on the eastern, while the rest is mostly industries water bodies, trade and service areas (Figure 3).

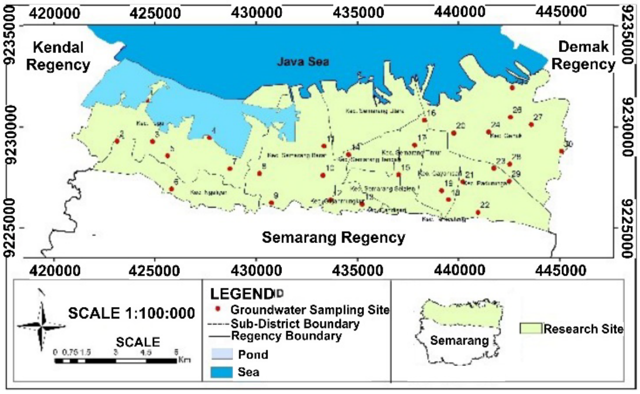


Fig. 1 Location of groundwater samples from dug wells

The statistical method used in this research includes correlation and multivariate analysis. Water quality is determined by observing the chemical compound contained in the water using correlation analysis [19,20,21,22]. Correlation analysis is a measurement of the interdependency of one variable with another variable [23].

The multivariate analysis depicts hydrogeochemical pattern and correlation among parameters which determine water quality. Several kinds of research effectively employed multivariate analysis in understanding hydrochemical processes [14] [24-32]. Multivariate statistical analysis indirectly shows ongoing hydrochemical process yet depicts the controlling factors in this process.

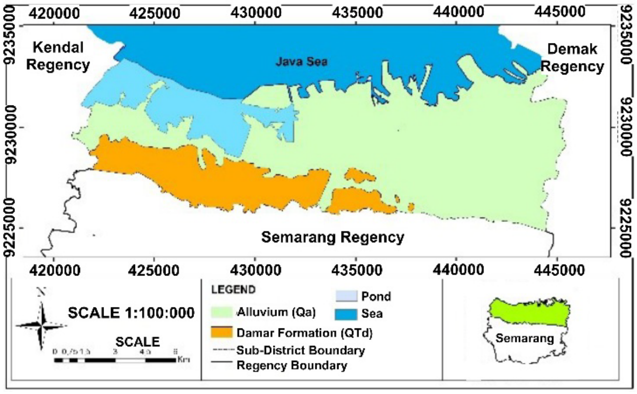


Fig. 2 Regional geological map of the coastal plains and lowlands of Semarang

Multivariate analysis is divided into two, namely dependency analysis and interdependence analysis. Interdependence analysis includes factor analysis, cluster analysis and multi-dimensional scaling. Cluster analysis is an analysis that aims to group observational objects.

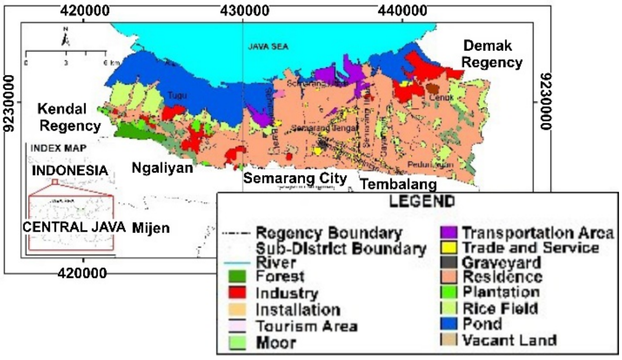


Fig. 3 Study area and the land use

Multivariate statistical analysis such as principal component analysis (PCA) and hierarchical clustering analysis (HCA) are employed to assess groundwater quality. HCA is a multivariate classification to determine the natural grouping [33]. Various researches used HCA to evaluate surface water and groundwater as well as water quality analysis [24,33]. PCA is employed to identify data pattern from many variables. Factor analysis with principal component analysis method is used to identify the cause of change in water quality through using multiple parameter testing [28]. Kaiser Normalization and Varimax Rotation require the use of principal component analysis and factor analysis [34].

Correlation analysis, HCA, and PCA was computed by using SPSS 20 software.

3. RESULTS AND DISCUSSION

There are 16 chemical parameters of groundwater quality which are analysed. Table 1 shows the physicochemical and descriptive statistic of 30 groundwater samples. Table 2 depicted the statistical distribution of the physicochemical properties of wells.

