

Changes in soil chemical composition due to the influence of seawater and its effect on geotechnical investigations

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Abstract. North coast area of Semarang affected by the effect of seawater intrusion due to excessive groundwater pumping and seawater level rise, which impacted to characteristics of sediment and even the environment. The interaction between seawater and sediment can accelerate the compressibility process in sediments of areas in Semarang, resulting in land subsidence, as mentioned in previous studies mentioned. This research aimed to observe the influence of seawater intrusion on physical and chemical of sediment's characteristics in north coastal area of Semarang. Sediment samples (obtained by drilling) and seawater samples are collected from 4 locations in Tambakharjo area, West Semarang. The sediment samples analyzed using XRD, whereas the seawater samples area tested using water chemistry test. The results of both tests are used to model the interaction between seawater and sediments, which is equilibrium modeling using Phreeqc 3.4. The modeling reveals the volume reduction in sediment, due to tendency of montmorillonite to release SiO₂ in seawater. The interaction between sediment and seawater shows a change in montmorillonite to illite under the same conditions. This research convey that chemical composition is important to be considered in geotechnical investigation, alongside the physical properties of the lithology in usual.

1 Introduction

Rapid population growth has led to an increasement in the demand of water. One of the cities with rapid population growth in Central Java is Semarang. The seawater intrusion has caused problem regarding the salinity of groundwater. Excessive groundwater extraction can cause reduction in fresh water and is filled by seawater which its density is greater than the density of fresh water so that seawater intrusion occurs and is mixed [1]. The extraction of groundwater that is not inappropriate with the regulation can cause negative impacts on the environmental issue. Until now, people still use groundwater, both shallow and deep groundwater to fulfill their daily needs. The number of drilled wells in Semarang area has increased by 45.01% every year [2]. Apart from the excessive groundwater extraction, seawater intrusion can also be caused by sea level rise [3, 4]. The condition of groundwater contaminated with seawater can be identified based on the value of chloride concentration

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(Cl). Some areas in Semarang that are contaminated with seawater, have a Cl concentration value that more than 250 mg/L [5]. Changing in characteristics of sediments are influenced by the interaction of seawater with sediments, especially changing in the mineral montmorillonite in clay [6]. The north coast area of Semarang is an alluvial plain consisted of clay, silt, and sand [7]. The consolidation process of sediments in Semarang occurs more quickly which results in land subsidence experiencing a volume reduction rate of 4.1-8 cm per year [8]. This condition is influenced by the high salinity in seawater which affects the changing in physical properties of pore numbers in sediment [9].

2 Literature Review

2.1 Geological Condition

The research area is located in the northern area of Semarang city which consisted of coastal plain deposits, lakes, and rivers, with litology clay, silt, sand and mixed deposits [10]. The distribution of clay tends to thicken to the north, while to the south it tends to have silt-clay-sand [11] and the sedimentation process which is repeated during its deposition [12]. The composition of the subsurface soil layer into 50 m depth consisting of clay, silt-clay, and siltsand is located in western part of Semarang. The presence of clay indicates the potential to swell and shrink in sediments because of clay minerals which have characteristics to swell and shrink [13]. The lithology was deposited from Late Pleistocene until the present due to the sedimentation process which is influenced by changes in sea level [14].

2.2 Overview of Clay Minerals

The clay grain size is ≤ 0.002 mm and has flat sheet shape consisted of clay minerals and very fine minerals [15,16]. The main clay minerals are montmorillonite, illite and kaolinite. The mineral structure of montmorillonite is similar to that is found in isomorphic substitution of magnesium and iron in octahedral aluminium sheets and does not have potassium ions in this mineral because water enters between these layers. When in seawater, SiO₂ compounds tend to be released from montmorillonite [17]. Potassium ions can also bond to montmorillonite and can alter montmorillonite into illite [18]. Illite minerals consist of two tetrahedral gibbsite chips and an octahedral silica chip bonded to each other by bonds between potassium ions/potassium present in each chip. Kaolinite is composed of one tetrahedral gibbsite chip and one octahedral silica chip.

Clay is dominating the northern coastal area of Semarang. The eastern coastal area of Semarang has clay with a high degree of expansiveness, dominated by montmorillonite. On the other hand, the western part tends to have a lower level of expansiveness, composed by kaolinite, illite, and, mixed layers between illite and montmorillonite [19].

2.3 Seawater Intrusion in Semarang Coast

Seawater intrusion has been going on for a long time in Semarang. This can be known based on the low resistivity value in coastal areas, which can be interpreted as containing saline water [20]. Salinity has increased from 1995 to 2008, and about 55% of groundwater on the coast of Semarang is saline water [21].

Excessive groundwater extraction and sea level rise are some of the causes of seawater intrusion. Sea level rise due to melting of glaciers and polar ice caps, causing the volume of water in the ocean to increase drastically. This phenomenon is very influential on cities located on the coast, one of which is the city of Semarang, this is indicated by the sea level

anomaly which shows an upward trend from 2009 to 2011 of 12.83 mm/year [22].

