# Influence of Rock's Chemical Composition to Groundwater Quality in Jakarta Basin

*By* Listiyani Retno Astuti

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## Abstract

*The quality of groundwater in the region in general is influenced by the local geological conditions, for example in terms of the type of rock. The study of the quality of groundwater in Jakarta Groundwater Basin has been done to see how far the relationship between chemical characteristic of the rocks and the quality of groundwater. The existence of a wide variety of rock and groundwater quality in the study area prompted the author to determine the correlation or the influence of rock to groundwater, particularly in the chemical aspect. The analysis was conducted based on some field and laboratory data and supported by secondary data such as geological and hydrogeology data. Sampling of rocks and groundwater in the field were taken from Babakan and Sunter drilled wells, and then performed the chemical constituents of rocks and groundwater testing. The results showed that the quality of groundwater in the study area is quite influenced by the chemical content of rocks at studied area. The content of the studied groundwater is dominated by the major cations* $Na^+$ *and* $Ca^{2+}$*, as well as the major anion* $HCO_3^-$ *and* $Cl^-$*, while rocks showed the dominant element of* $Fe^{3+}$ *(4,460-107,000 ppm) and* $CO_3^{2-}$ *(0.14 to 2.22)%. Difference of dominant composition in rocks and groundwater is highly influenced by the ease of minerals to dissolve in certain geological conditions. The content of cations and anions in the groundwater under study supplied by the result of rock minerals weathering that are interpreted primarily derived from the weathering of silicate minerals. Thus, sedimentary rocks that consist of the studied basin usually have a role in determining groundwater quality, and supported by geological and hydrogeological conditions as well as mineral stability factor. However, correlation between chemical composition in rocks and groundwater is not clearly significant.*

***Key words: groundwater, quality, chemical composition.***

## I. Introduction

The research area is Jakarta Groundwater Basin which is a Quaternary groundwater basin. This area is spread from Jakarta and surrounding areas to Bogor in the south, in the northwestern part of Java Island, Indonesia (Figure 1). The groundwater basin has various lithology, with varying chemical characteristics of rocks.

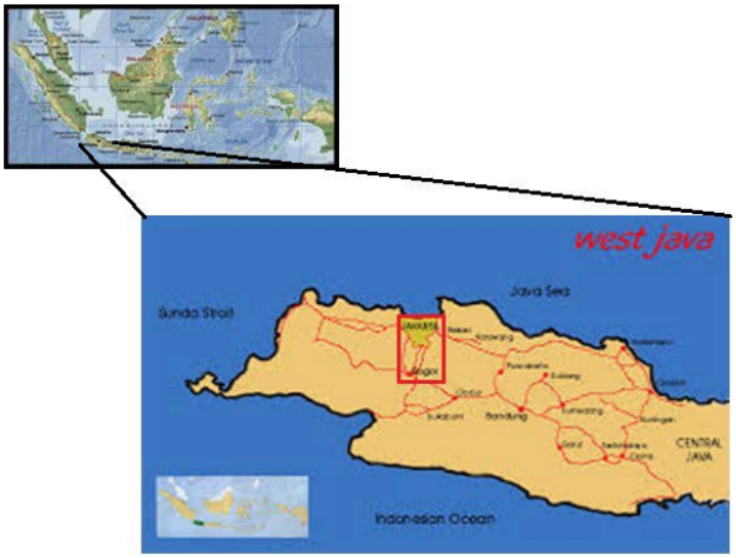

*Figure 1. Research area indicated by red rectangle.*

This paper is going to review the chemical composition of rocks relationship to the chemical composition of groundwater in the basin. The chemical compositions of rocks are usually highly dependent on the mineral composition of the rocks in the basin, both as aquifer or aquiclude. The quality of groundwater is generally varied in the different rock. The rock has a diverse mineral composition, but not all of the chemical composition can be dissolved in the groundwater.