Table 1 shows electricity conductivity value (EC) ranges from 411 µS/cm to 7,300 µS/cm with a mean of 1,467 µS/cm. It shows that a large part of groundwater contains brackish and seawater. pH value ranges from 6.34 to 7.74 with mean of 7.02, showing groundwater samples have neutral pH. Total Dissolved Solids (TDS) concentration varied from 276 to 4,868 mg/L with an average of 979 mg/L. There is a presence of dissolved solids consisted of the organic and inorganic compound at several sample points exceeding drink water quality standards with a limit of 500 mg/L. A high TDS may come from natural factor, waste disposal both households or industrials.

The chemical parameters contain $CaCO_3$, Ca^{2+}, Mg^{2+}, Fe^{3+}, Mn^{2+}, K^+, Na^+, NH_4^+, HCO_3^-, Cl^-, SO_4^{2-}, NO_2^- and NO_3^-. Several chemical parameters are exceeding Indonesian drinking water standards (Permenkes No. 492/2010) such as Fe^{3+}, Mn^{2+}, Cl^-, SO_4^{2-}, and NO_2^- as shown in Table 2. The wells which exceed drinking water standards from 7 to 26 wells. The values of SO_4^{2-} of groundwater samples are dominated exceeding water drinking standard limit.

The Ca^{2+} concentration ranges from 37 to 251 mg/L with a mean of 83.7 mg/L. $CaCO_3$ concentration ranges from 122 to 985 mg/L with a mean of 333 mg/L. Mg^{2+} concentration in water ranges from 1.6 to 136 mg/L with a mean of 28.9 mg/L. K^+ concentration in water ranges from 2.6 to 63.5 mg/L with a mean of 19.9 mg/L.

Na^+ concentration in water ranges from 3.1 to 1,555 mg/L with a mean of 233 mg/L. NH_4^+ concentration in water ranges from 0 to 82 mg/L with a mean of 5.21 mg/L. HCO_3^- concentration in water ranges from 161 to 1,041 mg/L with a mean of 523 mg/L. Indonesian Minister of Health Regulation (Permenkes) No. 492/2010 has not yet set the upper and lower limit of Ca^{2+}, $CaCO_3$, Mg^{2+}, K^+, Na^+, NH_4^+, HCO_3^- therefore all wells have fulfilled the quality standards.

Table 1. Physiochemical and descriptive statistic of groundwater samples

Parameter	Unit	Min	Max
EC	µS/cm	411	7,300
pH	-	6.34	7.74
$CaCO_3$	mg/L	122	985
Ca^{2+}	mg/L	37	251
Mg^{2+}	mg/L	1.6	136
Fe^{3+}	mg/L	0	3.64
Mn^{2+}	mg/L	0.003	9.01
K^+	mg/L	2.6	63.5
Na^+	mg/L	30.1	1,555
NH_4^+	mg/L	0.0	82
HCO_3^-	mg/L	161	1,041
CI-	mg/L	23.5	2,374
SO_4^{2-}	mg/L	0	274.5
NO_2^-	mg/L	0	6.88
NO_3^-	mg/L	0	35.9
TDS	µS/cm	276	4,868

