Ground Water Management in Coastal Areas

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Abstract

India has a very long coast line which is the backbone of its national economy. Three out of the four metros, the major industrial hubs, about one fourth of the country's population and the most fertile agricultural land are situated in this area. This is the region where natural calamities like tsunami; cyclones etc frequently affect the normal life. The coastal region occupies some of the most potential aquifer systems of the country. The coastal aquifers of India ranges from that of Jurassic to Recent and is seen almost all along the coast right from Gujarat to West Bengal. Some of the aquifers especially the Tertiary to Recent ones are highly potential and are developed extensively. The small island aquifers of Lakshadweep are highly sensitive since fresh water is seen floating as a thin lens over sea water here. The problems are also complex in the coastal area. Some of them are sea water intrusion, salinity from the aquifer (in situ) material, pollution, global warming and its impact on these aquifer systems. The hydogeologic scenario of the coastal area is discussed briefly in the paper. Sea water intrusion is reported in Gujarat and Tamil Nadu and the salinity in other areas are mostly derived from the aquifer materials. The sea level changes in the past and the present day sea level rise due to global warming and the impact on the coastal aquifers especially that of the small island aquifers of Lakshadweep are discussed in detail. The paper also discusses the details of these problems, remedial measures and how it is going to affect the aquifers of the coastal areas of country.

1.0 Introduction

India has a very long coastline and 25% of the country's population lives in the coastal zone. Similarly, urban centers are located mostly along the coast when compared to other parts of the country and three out of the four metros are located on the coast. The coastal zone is the most industrialized area in the country. Fourteen major, forty four medium and fifty five minor rivers/streams discharge into the sea through the entire length of the coast. The eastern coast is much wider than its western counterpart and the Arabian sea water is more saline compared to the Bay of Bengal. This is due to the high evaporation combined with low river discharge along the western coast.

The high population density along the banks of major rivers and coastal areas is attributed to the easy availability of water. The search for ground water also began along the alluvial tracts of rivers and coastal areas. The semi consolidated and unconsolidated sediments along the coastline helped mankind to go in for deeper groundwater exploration during the first half of the last century. As the exploration advanced towards deeper horizons, problems like salinity hazard, salt water intrusion, land subsidence etc. were faced, which made the situation quite complex. The high population and the modern

living standards demand more water, which has put the coastal aquifers under stress. Most of the coastal aquifers are sedimentary in nature, with a few out crops of hard rocks along the coast.

2.0 Hydrogeological Set up

One of the important features of the coastal deposits is the occurrence of ground water in the inter-bedded alluvial and marine sands, silts, clays and carbonate rocks deposited under beach, lagoonal, estuarine and marine environments. Coarse sediments are found to occur along the coast where youthful rivers discharge. Generally due to the differential compaction and the nature of the bedrock topography, the coastal sediments attain a seaward dip. All these factors have a control on the quality of the formation water. The coastal configuration and land forms vary widely depending upon the intensity of wave action, tides, other currents, sediment load, stage of the rivers, wind action and the ever changing riverine regime. The shorelines can be straight or irregular depending upon the structural features and wave energy. The delta formation along the river mouths has also an important role in the coastal hydro geologic scenario. The distribution of fresh water aquifers is controlled by the dynamic equilibrium between hydrostatic heads in the fresh and saline water zones, in flux of sea water into the streams and lagoons and the relative mound of sea with respect to the land mass.

3.0 Factors Affecting the Coastal Aquifers

Coastal sedimentary aquifers are among the most productive aquifers and due to this the stress on them are also more. Caution needs to be exercised while developing these aquifers, as over development can result in various adverse environmental impacts including seawater intrusion and land subsidence.

3.1 Land Subsidence:

Large scale of withdrawal of ground water, especially from the artesian aquifers can sometimes result in land subsidence due to compression of the aquifers. Land subsidence poses serious problems to buildings and other structures. Sometimes this causes inundation of low lying areas, resulting in sea water ingress. The subsidence depends on the nature of sub surface formations, their extent, magnitude and duration of the artesian pressure decline.