Listyani (2016) stated that the content of cations and anions in the groundwater in the basin under study is affected by mineral composition of rocks composing. Elements that are easily dissolved in groundwater will dominate the composition of groundwater. The number of Ca, Na and silica elements in groundwater are affected by the weathering of silicate minerals eg feldspar / albite and anortite plagioclase form and clay minerals, both derived from Na-montmorillonite and Ca-montmorillonite. The number of elements dissolved in the groundwater is also controlled by geological and hydrogeological conditions of local area. Mineralogy composition affects the quality of groundwater, but the chemical composition of rocks also needs to be assessed in relation to the groundwater quality.

Relationship between hydrochemistry and geochemistry of rock in its path at Ungaran geothermal area has been examined by Budiadi & Listyani (2008). The results of research showed a fairly good correlation between the chemical content of groundwater from springs with rock geochemistry. This means that the chemical content of the water is strongly supported by the presence of rock's minerals in geothermal prospect area. Referring to the study, research on rock geochemistry and groundwater developed in Jakarta in this study. It needs to assess the extent of the chemical composition of rocks factor affecting groundwater chemistry in the studied area, in order to interpret the solubility of minerals that contribute to the quality of groundwater in the area.

## II. Method

The study was conducted at several places in Jakarta Groundwater Basin, especially around the exploration wells. The field survey as well as groundwater and rock chemistry laboratory testing performed on the same period, i.e. in 1997. The field geological survey done to see hydrogeological condition of the study area, equipped with rock and groundwater sampling. Laboratory testing conducted to determine the chemical content of groundwater. Two groundwater samples taken at Babakan well in the southern part of the basin, representing groundwater in the shallow and deep aquifer; whereas the three groundwater samples taken from Sunter well in the northern part of basin, each representing a shallow, intermediate and deep aquifer zones. The primary data in the form of groundwater samples were conformable with regional groundwater flow which generally runs from south to north so that samples from Babakan well expected to show initial process, while samples from groundwater Sunter well represent the end of the groundwater traverse. Secondary data such as geochemistry of rocks used in the analysis were taken from coring of Babakan and Sunter wells.

## III. Geological Setting

The research area is the Quaternary groundwater basin which is included in the Coastal Plain physiographic region of Jakarta, Bogor and Volcano Quaternary Anticlinorium according to Van Bemmelen (1949). This groundwater basin is consisted by rock which has a thickness of up to 250 m and deposited in a marine, delta and fluvial environments (Maathuis et al., 1996).

Mining Agency (Disbang) Jakarta and the Institute of Community Service (LPM) - ITB (1997a) developed Jakarta Groundwater Basin stratigraphy based on a compilation of the Jakarta Sheet Geological Map (Turkandi *et al*, 1992). Rock's constituent of aquifer are generally Quaternary sediments such as debris of young volcanoes, fluvial and beach sediments, overlay unconformable on Tertiary rocks (Figure 2). The Tertiary rocks that restrict Jakarta Groundwater Basin are outcropped at the west – southwest area, namely Serpong, Bojongmanik Formations and basalt intrusion; at the southern part around Bogor found Klapanunggal Formation; while at the southeastern region found outcrops of Serpong, Jatiluhur and Klapanunggal Formations.

Quaternary sediment boundaries in Jakarta Groundwater Basin in three dimensions haven't been clear yet. Data from Disbang Jakarta and LPM-ITB (1997b) indicate the presence of Tertiary rocks at a depth of 69.5 in Babakan Pond. Based on geological map and wellbore data seen lower limit of Quaternary sediment is uneven making a block of horse and graben of Bogor until Depok which deeper in the direction of the north-northeast (Disbang Jakarta and LPM-ITB, 1997b).

The division of the aquifer system in Jakarta Groundwater Basin used in this study refers to Soekardi (1982, in Soekardi, 1986) as follows.