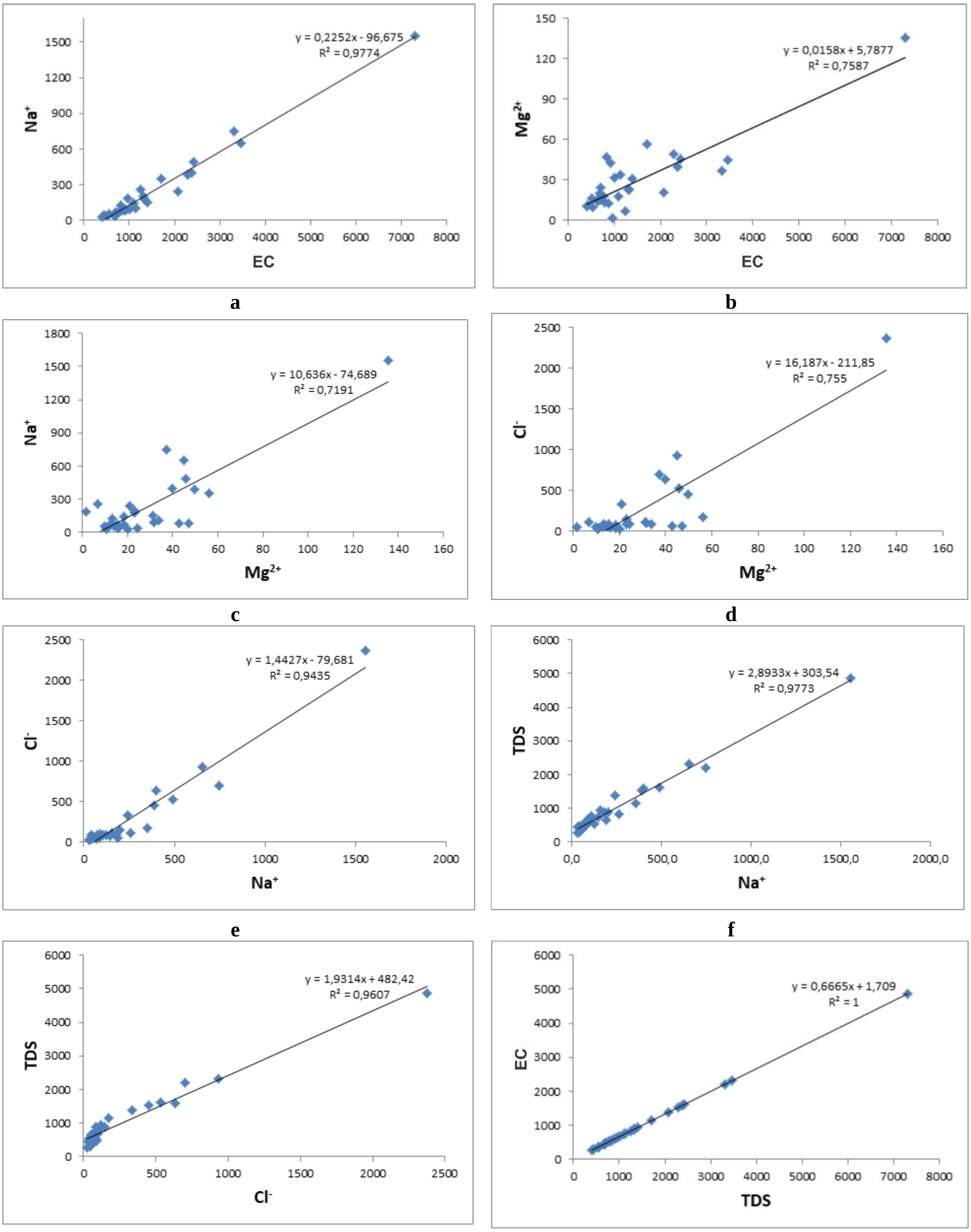
Table 2. Statistical distribution of physicochemical properties of wells

Parameter	Unit	Permenkes No 49/2010	Wells within permitted range	Total	Wells exceeding the permitted range	Total
EC	µS/cm	-	All wells	30		0
pH		6.5-8.5	Most wells except 10	29	10	1
$CaCO_3$	mg/L	-	All wells	30		0
Ca^{2+}	mg/L	-	All wells	30		0
Mg^{2+}	mg/L	-	All wells	30		0
Fe^{3+}	mg/L	0.3	1, 2, 3, 5, 6, 7, 8, 10, 12, 14, 17, 18, 19, 21, 22, 23, 24, 26, 27, 28, 29, 30	22	4, 9, 11, 13, 15, 16, 20, 25	8
Mn^{2+}	mg/L	0.4	2, 5, 6, 8, 12, 13, 14, 21, 23, 24, 26, 29, 30	13	1, 3, 4, 7, 9, 10, 11, 15, 16, 17, 18, 19, 20, 22, 25, 27, 28	17
K^+	mg/L	-	All wells	30		0
Na^+	mg/L	-	All wells	30		0
NH_4^+	mg/L	-	All wells	30		0
HCO_3^-	mg/L	-	All wells	30		0
CI^-	mg/L	250	2, 3, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 18, 19, 20, 21, 22, 23, 26, 28, 29, 30	23	1, 4, 16, 17, 24, 25, 27	7
SO_4^{2-}	mg/L	250	Most wells except 4	29	4	26
NO_2^-	mg/L	3	1, 2, 3, 5, 7, 8, 10, 12, 13, 14, 16, 17, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30	23	4, 6, 9, 11, 15, 18, 19	7
NO_3^-	mg/L	50	All wells	30		0
TDS	µS/cm	500	5, 6, 7, 9, 10, 11, 12, 13, 14	9	1, 2, 3, 4, 8, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30	21

Fe^{3+} concentration ranges from 0 to 3.64 mg/L with a mean of 0.37 mg/L. Thus several wells exceeded the set upper limit of 0.3 mg/L.

