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Survey Article

Saline Water Intrusion: Its Management and Control

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Abstract. This paper brings to the fore techniques for proper management of saline water intrusion in coastal region because of the hardship its negligence bring upon the public that rely on it for livelihood. Groundwater remains the main source of quality and adequate water supply in the world over from which we get water for domestic, agricultural and industrial usage. One of the factors affecting the quality of water from this source is saline water intrusion, especially in coastal aquifers. This problem affects the potability of the water and the population that depends on it. Therefore, due to the aforementioned problem, measures must be put in place in order to adequately manage and control saline water intrusion so as to protect the dependent population from untold hardship that may result in near future.

Keywords. Saltwater intrusion; Potability of water; Techniques for control; Management of groundwater; Recharge rate

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1. Introduction

Saline water or saltwater intrusion is the movement of saline water into fresh water aquifers (Werner and Simmons [22]). This problem is common with coastal aquifers all around the world

(Oladapo *et al.* [17]; Priyanka and Mahesha [18]). Certain factors have been identified as the causes of this intrusion, among these are excess groundwater pumping from coastal aquifers than the rate of recharge. Secondly, it has been identified that saline water intrusion can also result from the density difference between the more dense saline water in the sea and the less dense fresh water in the aquifer (Robinson *et al.* [20]).

It occurs where groundwater is being pumped from aquifers that are in hydraulic connection with the sea, the induced gradients may cause the migration of salt water from the sea towards a well, making the freshwater well unusable (Lanbo [15]). Fresh water floats on top because it is less dense than salt water (Figure 1) although, the boundary between saltwater and fresh water is not distinct. Basically, groundwater flows from areas with higher groundwater levels (hydraulic head) to areas with lower groundwater levels. This natural movement of fresh water towards the sea prevents salt water from entering freshwater coastal aquifers (Barlow [3]).

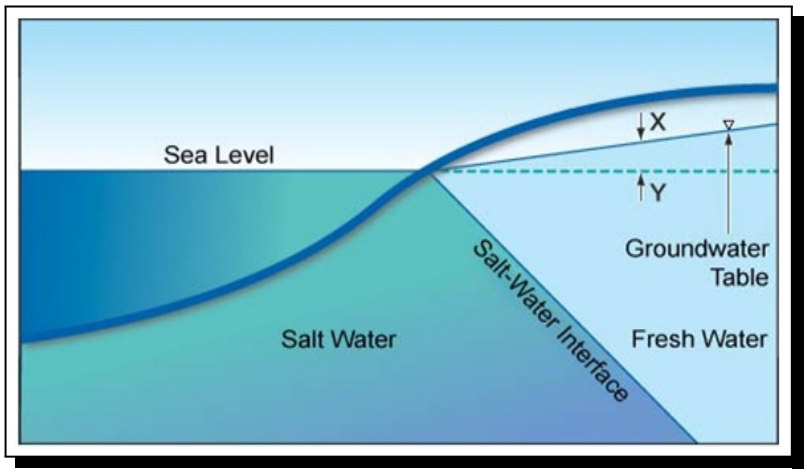

Figure 1. Salt-water interface in an unconfined coastal aquifer according to the Ghyben-Herzberg relation. (X Groundwater Level, Y Sea water Level) (Courtesy: `www.solinst.com`)

Groundwater pumping or development draws saltwater into freshwater zones, thereby decreasing the amount of freshwater stored in the aquifer. The extent of saltwater intrusion varies among localities and hydro-geologic settings. In many cases, contamination by saltwater is limited to small parts of the aquifer and has little or no effect on the wells pumped for groundwater supply (Felisa *et al.* [8]). Contamination may be of regional extent and has substantial effect on groundwater supplies (Eissa *et al.* [7]).

Higher salinity levels has also been researched to reduce germination, growth and yield attributing parameters in plants (Kumar *et al.* [14]; Al-Abdoulhadi *et al.* [2]; Das *et al.* [5]; Ghislain *et al.* [9]). Krupavathi and Movva ([13]) reviewed that saltwater intrusion into coastal aquifers is generally caused by two mechanisms:

- Lateral encroachment from the ocean due to excessive water withdrawals from coastal aquifers, or

- Upward movement from deeper saline zones due to upcoming near coastal discharge or pumping wells.

2. Factors Influencing Saltwater Intrusion

Several factors influence saltwater intrusion into coastal aquifers but the following listed below are the most prevalent.

(i) Tidal fluctuations

(ii) Long-term climate and sea level changes

(iii) Fractures in coastal rock formations

(iv) Seasonal changes in evaporation and

(v) Recharge rates

Recharge rates can also be lowered in areas with increased urbanization and thus impervious surfaces. Intrusion has also occurred in areas because of water levels being lowered by the construction of drainage canals (Barlow [3]). Climate change is a long-term change in the weather pattern especially due to an increase average atmospheric temperature. Climate change can result from natural or/and man-made activities. Effects of change in climate on coastal region on long-term is alarming. Sea level rise is a major effect which results in increase in coastal erosion and sea water intrusion (Zhou [24]).