1. Group of unconfined aquifer (Aquifer I) at a depth of 0-40 m.
2. Group of upper confined aquifer (Aquifer II) at a depth of 40-140 m.
3. Group of middle confined aquifer (Aquifer III) at a depth of 140-250 m.

The division was done based on their aquifer marine facies clay layers that separate the third of the aquifer system.

## IV. Basic Theory

During its path from local recharge to discharge area, the chemical element of groundwater change due to various geochemical processes (Freeze and Cherry, 1979). Groundwater chemistry has the evolution as long as its travel time. Hydrochemistry evolution results change of groundwater quality due to change of its chemical compositions. Changes in groundwater quality are not only caused by processes that occur during the groundwater evolution, but also because of the aspect of the chemical elements availability in rocks in its path.

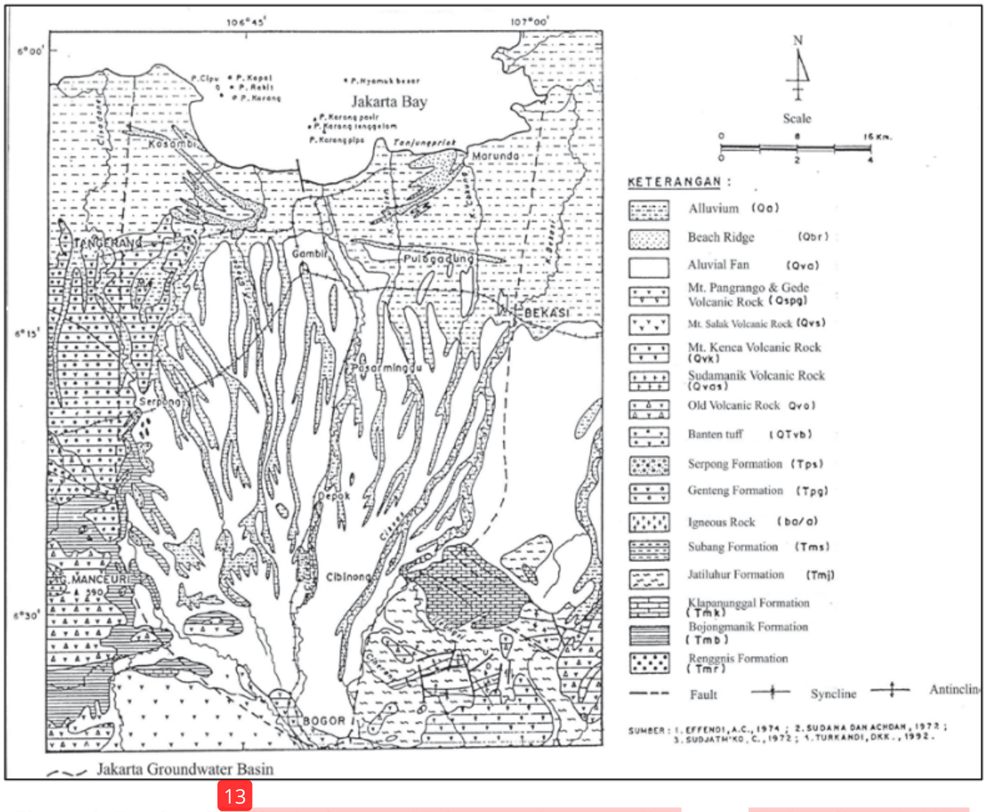

Figure 2. Regional geological map of Jakarta and surrounding area (Turkandi *et al*, 1992).

Groundwater quality is affected by the rock material in its path. The quality of groundwater reflected in its chemical properties is highly dependent on mineral availability and mineral solubility (Davis and De Wiest, 1966). The researchers also reveal relationship between constituent ions of groundwater with rock minerals. Ease of dissolved minerals in rocks is often supported by the weathering process. The more weathered rock the easier ions loose from rocks and dissolved in the groundwater. Geochemical composition of terrigenous sedimentary rocks have been used extensively to perform interpretation of weathering conditions (Qiu *et al*, 2014 vide Armstrong -Altrin *et al*, 2016). This rock weathering conditions will affect the level of solubility of ions, in addition to environmental factors along groundwater flow. This is supported by Ako *et al* (2012) which explained that $CO_2$-driven silicate weathering and reverse cation exchange are the most important processes affecting the hydrochemistry of the spring waters.

