Catena 172 (2019) 558–571

Contents lists available at ScienceDirect

Catena

journal homepage: www.elsevier.com/locate/catena

Hydrogeochemical, seawater intrusion and oxygen isotope studies on a coastal region in the Puri District of Odisha, India

Atulya Kumar Mohanty*, V.V.S. Gurunadha Rao

Hydrogeochemistry Division, CSIR- National Geophysical Research Institute, Uppal Road, Hyderabad 500 007, India

ARTICLE INFO

Keywords:
Coastal aquifers
Hydrogeochemical processes
Salinization
Oxygen isotopes
Ionic ratios
Saturation index
Puri District of Odisha

ABSTRACT

Groundwater is the major source of freshwater in coastal areas, and gradual declining of water quality is a major cause of concern. The present study is focused on a coastal aquifer, to study the groundwater chemistry, hydrogeochemical characteristics, and salinization processes in a coastal area of the Puri District of Odisha, southeastern coast of India. Groundwater chemistry reveals, water compositions are generally near neutral to slightly alkaline nature in pH, and the total dissolved solids (TDS) concentrations varies from 150 mg/l in the inland area to 4006 mg/l towards the shorelines. Piper plot shows four principal hydrochemical water types prevailed in the groundwater zones with water composition changes from fresh water to the saline water mixing. The oxygen isotope ($\delta^{18}O$) values are found between −5.3‰ to and −2.96‰, which indicates groundwater compositions were influenced by the evaporation process. Based on Cl^- concentrations (0.4–35 meq/l), the saline end-member is mixing of seawater with the groundwater. Calculations of ionic deltas in groundwater show deficiency of Na^+, Ca^{2+}, Mg^{2+}, SO_4^{2-} ions and significantly mixed with seawater and subsequent reactions governed by ion exchange processes in the aquifer. Saturation index shows groundwater were subsaturated to near equilibrium conditions with mineral phases such as dolomite, gypsum, halite and under-saturated with calcite, aragonite and anhydrite. Sulphate depletion observed in groundwater indicates the seawater mixing. Groundwater flow path shows, there is a gradual increasing of TDS concentrations from inland recharge areas to towards the discharge areas of shoreline and groundwater facies changes from Na-K-HCO_3 to Na-Mg-Cl type. The coastal aquifers are subjected to the continuous influence of seawater mixing, dissolution of carbonate phase minerals, aided with rock-water interaction, and ion exchange processes are the significant governing factors, which controls the groundwater evolution.

1. Introduction

Ground waters are the major sources of freshwaters and used for the drinking water and domestic uses in many parts of the world. The rise of sea-levels in which salt water intruded into the coastal groundwater aquifer systems and mixed with the freshwater and that gradually aided to the declining of water quality in the entire region. The close proximity of coastal aquifers to saline water intrusions which creates a unique issues with respect to groundwater sustainability in coastal regions and has become a major constraint on groundwater utilization (Bear et al., 1999). Seawater migration towards the freshwater resources is a common phenomenon and gradual declining of the water quality in coastal regions. When there is a reduction in the freshwater head due to the high volume of groundwater abstraction, over pumping, less recharge in coastal wells, which allows the saltwater migration towards the inland sites. The impact of seawater intrusion leads to the depletion of groundwater storage in quantity and quality with increasing in ion concentrations. When concentrations of dissolved ions exceed permissible drinking water standards, which leads to the abandonment of fresh groundwater resources and supply wells in the coastal regions (Barlow and Reichard, 2010).

Seawater mixing with groundwater zones in coastal aquifers has resulted in degradation of drinking water supplies and seriously affected the quality of fresh groundwater discharges to coastal ecosystems. The increase in groundwater salinity due to the influx of natural seawater, dissolution of minerals and soluble salts in the unsaturated zone in the coastal aquifer zones. The combined effect of natural mixing processes between seawater and continental water, ion exchange processes, upconing processes due to groundwater extraction and the groundwater flow from the adjacent coastal alluvial aquifers aids the increase in salinity of the region. The impacts of seawater intrusion on coastal aquifers, salinization processes, and its hydrogeochemical

* Corresponding author.
E-mail addresses: akmohanty@ngri.res.in, atulyakmohanty@gmail.com (A.K. Mohanty).

https://doi.org/10.1016/j.catena.2018.09.010
Received 6 February 2018; Received in revised form 9 August 2018; Accepted 5 September 2018

studies were reported by several authors in different parts of world (Allen and Suchy, 2001; Barlow, 2003; Sivan et al., 2005; de Montety et al., 2008; Carol et al., 2009; Werner and Simmons, 2009; Gimenez-Forcada et al., 2010; Ghiglieri et al., 2012; Wen et al., 2012; Han et al., 2014, Haile and Frayer, 2017; Werner, 2017, Klassen and Allen, 2017).