3.2 Sea Water Intrusion

When groundwater is pumped from aquifers that are in hydraulic connection with the sea, the gradients that are set up may induce a flow of salt water from the sea toward the well. The migration of salt water into freshwater aquifers under the influence of groundwater development is known as *seawater intrusion.* There is a tendency to indicate occurrence of any saline or brackish water along the coastal formations to sea water intrusion. The

salinity can be due to several reasons and mostly it can be due to the leaching out of the salts from the aquifer material. In order to avoid mistaken diagnoses of seawater intrusion as evidenced by temporary increases of total dissolved salts, Revelle recommended Chloride-Bicarbonate ratio as a criterion to evaluate intrusion. In India, sea water intrusion is observed along the coastal areas of Gujarat and Tamil Nadu.

3.3 Upconing of Saline Water

When an aquifer has an underlying layer of saline water and is pumped by a well penetrating only the upper freshwater portion of the aquifer, a local rise of the interface below the well occurs. This phenomenon is known as upconing. The interface is generally near horizontal at the start of pumping. With continued pumping, the interface rises to progressively higher levels until eventually it reaches the well. This generally necessitates the well having to be shut down because of the degrading influence of the saline water. When pumping is stopped, the denser saline water tends to settle downward and to return to its former position.

Upconing of sea water is reported from the Lakshadweep and other small islands. In these islands, the fresh water floats over saline water as a thin lens and for every drop one unit of the fresh water the saline water rises by forty units. Due to this, the islands do have very fragile ground water system and no pumping can be recommended here. The fresh water has to be skimmed to avoid upcoming.

3.4 Geogenic Salinity

This is the most common quality problem observed in the coastal aquifers. Here the salinity is due to the leaching of the salts in the aquifer material. In some cases, the formation water gets freshened year after year due to the leaching effect.

A case study from Kerala is discussed in the later part of this paper.

3.4 Pollution

Rivers are the major contributors of pollution of the coast and coastal aquifers. Almost all the rivers in our country are polluted mostly due to sewerages and industrial effluents.

3.5 Sea Level Rise:

The anticipated sea level rise due to global warming poses a serious threat to the coastal aquifers, especially the small island aquifers. The rise in the sea level will push the fresh water seawater interface more inland along coastal aquifers and will submerge low lying areas with sea water, thereby making the shallow aquifers saline. The small Lakshadweep islands will be the worst affected by sea level rise.

4.0 Hydrochemical Case Studies from Kerala

Detailed hydro chemical studies carried out in Kerala had revealed very interesting results on the source of salinity and the change of ground water type geographically. Some of them are discussed below.

Warkali aquifers – Change in geochemical type:

The change in the degree and type of mineralisation of the water in this aquifer can be explained as a reflection of the different stages of the interaction of the recharging fresh water with the sediments deposited under marine environment.

Initially, Ca – HCO_3 type water was formed by the chemical action of rain water, containing carbon dioxide, on Calcium Carbonate bearing minerals along the recharge area. The Calcium rich water, during its movement, releases Sodium by ion exchange from clay minerals (under marine conditions the clay minerals are sodium rich). This results in Na – HCO_3 type water. The higher content of Fluoride in this area is also due to this reason. The alkaline water depleted in Calcium is effective in releasing fluoride from minerals like fluor-apatite. Further north, where the freshening is incomplete, hard brackish water of Ca-Mg-Cl or Na-Cl type occurs. Similar situation is observed in Sweden as well (Agerstrand et.al. 1981)

Isotope Studies:

