Ratio of Major Ions in Groundwater to Determine Saltwater Intrusion in Coastal Areas

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Abstract. Saltwater or seawater intrusion into groundwater aquifers occurs mostly in big cities and developing coastal cities. Coastal hydrology is associated with complex and highly dynamic environmental characteristics of interactions between groundwater, surface water, and water from the estuary. The rise of sea levels and excessive use of groundwater for clean water source trigger saltwater intrusion. Identification of saltwater intrusion into groundwater can be done by groundwater sampling and major ion analysis. The major ions dissolved in water are Ca, Mg, Na, K, Cl, HCO$_3$, and SO$_4$; the major ion ratios are Cl/Br, Ca/Mg, Ca/(HCO$_3$ and SO$_4$), and Na/Cl. By knowing whether groundwater quality has been or has not been influenced by saltwater, groundwater zones can be determined in every coastal area. In addition, by analyzing and reviewing some concepts about the intrusion or contamination of saltwater into groundwater, there will be sufficient results for the identification of saltwater intrusion.

1. Introduction

Coastal areas are the areas of transition between terrestrial and marine ecosystems that are affected by changes in land and sea [1]. Significant global phenomena have created groundwater salinization, which in many cases is caused by highly uncontrolled groundwater utilization, so that seawater enters groundwater aquifers, and is also possibly caused by a sea level rise that triggers tidal flooding [2]. In coastal areas, groundwater aquifers will be in direct contact with the sea and there is some kind of interface between the freshwater and saltwater [3]. The interface will also move towards the aquifers in land. If the water moves inland, the saltwater will fill the void [4]. In that position, the transition or mixing between saltwater with freshwater occurs, or what is alternatively called a diffusion process. The condition is known as the intrusion of saltwater, where saltwater moves into aquatic aquifers. The movement is caused by the excessive collection or pumping of water that exceeds the amount of recharge, resulting in an imbalance.

Cities located in coastal areas are generally built with rocks mainly composed of quaternary sedimentary deposits from the sea and loose fluvial deposits. Uncontrolled groundwater pumping will also cause a decrease in the groundwater level which can lead to land subsidence in quite large areas [5–7]. Consequently, seawater enters the land during the tide, especially if the lowering land surface is below the sea level. The tide triggers an intrusion into the unconfined groundwater [8–11], so the characteristics of the groundwater will change.

The hydrology of coastal areas is related to the complex and highly dynamic environmental characteristics of the interactions between groundwater, surface water and water coming from the estuary [12]. Water quality can be determined based on its concentration of major ions because naturally the chemical composition of water changes, so that the concentration of major ions in water can help identify whether the water has been polluted with saltwater or not [3,13,14].
The ratio of the major ions in water is highly affected by the interaction between freshwater and saltwater (oxidation-reduction, ion exchange) [15,16]. In groundwater that has not been affected by saltwater, the dominant ions are CO\textsubscript{3} and HCO\textsubscript{3}, whereas in groundwater affected by saltwater or containing dissolved mineral salts in aquifer rocks, the composition will change [17]. The groundwater in coastal areas has a high content of Cl, because sea water contains 19,000 mg/L of chloride [4,18,19]. Similarly, sea water has a high content of Na (around 10 mg/L) because the constant contact causes the release of cation to replace Ca, so that the water type changes into that of a Na-HCO\textsubscript{3} type [20]. By conducting an analysis of the environmental conditions, the ratio of major ions in water can be found and hence, it can also be identified whether seawater intrusion has occurred or not.

2. The Ratio of Major Ion
To determine sea water intrusion, the whole indicators should be considered, such as the high content of chloride in groundwater which indicates the occurrence of sea water intrusion [13] and quantitative as well as graphic calculations should be done. The basis of this approach is that chemical contents of sea water are different from one location to another; however, according to [21] there are at least 11 types of ions contained in sea water (in gram per kilogram of seawater), namely Chloride/Cl (19.135), Sodium/N (10.76), Sulfate/SO\textsubscript{4} (2.712), Magnesium/Mg (1.294), Calcium/Ca (0.413), Potassium/K (0.387), Bicarbonate/HCO\textsubscript{3} (0.142), Bromide/Br (0.067), Strontium/Sr (0.008), Boron/B (0.004) and Fluoride/F (0.001).

Electrical conductivity (EC) is the basic indicator to determine whether an aquifer is contaminated by seawater or not. If EC is under 1000 µS/cm, the groundwater is in a normal condition [22], but in determining the normality of groundwater, observation should be done comprehensively. The EC of seawater is more or less 51,000. The rate of EC is closely linked to the total dissolved solids (TDS) value, which can be estimated by multiplying EC by 0.55-0.75 [18]. One of the single parameters for the major ion content of Cl can be used as an indication that seawater intrusion or pollution has occurred [23]. Bear (1999) stated that the high content of Cl is an indication that intrusion of seawater or connate water has taken place. The amount of Cl in groundwater can be used as a basis to classify its type [24], whether the groundwater is pure freshwater or water with high salt content.

The ratio of Chloride and Bromide can be used as a tracker to see the condition of groundwater. Some processes can be observed from the ratio of Cl/Br [25]. The ratio of Cl/Br in sea water is around 297 and the ratio of < 297 indicates hypersaline brine, >1000 indicates evaporate-dissolution, and one derived from anthropogenic sewage or the effect of agriculture is < 800.

Some research explained that when calculating the Na/Cl ratio, if the result is smaller than 0.86, it means that the groundwater has been contaminated by seawater; meanwhile, if the ratio is >1, it means the groundwater is contaminated by anthropogenic source. The ratio of Ca/Mg and Ca/(HCO\textsubscript{3} and SO\textsubscript{4}) can also be used as an indicator, where if it is >1, it means that sea water intrusion is taking place [26–28]. The enrichment of Ca as the principal ion can also be used as an indicator of seawater intrusion into groundwater [12,26,27] and if the ratio of Ca/Mg is greater than 1, it indicates that seawater intrusion is taking place.

[28] explained the Simpson Ratio, namely Cl\textsubscript{-} / (HCO\textsubscript{3} + CO\textsubscript{3}). The ratio is divided into five classes: first is good quality (< 0.5); second, is slightly contaminated (0.5 – 1.3); third, moderately contaminated (1.3 – 2.8); fourth, highly contaminated (2.8 – 6.6); and fifth, extremely contaminated (6.6 – 15.5).

The hydrochemical indicator of shallow groundwater in coastal areas can also be seen based on the relationship between Na - Cl and (HCO\textsubscript{3} + SO\textsubscript{4}) - (Ca + Mg) that should indicate a ratio of 1:1, but the two variables should result in r = 0.87. The value of r indicates a quite close link between the two variables. The value clarifies that there has been an excess of Na and a deficiency of Ca and Mg, so that the groundwater enables the process of ion exchange for the types of Na/Ca and Na/Mg [27].

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