## V. Result and Discussion

### 5.1. Chemical Composition of Groundwater and Rocks

Groundwater in the Babakan drilled well has a composition as fresh groundwater, represents the initial phase of groundwater flow in recharge area, while groundwater in

Sunter was in advanced phases or near the discharge area. Groundwater chemistry data were tested at the Directorate of Environmental Geology, Bandung to determine the content of major chemical elements (Table 1). The groundwater is dominated by the major cations $Na^+$ and $Ca^{2+}$, as well as the major anion $HCO_3^-$ and $Cl^-$, while rocks showed the dominant element of $Fe^{3+}$ (4,460-107,000 ppm) and $CO_3^{2-}$ (0.14 to 2.22)%. Moreover, the chemistry data of studied rocks presented in Table 2-3.

Table 1. Hydrochemical data.

| Element (mg/l) | | Babakan Well | | Sunter Well | | |
|---|---|---|---|---|---|---|
| | | Aquifer I | Aquifer II | Aquifer I | Aquifer II | Aquifer III |
| Cation | $Ca^{2+}$ | 20.3 | 24.8 | 950.8 | 248.4 | 191.2 |
| | $Mg^{2+}$ | 8.5 | 5.9 | 544.3 | 120.5 | 73.8 |
| | $Fe^{3+}$ | 0.0 | 0.0 | 0.25 | 1.58 | 0.78 |
| | $Mn^{2+}$ | 0.0 | 0.0 | 9.3 | 1.65 | 1.08 |
| | $K^+$ | 2.5 | 6.5 | 59.0 | 26.0 | 18.0 |
| | $Na^+$ | 20.0 | 47.0 | 4490.0 | 1346.0 | 942.0 |
| Anion | $CO_3^{2-}$ | 7.8 | 10.2 | 0.0 | 0.0 | 42.3 |
| | $HCO_3^-$ | 121.4 | 183.0 | 790.5 | 560.6 | 443.4 |
| | $Cl^-$ | 7.6 | 6.4 | 9255.0 | 2276.4 | 1590.6 |
| | $SO_4^{2-}$ | 3.3 | 6.8 | 330.8 | 183.0 | 148.0 |
| | $NO_2^-$ | 0.0 | 0.01 | 0.4 | 0.3 | 0.2 |
| | $NO_3^-$ | 1.5 | 1.1 | 2.8 | 1.6 | 1.2 |
| pH | | 8.58 | 8.32 | 7.52 | 7.88 | 8.12 |

Tabel 2. Chemical rock constituents of Babakan well (Disbang DKI Jakarta dan LPM-ITB, 1997b).

| Element | | Sunter Well | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1A | 1B | 2A | 2B | 3A | 3B |
| Cation (ppm) | $Ca^{2+}$ | 3,750 | 790 | 2,860 | 1,460 | 2,950 | 3,150 |
| | $Mg^{2+}$ | 27,500 | 20,960 | 21,940 | 13,840 | 19,860 | 25,640 |
| | $Fe^{3+}$ | 51,130 | 51,070 | 48,580 | 45,180 | 4,460 | 48,760 |
| | $Mn^{2+}$ | 1,221 | 914 | 1,011 | 614 | 1,049 | 1,187 |
| | $K^+$ | 7,080 | 11,230 | 10,460 | 10,480 | 11,000 | 11,070 |
| | $Na^+$ | 11,160 | 6,840 | 11,900 | 14,260 | 10,860 | 11,260 |
| Anion (%) | $CO_3^{2-}$ | 1.6 | 0.78 | 0.14 | 0.36 | 2.22 | 1.68 |
| | $HCO_3^-$ | 0.11 | 0.11 | 0.14 | 0.14 | 0.14 | 0.11 |
| | $Cl^-$ | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 | 0.02 |
| | $SO_4^{2-}$ | 0.35 | 0.25 | 0.23 | 0.04 | 0.14 | 0.18 |