The Mn^{2+} concentration ranges from 0.003 to 9.01 mg/L with a mean of 1.13 mg/L. Thus several wells (17 wells) have exceeded the set upper limit of 0.4.

The Cl^- concentration in ranges from 23.5 to 2,374 mg/L with a mean of 257 mg/L. Therefore, several wells exceeded the set upper limit of 250 mg/L. SO_4^{2-} concentration ranges from 0 to 274 mg/L with a mean of 29.5 mg/L therefore, almost all wells have fulfilled the quality standard except well no. 4. While the NO_2^- concentration ranges from 0 to 6.88 mg/L with a mean of 1.57 mg/L, there are 23 wells which fulfilled the standard quality and 7 wells exceeding the set quality standard.



a b c d e f g h

Fig. 4 Correlation of chemical parameters. EC/Na^+(a); EC/Mg^{2+}(b); Mg^{2+}/Na^+ (c); Mg^{2+}/Cl^- (d); Na^+/Cl^- (e); Na^+/EC (f); Cl^-/TDS; Cl^-/TDS (g); TDS/EC (h)

Principal Component Analysis (PCA) is a multivariate statistical method that can explain the factors that influence the decline in groundwater quality. The initial stages in PCA are the Kaiser-Meyer-Olkin (KMO) test and Bartlett's test. The KMO values obtained from the KMO test and the Bartletts test are presented in Table 3. From Table 3, the significance value is 0 which means less than 0.05, this shows that there is a correlation between variables. The KMO and Bartlett's test values are more than 0.05 which is 0.55. This can be interpreted that factor analysis can be used to simplify 16 variables in analyzing groundwater quality. In PCA, even though the KMO value is more than 0.5, a few variables can be analyzed. Variables that can be analyzed are variables with a Measure of Sampling Adequacy (MSA) value of more than 0.5. MSA values of 16 variables are presented in Table 4. Based on Table 4, it can be seen that there are only 10 variables that have MSA values of more than 0.5, namely the variables EC, pH, $CaCO_3$, Mg^{2+}, Fe^{3+}, K^+, Na^+, Cl^-, NO_3^-, and TDS while for the variables Ca^{2+}, Mn^{2+}, NH_4^+, HCO_3^-, SO_4^{2-}, and NO_2^- have KMO values are less than 0.5. Thus, the six variables will be excluded from the matrix and retested. The second KMO test is presented in Table 5.

Table 5 shows that there is a correlation between variables because the significance is 0 which means less than 0.05 while the KMO value and Bartlett's test are 0.81 or more than 0.05. This can be interpreted that the principal component analysis can be used to simplify 10 variables in analyzing groundwater quality. The MSA values of 10 variables are presented in Table 6.

From Table 6 it is found that all MSA values of EC, pH, $CaCO_3$, Mg^{2+}, Fe^{3+}, K^+, Na^+, Cl^-, NO_3^-, and TDS are more than 0.5 so that the ten variables can be further analyzed. The relationships between variables are presented in Table 7. From Table 7, it can be derived that there are 8 very strong and positive correlation between EC and Mg^{2+}, EC and Na^+, EC and Cl^-, Mg^{2+} and Na^+, Mg^{2+} and Cl^-, Na^+ and Cl^-, Na^+ and TDS, Cl^- and TDS and a perfect correlation between TDS and EC. Correlation analysis is depicted in Figure 4. It shows a very strong correlation of Na^+/Cl^- with $R^2 = 0.94$.

Moreover, HCA is used to classify 10 parameters into 3 classes (Figure 5). The grouping of these 10 variables is clarified by the clusters analysis on the dendrogram as presented in Figure 5. There are 3 clusters namely cluster 1 consisting of variables EC, TDS, Na^+, Cl^-, $CaCO_3$, Mg^{2+} and K^+. Cluster 2 consists of the variables pH and NO_3^- while Cluster 3 consists of the variable Fe^{2+}.

