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SUBMARINE GROUNDWATER DISCHARGE FROM AN URBANIZED COASTAL AQUIFER OF THE SOUTHWEST COAST, INDIA

Mintu Elezebath George*[1,2], Akhil T[1], Remya R[1,3], Rafeeque M K[1,3], and Suresh Babu DS[1]

ABSTRACT

Sustainable development of an urban region requires special attention towards water and waste management. Both of these are linked to each other like the facets of a coin. Improper disposal of waste in an urbanized area can impair its groundwater quality as well as it can lead to discharge to the marine environment through submarine groundwater discharge creating an imbalance in the marine ecosystem. The present study analyzed the urbanization effects on submarine groundwater discharge (SGD) and associated nutrient flux in the urbanized coastal aquifer considering a harbor environment inside Kozhikode city. The geochemical tracer radon was used to calculate the groundwater discharge and associated nutrient flux. Nutrient fluxes associated with SGD, like dissolved inorganic nitrogen (DIN), dissolved inorganic phosphate (DIP), dissolved silicate (DSi), dissolved inorganic carbon (DIC), and dissolved organic carbon (DOC) are assessed. SGD flux of 13.25×10^4 m^3/day is responsible for the nutrient discharge of 1.07×10^4 mol/day DIN, 5.83×10^2 mol/day DIP, 7.4×10^3 mol/day DSi, 3.79×10^5 mol/day DIC and 1.96×10^4 mol/day DOC in the harbor. The results indicated that urbanization has a great role on the nutrient transfer through SGD. The decrease in groundwater quality in urbanized coast leads to the nutrient input through SGD into the sea. This shows that even a small amount of discharge can affect the marine environment through a considerable amount of solutes like nutrients, trace metals, and other pollutants that are transferred into the nearshore region. Judicial management of waste disposal (sanitation) and groundwater in the urbanized sections is required for the sustainable development of Kozhikode City.

Keywords: *Submarine groundwater discharge; coastal aquifer management; southwest coast of India; Kozhikode; Kerala*

INTRODUCTION

The urban development raised challenges for sustainable water resources both surface water and groundwater (Sivaraj et al., 2016; Uddameri et al., 2014). Land use patterns and population density is altered with growing developments leading to high stress on aquifers (Uddameri et al., 2014). The gradual development of cities and an increase in transportation facilities build the roads and paved walkways decreasing the permeable area for infiltration and recharging. According to the census of India (2011), the population density of India increased from 324 per square kilometer to 382 per square kilometer and the population rate is growing immensely. The coasts along the Indian Peninsula get settled with people as inland inhabitation gets limited with an increase in population density. Urban settlements close to the coast lead to wastewater effluent discharge from fishing and allied industries associated with fishermen's community contaminating the surface and groundwater either partly or to a limited extent. This seriously affects the terrestrial and marine ecosystem through surface flow and infiltration of rain and then subsurface flow in the form of groundwater discharge (Eckhardt and Stackelberg, 1995; Cole et al., 2006; Bowen et al., 2007). When there is a lack of streamflow, subterranean flows take a role in transferring nutrient discharge (Johnson et al., 2008). Thus groundwater discharge through the subsurface medium (Submarine groundwater discharge –SGD) is a serious concern that attracts attention. Any subsurface flow of groundwater to the marine environment despite its composition and driving force is known as submarine groundwater discharge (Burnett et al., 2003; Moore, 2010; Taniguchi et al., 2002; Senafy and Fadlelmawla, 2014). The groundwater discharge may be less but the nutrient flow associated with it is generally greater than that of the streamflow (Moore, 1999; Taniguchi et al., 2002; Kim et al., 2005; Rodellas et al., 2015). This study examines the influence of urbanization on SGD in a harbor environment (Vellayil Harbor), situated in the urban setting of Kozhikode district which is the second-largest urban agglomeration in Kerala and 20th largest in the country with a population of two million. Moreover, this work contributes towards achieving the sustainable goals of water and sanitation through waste and groundwater management by understanding the role of urbanization on nutrient input to the groundwater and its discharge to the coastal environment in a city residing in the coastal section.