The chemical composition of groundwater could be affected by the chemical composition of the rocks that compose the groundwater basin. How far is the chemical composition of rocks affect the quality of groundwater can be understood through Figure 3-4 below.

Tabel 3. Chemical rock constituents of Sunter well (Disbang DKI Jakarta dan LPM-ITB, 1997b).

| Element | | Sunter Well | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1A | 1B | 2A | 2B | 3A | 3B |
| Cation (ppm) | $Ca^{2+}$ | 3,750 | 790 | 2,860 | 1,460 | 2,950 | 3,150 |
| | $Mg^{2+}$ | 27,500 | 20,960 | 21,940 | 13,840 | 19,860 | 25,640 |
| | $Fe^{3+}$ | 51,130 | 51,070 | 48,580 | 45,180 | 4,460 | 48,760 |
| | $Mn^{2+}$ | 1,221 | 914 | 1,011 | 614 | 1,049 | 1,187 |
| | $K^{+}$ | 7,080 | 11,230 | 10,460 | 10,480 | 11,000 | 11,070 |
| | $Na^{+}$ | 11,160 | 6,840 | 11,900 | 14,260 | 10,860 | 11,260 |
| Anion (%) | $CO_3^{2-}$ | 1.6 | 0.78 | 0.14 | 0.36 | 2.22 | 1.68 |
| | $HCO_3^{-}$ | 0.11 | 0.11 | 0.14 | 0.14 | 0.14 | 0.11 |
| | $Cl^{-}$ | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 | 0.02 |
| | $SO_4^{2-}$ | 0.35 | 0.25 | 0.23 | 0.04 | 0.14 | 0.18 |

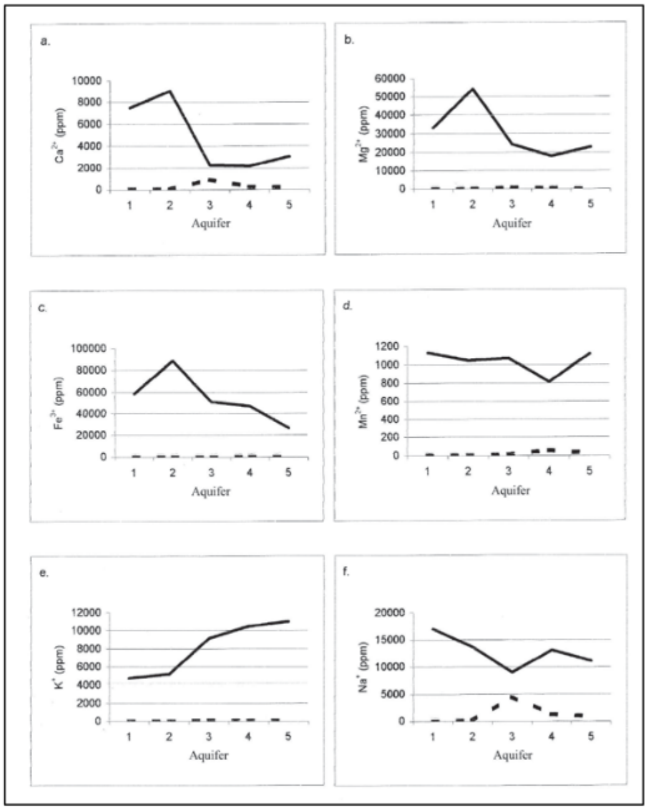

Figure 3. Cations content of groundwater and rocks.