The consequences of climate change on groundwater are long term and can be far reaching. One of the major consequences is the increased migration of salt water inland in coastal aquifers. Therefore, the present state of groundwater tables, piezometric levels and salinity distribution and exploitation, i.e. location and rates of abstraction should be known.

3. Techniques For Managing/Controlling Saltwater Intrusion

In managing or controlling saltwater intrusion, it is necessary to have certain fundamental information on the present state of the groundwater such as the groundwater tables, piezometric levels, salinity distribution and terms of exploitation, i.e. location and rates of abstraction. A lot of techniques have been used to manage/control salt/seawater intrusion and protect groundwater resources (Jahanshahi [11]). The principle is basically to reduce the volume of saltwater intrusion and increase the volume of freshwater.

Previous methods used for controlling saltwater intrusion have many limitations. Mahesha [16] and Rastogi *et al.* [19] combined the methods of injection of freshwater and extraction of saline water to increase the volume of freshwater and to reduce the volume of saltwater pose effective but the setback is the cost factor involved in the construction and maintenance of the wells. Several of these methods are costly and some might not be applicable in certain cases especially with the growing population and increasing demand for water (Colon-Rivera *et al.* [4]; Kazakis *et al.* [12]).

Another approach is fresh water injection, the source and cost of this might be expensive and this is particularly difficult in regions where there is scarcity of water. Effects of climate change and sea level rise are some of the factors to consider when choosing control techniques for saltwater intrusion. Climate change has resulted in increase in the sea level because rising temperature causes expansion of seawater and melting of glaciers/ice caps. This change in climatic condition also results in reduction in the atmospheric pressure which as a result leads to increase in water level in seas (Kumar [14]; Hussain and Javadi [10]).

The new technique for controlling saltwater intrusion is the Abstraction, Desalination and Recharge (ADR) which consists of three (3) steps; abstraction of brackish water from the saltwater, desalination of the abstracted brackish water using treatment process, and recharge of the treated water into the aquifer. Abstraction-Recharge process helps to move freshwater/saltwater interface towards the sea and is considered as an efficient method to control saltwater intrusion.

Other technique of control is maintaining a seaward hydraulic gradient and a proportion of the natural freshwater recharge flowing into the sea (Oladapo *et al.* [17]; Zeng *et al.* [23]). Increase aquifer recharge using controlled river flood is another technique, in that, some adjacent river areas that gets flooded during high volume rainfall events can slowly infiltrate after the storm. Back movement of seawater could be seen after using this method within one year. The movement may be insignificant, but in collaboration with other methods, it is possible to eradicate saltwater intrusion (De Costa *et al.* [6]).

Another cheap control is to reduce and/or rearrange the pattern of boreholes abstraction of groundwater. This approach implies that in rainy season, boreholes near the sea are used to provide most of the supply while inland boreholes are rested because large quantity of freshwater flow to the sea during this season. This situation is reversed in the summer when the flow of freshwater to the sea is much reduced.

However, for proper management of groundwater against saltwater intrusion, the following measures (Van Dam [21]; Adebo [1]) can also be considered;

(a) Reduction of the rates of abstraction, in order not to exceed the sustainable yield.

(b) Recycling of water in industrial processes, after appropriate treatment have been administered to it.

(c) Waste water to be reused for application such as cooling, irrigation and injection into the subsurface to maintain barrier against saltwater intrusion.

(d) A three dimensional, transient groundwater modeling with variable densities of saltwater intrusion can be used.

These three dimensional, transient groundwater modeling with the aid of geographic information system (GIS) are used to study the sensitivity of the values of the hydrogeological constants and the results compared with the effects of different ways of groundwater exploitation

(Felisa *et al.* [8]; Eissa *et al.* [7]; Hussain and Javad [10]). Also, legislative measures can be used to control and manage the available freshwater resources properly. Sustainability of groundwater exploitation is safeguarded when these rules are effected, thereby halting or where needed, push back the saltwater intrusion.

4. Conclusion

A major problem in the coastal regions all over the world to be controlled and properly managed is seawater intrusion (Oladapo *et al.* [17]). Combination of ADR approach has been revealed to be the most cost effective method in controlling seawater intrusion into coastal aquifer. However, other cost effective methods of control should be researched and implemented for optimum results.

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Competing Interests

The authors declare that they have no competing interests.

Authors' Contributions

All the authors contributed significantly in writing this article. The authors read and approved the final manuscript.

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