1. *CSIR-SRF, Coastal Processes Group, National Centre for Earth Sciences Studies, Thiruvananthapuram, Kerala*

** E-mail: mint.george@gmail.com*

2. *Department of Marine Geology and Geophysics, School of Marine Sciences, Cochin University of Science and Technology, Kochi, Kerala, India*

3. *University of Kerala, India*

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METHODS

Study area

Vellayil Harbor in Kozhikode district of Northern Kerala lies in the southern part of the Southwest Coast of India along the Kerala-Konkan coast. Positioned at the latitude 11.264965 N and longitude 75.766292 E (Fig 1), it is a major fishing and economic hub in the Kozhikode district covering a total area of 2, 06,940 m^2. The harbor basin having a depth of 3m is enclosed within two breakwaters of length 750 m in the South and 530 m in the North. There occurs mixed semi-diurnal micro-tide with an average tidal range of 0.8 m. Even though Kozhikode has a stable coast,

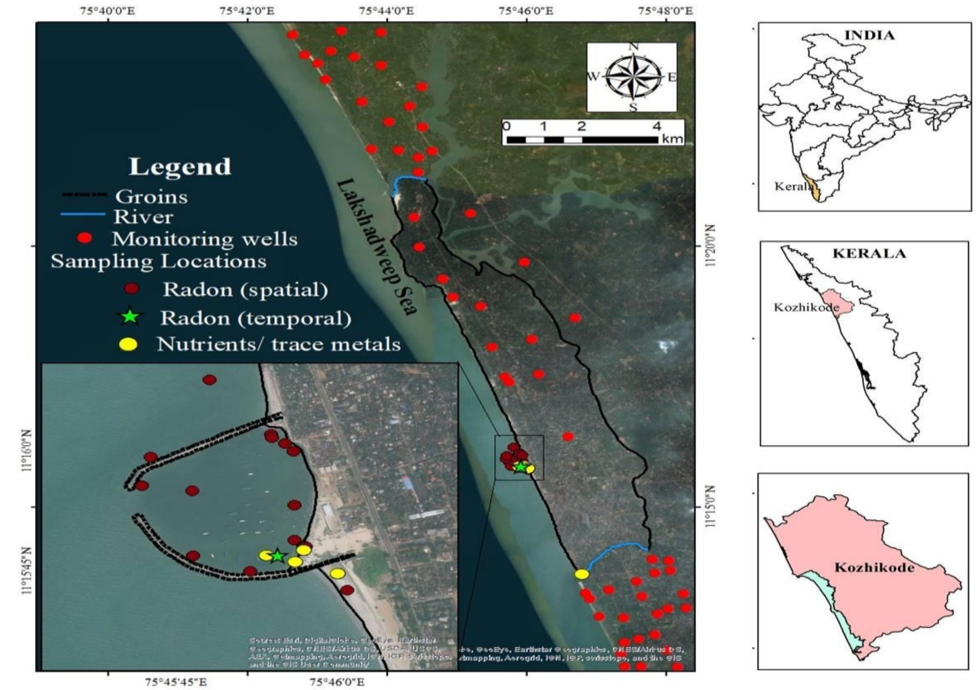

Fig. 1. Locations of sampling in and around Vellayil Harbor, Kozhikode Kerala

moderate erosion is found to occur just a few kilometers south of Elathur headland, which is close to Vellayil Harbor (Rafeeque et al., 2020).