Varimax rotated factor loadings presented in Table 8. Three factors with Eigen score have larger than 1 and rotation finished in six iterations. Figure 6 presents the scatter plot result based on the Eigen score of each component.

Factor 1 explains that 63.5% of total variant, pH, NO_3^- and Fe^{2+} concentration have a very low weight therefore insignificant on its contribution. EC, $CaCO_3$, Mg^{2+}, K^+, Na^+, Cl^- and TDS have a strong positive weight, showing a contamination source possibly from seawater intrusion. Figure 7 and figure 8 show Na^+ and Cl^- distribution maps, respectively. The area with the highest concentration of Na^+ and Cl^- lies in the northeast of the research area where industries utilize the water for its activities which leads to seawater intrusion.

Factor 2 explains that 13.5% from total variant with pH dan NO_3^- have a very strong positive weight, showing a contamination source possibly from household waste.

Factor 3 explains that 10.4% from total variant with Fe^{2+} having a large contribution which may be assumed that the contaminant source derives from lithology in the study area.

Table 3. KMO and *Bartlett's Test* Result 1

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.54
Bartlett's Test of Sphericity	*Approx. Chi-Square*	1.172
	df	120
	Sig.	0

Table 4. MSA Score of phase 1

No	Variable	MSA Value
1	EC	0.703
2	pH	0.751
3	$CaCO_3$	0.570
4	Ca^{2+}	0.409
5	Mg^{2+}	0.576
6	Fe^{3+}	0.567
7	Mn^{2+}	0.400
8	K^+	0.696
9	Na^+	0.629
10	NH_4^+	0.137
11	HCO_3^-	0.481
12	Cl^-	0.577
13	SO_4^{2-}	0.276
14	NO_2^-	0.275
15	NO_3^-	0.609
16	TDS	0.700

Table 5. KMO and Bartlett's Test Result 2

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.81
Bartlett's Test of Sphericity	Approx. Chi-Square	682
	df	45
	Sig.	0

Tabel.6. MSA Score Phase 2

No	Variable	MSA Value
1	EC	0.82
2	pH	0.63
3	$CaCO_3$	0.71
4	Mg^{2+}	0.86
5	Fe^{3+}	0.57
6	K^+	0.8
7	Na^+	0.81
8	Cl^-	0.91
9	NO_3^-	0.67
10	TDS	0.83

Table 7. Correlation coefficient matrix

Parameter	pH	$CaCO_3$	Mg^{2+}	Fe^{3+}	K^+	Na^+	Cl^-	NO_3^-	TDS
EC	0.41*	0.79**	0.87**	0.19	0.79**	0.99**	0.98**	-0.24	1**
pH		0.12	0.36*	0.05	0.33	0.46**	0.32	-0.53**	0.41*
$CaCO_3$			0.8**	0.22	0.6**	0.71**	0.77**	-0.15	0.79**
Mg^{2+}				0.34	0.67**	0.85**	0.87**	-0.18	0.87**
Fe^{3+}					0.06	0.18	0.23	-0.21	0.19
K^+						0.76**	0.74**	-0.18	0.79**
Na^+							0.97**	-0.25	0.99**
Cl^-								-0.18	0.98**
NO_3^-									-0.24

(*) Significant correlation at α =0.05

(**) Significant correlation at α =0.01

Table 8. Varimax Rotate Factor Loadings

	Factor 1	Factor 2	Factor 3
EC	0.97	0.2	0.05
pH	0.26	0.85	-0.12
$CaCO_3$	0.84	-0.06	0.21
Mg^{2+}	0.89	0.12	0.25
Fe^{3+}	0.13	0.08	0.96
K^+	0.82	0.17	-0.12
Na^+	0.94	0.25	0.02
Cl^-	0.96	0.11	0.1
NO_3^-	-0.06	0.86	-0.22
TDS	0.97	0.2	0.05
Eigen Value	6.35	1.35	1.04
% Variance	63.5	13.5	10.4
Cumulative % variance	63.5	77	87.4