3 Methods

The methodology used in this research includes an XRD test of several sediment samples taken from 4 locations in Tambakharjo area. The purpose of this XRD test is to determine the presence of constituent minerals in the sediment. The seawater samples are chemically tested to determine the mineral composition in the water. The next step is modeling the interaction between seawater and sediment in the research area with the aim of knowing the effect of seawater on physical and chemical characteristics of the sediment. The modeling using software Phreeqc 3.4 of equilibrium modeling.

4 Result and Discussion

Conversion of the percentage of XRD mineral which are converted into moles is carried out on the sediment parameters to be modeled according to the equation (1).

$$M = W \cdot V \cdot \rho \cdot \text{GFW} \quad (1)$$

- M = total moles (mol)
- ρ = sediment density (g/cm³)
- W = mineral percentage (%)
- GFW = moles mass (g/mol)
- V = volume (cm³)

The results of the conversion of mineral percentages into molar form are shown in Table 1.

Table 1. Results of conversion of mineral percentage into moles.

Location	Kaolinite	Illite	Montmorillonite
BM1	4.1	0.3	0
BM3	1.8	1.9	0.04
BM4	2.2	0	0.05
BM5	2.9	0	0.22

4.1 Sediment Samples Modeling

The model shows that there is changing in the total volume of sediment obtained from the total volume of each mineral in some sediment samples, except for BM-01 that does not show any change in volume (Table 2).

Table 2. Modeling results on BM-01

Mineral Type	BM-01	
	Initial Volume (cm ³)	Final Volume (cm ³)
Kaolinite	405.60	405.60
Illite	44.70	44.70

Sample BM-03 shows a reduction in total volume of sediment where final volume in kaolinite is 176.78 cm³; illite is 281.37 cm³; and montmorillonite is 3.22 cm³. The model suggested the initial and final volumes of minerals in BM-03 sample as shown in Table 3.

Table 3. Modeling results on BM-03.

Mineral Type	BM-03	
	Initial Volume (cm ³)	Final Volume (cm ³)
Kaolinite	177.10	176.78
Illite	278.60	281.37
Montmorillonite	7.80	3.22

Sample BM-04 shows a reduction in total sediment volume. The final volume for kaolinite is 218.69 cm³ and montmorillonite is 6.28 cm³. Additional volume of 2.86 cm³ illite is formed. The model recapitulation of the initial and final volumes of minerals in BM-04 sample are shown in Table 4.

Table 4. Modeling results on BM-04

Mineral Type	BM-04	
	Initial Volume (cm ³)	Final Volume (cm ³)
Kaolinite	219.00	218.69
Illite	0.00	2.86
Montmorillonite	11.00	6.28

Sample BM-05 shows a reduction in sediment volume with final volume in kaolinite is 300.54 cm³ and montmorillonite is 43.75 cm³. In this sample, 2.94 cm³ of illite mineral is formed. The initial and final volumes of minerals in BM-05 sample are shown in Table 5.

Table 5. Modeling results on BM-05

Mineral Type	BM-05	
	Initial Volume (cm ³)	Final Volume (cm ³)
Kaolinite	300.90	300.54
Illite	0.00	2.94
Montmorillonite	48.60	43.75

Excessive groundwater extraction and sea level rise are the causes of seawater intrusion in Semarang area. Seawater breaking through the aquifer causes seawater to contact the lithology/ sediment of aquifer. As a result of the interaction between seawater and sediment, it causes the changes in characteristics of sediment.

Equilibrium modeling that has been carried out on the interaction between seawater and sediment shows a reduction in sediment volume in several samples such as BM-03, BM-04, and BM-05. This is due to the presence of the mineral montmorillonite in samples BM-03, BM-04, and BM-05. While in BM-01 sample does not contain montmorillonite causing BM-01 to not decrease in volume when interacting with seawater. Montmorillonite tends to more easily release SiO₂ when in seawater [17].

In samples BM-03, BM-04, and BM-05, apart from showing a reduction in volume of montmorillonite, it also shows the addition of illite minerals as shown in Table 3 to Table 6. This process is caused by the addition or the bonding of potassium ions into montmorillonite mineral which can form illite minerals [18]. The potassium reduction in seawater that interacts with samples BM-03, BM-04, and BM-06 is most likely because of the bonding reaction to the montmorillonite and altered the montmorillonite to become illite.

5 Conclusion

According to the interaction between seawater and sediment modeling, changes are identified from sample BM-03, BM-04, and BM-05. The three samples show a reduction in volume after the contact with seawater, which is coincided with the reduction of the montmorillonite contained in three samples. The reduction happened due to the montmorillonite characteristics which is easier to release SiO₂ compounds when in seawater. In addition, the interaction between sediment and seawater also causes montmorillonite to change into illite. The presence of potassium ions in seawater bonded to the montmorillonite causes the mineral to alter into illite. The modeling results indicate that the presence of seawater can cause changes in physical and chemical characteristic of sediments, especially in sediments containing montmorillonite. Geotechnical investigations usually only look at the physical properties of the lithology. This research shows that chemical composition is important to know in geotechnical investigation.

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