Studies on the ^{18}O content were carried out to know the source of brackishness in ground water in the Tertiary aquifers. A rain water sample, 14 shallow ground water samples from the recharge area, 31 ground water samples tapping the deeper Tertiary aquifers and a sea water sample were subjected to analysis. Chloride is chosen as the parameter indicative of evaporation processes leading to the fractionation of isotopes and also indicative of mixing of saline and fresh waters. The data plot at the first stage shows an increase in both Chloride and ^{18}O indicating the evaporation processes. The second is a rise only in Chloride whereas the ^{18}O has stabilized at about –2 per mil. The evaporation stops at depth and hence there is no further increase of ^{18}O whereas the saline pore waters of the clay layers continue to diffuse into the formation waters thereby increasing the Chloride content. Analysis of a clay sample from a borehole indicated Chloride content of 660 mg per kg of dry clay. The Chloride content of the pore water was calculated to be around 2000 mg/l (Jacks 1987). Mixing of sea water, if any, shall show an increase in the trend of both Chloride and ^{18}O.

The isotope studies thus indicate that the brackishness in parts of the Tertiary aquifers of Kerala is not due to mixing of sea water but due to the diffusion of salinity from the intercalating clay beds.

Freshening process:

The quality of water in the Tertiary aquifers indicates that the relative concentrations of the major ions and trace elements are different from that obtainable by sea water dilution/ mixing. Detailed studies indicate that a freshening process is occurring in the aquifers. One of the parameter to indicate the long term process of freshening or sea water intrusion is the Na/Cl ratio (Jacks 1987 and Mercade 1985). In the course of sea water intrusion, part of the Sodium ion is exchanged for Calcium and Magnesium ions, which are the predominant cations in the exchange sites of clay minerals in the fresh water aquifers. The resulting water will be depleted in Sodium. The Chloride ions continue to remain in solution, since Chloride does not undergo ion exchange, precipitation, complexing, oxidation, reductions or biological reactions (Hem J.D. 1970). Thus, the Na/Cl mole ratio during intrusion shall be less than 0.85, the mole ratio in seawater. When freshening of saline aquifers occurs, the direction of the cation exchange is reversed and the opposite trends will be effective and the Na/Cl ratio will be higher than that in seawater. It is seen that the Na/Cl ratio for most of the water samples is higher than that of sea water fresh water mixing and majority of them fall in the field of freshening

5.0 Management of Coastal Aquifers

The coastal aquifers have to be managed carefully and cautiously to avoid problems like sea water intrusion and land subsidence. For this, detailed studies and regular monitoring are required.

- The aquifer geometry, distribution of the fresh water and saline water in the system has to be studied in detail.
- Constant monitoring of the pumping, movement of the fresh water saline water interface are to be carried out.
- Tidal influence into the aquifer has to be studied in detail and is to be monitored periodically.
- Safe yield of the aquifer has to be evaluated and accordingly the extraction has to be restricted.
- Remedial measures have to be done wherever sea water intrusion has taken place.

Some of the policy matters are discussed below in brief.

- Finding alternate source of water or other suitable remedial measure wherever serious ground water problem exists.
- Impose restriction for ground water withdrawal along over exploited, critical and other problem areas.
- Mass awareness/ mass interaction programmes shall be conducted to educate the masses and also to understand their problems.
- Preparing a policy document for the judicial and equitable distribution of the resource.

- Creating a buffer zone along the coast wherever there is a possible threat to the aquifers.
- Incorporate necessary measures required in the Coastal Regulation Act.

6.0 Regulations Needed

The regulations needed or to be considered in the coastal area are entirely different from those of other areas. In other words, these regulations are to be seen in a different perspective. In an over exploited area, regulation can be imposed once the over exploitation is confirmed whereas in a coastal area nobody can wait for something to happen since by that time the entire aquifer system would have been destroyed. In many cases, the restoration of such aquifers back to normal is either impossible or highly costly. Under these circumstances, prevention is better than cure. The regulations that can be considered for implementation are precaution/ prevention; control/ restriction and remedial measures/ restoration and are discussed below.

Precaution is the best way of approaching the problem. By constant monitoring, precautions can be taken at the right time to avoid any type of future problems. Prevention starts where precaution ends. Certain regulations have to be implemented to prevent any untoward happenings in future and this will be the preventive measure.