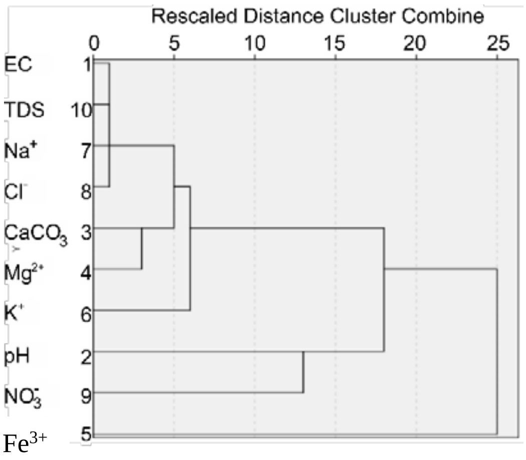


Fig. 5 Cluster analysis

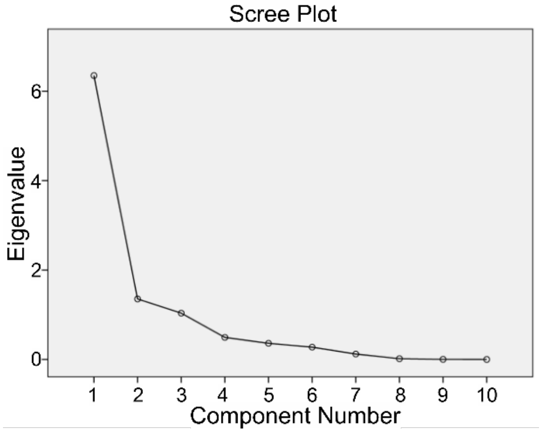


Fig. 6 Scatter plot

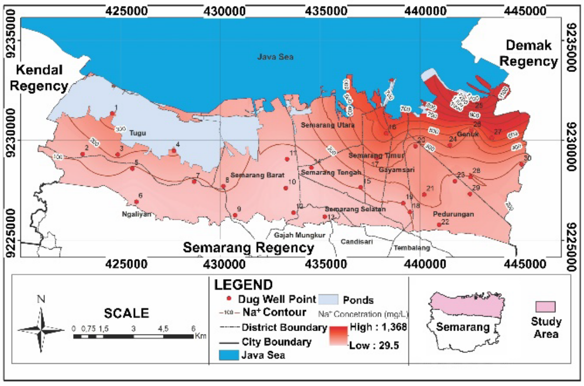


Fig. 7 Sodium distribution map

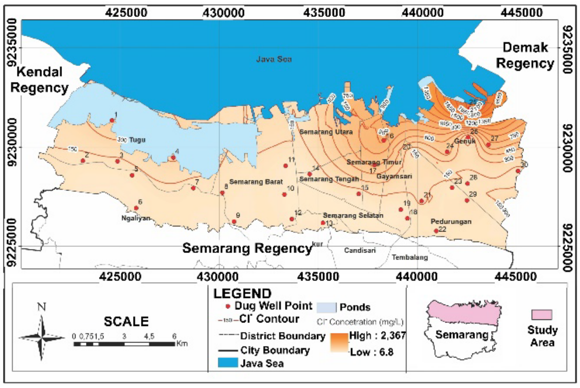


Fig. 8 Chloride concentration map

4. CONCLUSION

There are three (3) well samples secured to consume, i.e. well 5, well 12, and well 14. Samples from other wells showed concentrations of pH, Fe^{3+}, Cl^-, Mn^{2+}, SO_4^{2-}, and NO_2^-, in the water which exceeds the quality standards set by Minister of Health Regulation No 492/2010. There are 8 very strong positive relationships, one of them is Na^+ and Cl^-.

HCA and PCA showed 3 main factors. Factor 1 explained that 63.5% from total variant with EC, $CaCO_3$, Mg^{2+}, K^+, Na^+, Cl^- and TDS show a potential contamination source from seawater intrusion. Factor 2 explained that 13.5% from total variant with pH and NO_3^- show a potential contamination source from household waste. Factor 3 explained that 10.4% from total variant with Fe^{3+} is assumed to be contaminants from rocks around Semarang. The concentration of Na^+ and Cl^- have the highest concentration in the northeast of the study area which is as an industrial centre, further ensuring the inference that water contamination was due to seawater intrusion.

Evaluation of the microbiology distribution in groundwater needs to be implemented for details evaluation of groundwater quality in Semarang lowland area.

5. ACKNOWLEDGEMENT

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