In the recent years, several studies have been carried out a study on seawater intrusion along the coastal areas of India (CGWB, 2014). India is having a long coastline of 7500 km, and nearly about 25% of the people living in the coastal areas. The impact of urbanization, industrial growth, increase in agricultural uses and rising population in coastal areas and needing high consumption freshwater and putting coastal aquifers under distress conditions. In the Puri city area, earlier studies were carried out on assessment of water quality and its suitability for the drinking water purposes (Dash, 2017) and assessment of health risks due to bacteriological contamination with the groundwater (Vijay et al., 2011). However, there is a lack of study on the natural processes affecting the groundwater salinization, hydrogeochemical characteristics, understanding the relationship between seawater intrusion with groundwater and an application of stable isotope studies on the coastal areas of Odisha. The studies on water quality assessment, hydrogeochemical processes affecting on groundwater in coastal areas will be useful to understand the hydrochemical processes affecting the area, to promote sustainable developments and efficient management of the water resources of the region. The hydrogeochemical studies on coastal areas will be helpful to evaluate the major ion chemistry, solute transport process in the aquifer, saline water mixing and suitability for the drinking water and irrigation purposes. Also to understand the geological processes such as aquifer characteristics, and chemical fluxes change the dynamics of groundwater and seawater interface in coastal alluvial aquifers. The present study was carried out to investigate about the groundwater chemistry; and mechanisms of hydrogeochemical processes which controls the groundwater evolution in the coastal aquifer. The main objectives are to study the geochemistry of groundwater and surface water, the impact of seawater mixing, and the processes which control the groundwater evolution along the coastal aquifer. The present work will be useful for making a database for the long-term use of groundwater, management, and the future strategy to protect the water resources of the region in changing climatic scenarios.

2. Study area

2.1. Location and physiography

The Puri City lies in the eastern coastal part of Odisha State, an important pilgrimage and places in India. The present study area extends from 19°50′01.7″–19°56′32″ N latitude to 85°56′21″–86°01′50″ E longitude and is located about 10 km of southeastern direction of Puri City and closely lies on the bank of Bay of Bengal Sea and shown (Fig. 1). The coastal parts of Odisha, experience a humid tropical climate with an average annual rainfall of 1510 mm, mainly during southwest monsoon period (June to October). The southwest monsoon brings high tidal waves, flooding and affected by severe cyclonic storms near the coastlines. The tidal waves mix with the inlets and rivers and migrate in the low lying areas along the creeks, bays, backwater areas, to a large areal extent in the coastal areas. The migrating seawater mixes with the near surface coastal freshwater zones and contaminates the water supply wells. The littoral tracts of the coastal area are mainly of sandy ridges, due to the accumulation of the wind blown sand deposits. The width of the littoral tract varies from a few meters to approximately 5 km in width along the coast. Alluvial tracts along the coast are drained by small tributaries and streams mainly comprise of the distributaries of the Mahanadi River such as Kushabhadra, Bhargavi and Nuanai River.

2.2. Geology and hydrogeology

Geology of the coastal parts of Puri District and its adjoining areas are dominated by recent Quarternary sediments of Miocene to Pliocene age (Pascoe, 1950). The onset of the Quaternary period is marked by the epirogenic movements, which led to the upliftment of the continental crust and sedimentation under arid and humid climatic conditions resulting in the formation of older deltas. The sediments were deposited by river systems and subsequent build up of deltas in the river mouths, in the Recent to sub-recent age along the coast of the Bay of Bengal Sea. The coastal aquifers comprised of fluvial-deltaic sediments of thin in the outcrop areas and progressively thickening to a few thousand meters near the coast. Repeated sea-level changes and natural subsidence of the basin due to sediment loading produced a complex set of discontinuous bodies of sand, silt, clay, and gravel along the Coast (Fig. 2). The thickness of alluvium is about 150 m towards the coast. The coastal aquifers consist of unconsolidated sediments such as sands, gravels and pebbles of Upper Tertiary (Mio-Pliocene) to Recent age. Based on the exploratory drilling, the litho units are consists of a two-layer aquifer system prevailed in the area. The top layer of the unconfined aquifer consists of alluvium, clay and granular material and the deeper aquifer consists of sands, pebbles with intercalated clay bands (CGWB, 2013). In Tertiary sedimentary formations, groundwater occurs the under water table conditions at shallow depths. The water levels fluctuate from 1 to 10 m below ground level (bgl) and vary with the rainfall pattern. The water quality parameters in shallow aquifers are found to be in portable conditions in inland areas. The deeper aquifers are in fresh conditions in the northern parts, while the saline water concentrations are increases towards the coast. The Bhargavi and Nuanai River are draining into the Bay of Bengal and show intermittent discharge characteristics, depending on the rainfall pattern of the catchment areas. The river heads are normally occurs above ahead of few meters to the groundwater levels.

2.3. Materials and methods

2.3.1. Water sampling

In the present study area, 53 observation wells are selected, which includes 49 groundwater samples mostly from the populated residential villages and agricultural lands. The groundwater samples were collected from the dug wells, bore wells and hand pumps before the onset of the monsoon season (June 2009). Three surface water samples were collects from the Bhargavi River, Bangai Nadi, the confluence of Bhargavi and Bangai Nadi. Only one seawater sample was collected from the River mouth of Nuanai, which falls on the Bay of Bengal Sea. Observation wells were selected for the periodical monitoring of groundwater levels, and analyses of water chemistry parameters are shown (Table 1). The groundwater samples were collected from dug wells, hand pumps and bore wells; surface waters from streams and rivers using high-density polyethylene plastic bottles. The well inventory locations were determined with a handheld global positioning system (GARMIN, GPS). In situ field measurements were also made on water samples such as pH, EC, TDS, depth to water table (bgl) of wells during the sample collections to initially assess the groundwater composition.

2.3.2. Analytical methods

The physicochemical analyses of water samples were carried out at the Groundwater Department, Hyderabad of Telangana State. The parameters such as pH analyzed by a pH meter, TDS and electrical conductivity (EC) analyzed by a benchtop meter. These major ion analyses were carried out according to the standard procedures described by APHA (2005). The ions such as Ca^{2+}, Mg^{2+}, Cl^{-}, and HCO_3^{-} were analyzed by titration, sodium (Na^{+}) and potassium (K^{+}) by Flame Photometer; NO_3^{-} and F^{-} analyzed by ion electrodes methods; and SO_4^{2-} by Nephelo turbidity method. The accuracies of