——— Cations of rocks.

– – – Cations of groundwater.

Aquifer 1: Aquifer Zone I Babakan Well
Aquifer 2: Aquifer Zone I Babakan Well
Aquifer 3: Aquifer Zone I Sunter Well
Aquifer 4: Aquifer Zone II Sunter Well
Aquifer 5: Aquifer Zone III Sunter Well

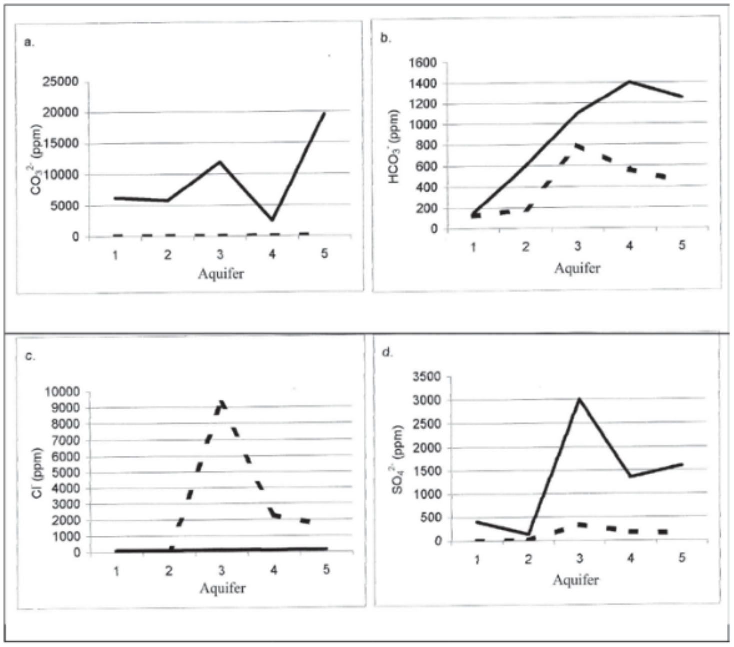

Figure 4. Anion content of groundwater and rocks.

——— Anion of rocks.

‒ ‒ ‒ Anion of groundwater.

### 5.2. Cation Characteristics

Rocks affect the chemical composition of the groundwater, as evidenced by the similarity of cations that are present in rocks and groundwater. However, the shape of the cations content graph in rock samples and groundwater is not too significant, meaning that the composition of cations in groundwater are not fully influenced by the content of these elements in the rock. Some of the trends that seem to decline in groundwater is not followed by a declining trend in rocks, on the contrary, there is a decrease in cations content in rocks followed by a rise in cations content of groundwater. This suggests that the cation composition of groundwater is not fully influenced by the amount of cations of rocks.

Figure 3 shows that all samples of rocks have cations content greater than that of the groundwater, especially phenomena that occur in iron ($Fe^{3+}$) element. This shows that the dissolution process occurs slowly in a quite long geological time. In fact, some groundwater samples show iron element content of 0 ppm. This fact can be explained by looking at Figure 5 below.

Figure 5 shows that the abundance of the iron element in the aquifers studied did not affect the chemical content of groundwater. This can occur due to groundwater chemistry environmental conditions (eH, pH and carbonate activity) does not permit the dissolution of iron.

Furthermore, Matthess (1982) explained the absence or less amount of iron element dissolved in the groundwater below.

- Ion $Fe^{3+}$ usually precipitates at pH above 3.
- $Fe^{3+}$ ions start to precipitate at pH 5.1 as hydroxide ions but not entirely precipitated even in neutral solution (pH 7).

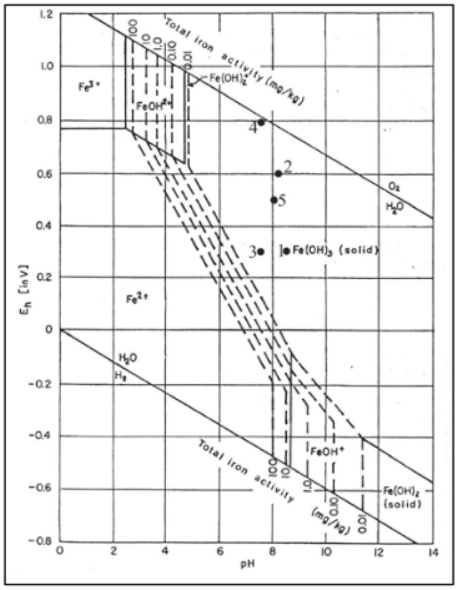

Figure 5. Plot some groundwater samples on the iron element stability diagram.

From the explanation above it appears that the rocks are not fully accounted for the chemical composition of groundwater. This may occur because not every element existing in the rock dissolves readily in groundwater. Besides the mineral stability factor, dissolution of minerals in groundwater rock heavily influenced by the physical and chemical environmental factors in groundwater such as temperature, air pressure and is indicated by the physical / chemical properties of groundwater such as pH, eH and degree of saturation elements in the groundwater itself.

Some reason that lead to a less significant correlation of the relationship between rocks and groundwater, i.e.:

1. Weathering conditions of sedimentary rocks consist the groundwater basin do not fully support the release of ions into the groundwater.
2. Less obvious correlations may occur because confounded by other factors, such as the occurrence of some hydrochemical processes which quite dominant in the groundwater basin.
3. The composition of groundwater is not solely influenced by the chemical content of rocks, but also for their hydrochemical evolution along the groundwater flow. According to Freeze and Cherry (1979) main cations variations in groundwater system is generally quite large because of cations exchange so the cations generalization likes Chebotarev anion sequence is rarely used. Matthess (1982) suggests the geochemical zonation based on cations evolution of the following: $Ca^{2+} \rightarrow Ca^{2+} + Mg^{2+} \rightarrow Na^{+}$. In groundwater flow, $Mg^{2+}$ ions tend to increase relative to $Ca^{2+}$. In the recharge area, groundwater tends to be saturated with $Ca(HCO_3)_2$. Furthermore, $Mg^{2+}$ will increase due to exchange of $Mg^{2+}$ - $Ca^{2+}$. Finally, the concentration of $Na^{+}$ ions will emerge as the dominant ion such as geochemical zonation above.
4. The wide variation of aquifer rock samples in Babakan and Sunter were not much different 18 it was difficult to detect differences of rock influence in both places.
5. Differences in the composition of the groundwater in two places are more influenced by other factors than r25ks, for example because of the chemical evolution of groundwater or seawater intrusion in the northern part of the study area.

## 1.3. Anion Characteristic

Similar with groundwater cation characteristics then from the four kinds of major anion content of groundwater as shown in Figure 4 appears that the correlation of rock to groundwater is generally less clear, except in Figure 4b where the increase in the content of the anion $HCO_3^-$ in several rock samples followed by increasing of this ion content in groundwater. The other difference is not all rock anion content always exceeds in number compared to that of the groundwater. This phenomenon is seen in Figure 4c where the Cl ion is very much higher in the groundwater than the amount in the rock (the example in the aquifer zone I at Sunter well). This is possible because of the influence of sea water intrusion that occurred in the zone, rather than hydrochemical evolution process. This is confirmed by Listyani (1999), which revealed the presence of the intrusion at shallow aquifer zone in the Sunter area. However, the hydrochemistry evolution process also greatly affects the chemical composition of groundwater in the study area.

Based on hydrochemical evolution anion expressed Chebotarev (1955, vide Freeze and Cherry, 1979), the longer the groundwater salinity will increase, therefore, saline groundwater can occur because of hydrochemical evolution. Chemical evolution of groundwater causes major anion content changes during the journey. Groundwater tends to evolve along groundwater flow toward the sea water composition. This evolution is followed by regional changes of the dominant anions as follows: $HCO_3^- \rightarrow HCO_3^- + SO_4^{2-} \rightarrow SO_4^{2-} + HCO_3^- \rightarrow SO_4^{2-} + Cl^- \rightarrow Cl^- + SO_4^{2-} \rightarrow Cl^-$. The anion evolution also marked with age increasing.

Although the hydrochemical evolution process is quite dominant in the study area, the availability of anions in rock certainly play a role in contributing to the chemical composition of groundwater. This was evidenced by the presence of these ions in the rock and groundwater.

$HCO_3^-$ ions present in considerable numbers in some instances groundwater from Babakan and Sunter. $HCO_3^-$ ion domination compared with $CO_3^{2-}$ in groundwater can be described in Figure 6 below.

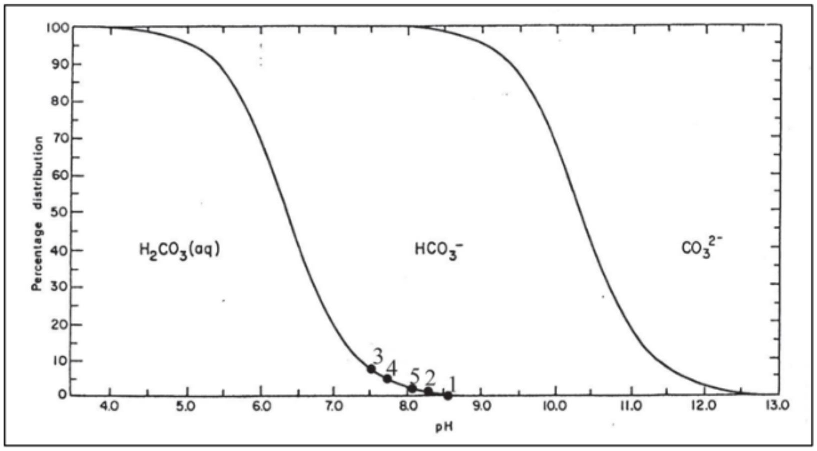

Figure 6. Plot some groundwater samples in the dissolved carbonate percentage diagram as a function of pH at standard temperature and pressure (Matthess, 1982).

The chemical analysis of groundwater as shown in Figure 6 shows that the content of $CO_3^{2-}$ very little due to dissolved carbonate is a function of pH, temperature and pressure. The conditions allowing the carbonate ion may be dissolved in the groundwater are bicarbonate ion ($HCO_3^-$). This ion is more dominant than $CO_3^{2-}$ ion as the pH of groundwater ranged from 7.52 to 8.58.

Sedimentary rocks of the basin certainly affect the quality of groundwater, especially driven by mineral solubility factors. This solubility level will also be influenced by the weathering of rocks. However, in general, the correlation of cations and anions in the composition of rocks against the groundwater is not clearly visible. The increase in the chemical content in rocks is not always followed by a rise in the amount of groundwater. This indicates that the chemical composition of groundwater is not the dominant factor affecting the quality of groundwater in the study area.

## VI. Conclusion

Jakarta Groundwater Basin is a Quaternary basin composed of marine, volcanic, coastal and fluvial sedimentary rocks. Some of the elements in these rocks have influence on the quality of groundwater in this basin. The content of groundwater is dominated by the major cations $Na^+$ and $Ca^{2+}$, as well as the major anion $HCO_3^-$ and $Cl^-$, while rocks showed the dominant element of $Fe^{3+}$ and $CO_3^{2-}$. However, the content of cations and anions in the groundwater are sometimes less clear correlated with the chemical content of rocks. This may occur because of the solubility of elements of different rock minerals, and depending on weathering conditions. Elements that are easily dissolved in groundwater will dominate the composition of groundwater. Furthermore, poor correlation between the chemical content of rocks and groundwater show that many factors affect the quality of the groundwater.

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