Data collection

Radon concentration of coastal water (temporal and spatial), and porewater in the harbor area was measured using the automated radon monitoring system (RAD 7 and RAD AQUA, Durridge Co.). The automated radon monitoring system was installed inside the harbor basin along the eastern end of the southern breakwater for the temporal survey of coastal water (Fig 2), measuring radon concentrations every 30 minutes for about 24 hours. A spatial survey for radon concentration inside and outside the harbor was done using the automated radon monitoring system (RAD 7 and RAD AQUA), tied in the boat, and rowed around the basin. Ten pore-water samples at the lower reaches of the harbor, adjoining the radon- time series location, were collected during low tide time. These samples were measured for radon concentration using RAD H_2O coupled with radon in the air monitoring system (RAD 7). The filtered samples were analyzed for ammonia, nitrate, nitrite, phosphate, and silicate using Skalar SAN++ Continuous Flow Analyzer. The salinity, pH, and temperature of porewater were measured in situ using a multi-parameter water quality analyzer (Aquaread AP-2000). Samples for Dissolved Organic Carbon (DOC) were measured via combustion with a non-dispersive infrared sensor detector (Shimadzu™ TOC-VCSH). Dissolved Inorganic Carbon (DIC) concentrations are measured with an automated attached-to-cavity ring-down spectrometer (Picarro G2201-I). Total Alkalinity was measured via gran titration (Grasshoff et al. 2009).

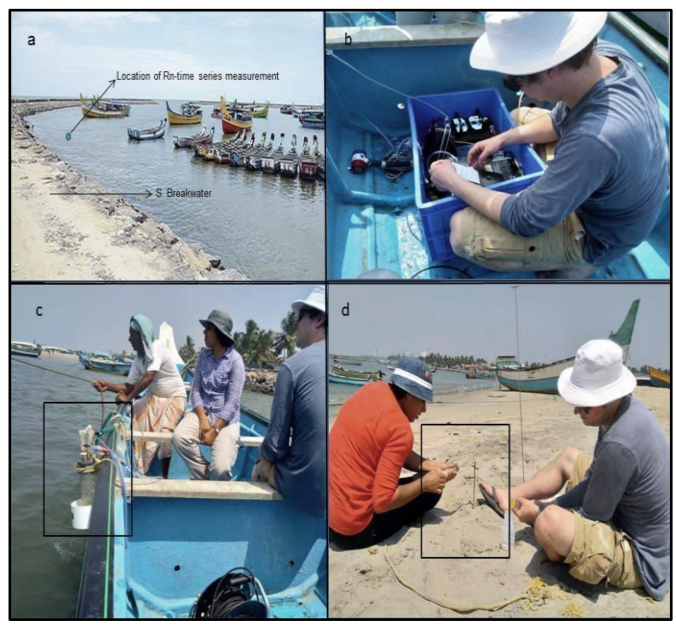

Fig. 2. (a) Location of temporal measurement of radon concentration; (b) and (c) RAD7 and RAD-Aqua water exchanger system for the spatial survey of radon concentration in seawater using boat; (d) Pore-water sample collection

RESULTS AND DISCUSSION

Physicochemical parameters

Physico-chemical parameters of porewater inside and outside harbor vary with distance from the shoreline to land. Inside the harbor, salinity varies from 0.4ppt at 5m from the shoreline to 24.5ppt at 1m from the shoreline. Outside the harbor, it varies from 0.7ppt at 5m to 22.2ppt at 1m from the shoreline. The pH varies from 7.58 at 1m from the shoreline to 8.09 at 5m from shoreline inside the harbor. Outside harbor it ranges from 7.69 at 1m to 8.16 at 4m from the shoreline. The depth of the harbor varies up to 3m depending on the location. The total alkalinity of pore water varies from 2114 to 5870 µmol/L with an average value of 3412 µmol/L.

Variation of radon (^{222}Rn) concentration

Radon concentration in seawater varies temporally from 12.5 to 33.3 Bq/m^3 (Fig 3) with an average of 22.5 Bq/m^3 and spatially from 5.62 Bq/m^3 at 2m depth to 26.4 Bq/m^3 at 0.5m with an average of 17.76 Bq/m^3. Inside the harbor, pore water radon concentration varies from 100.37 to 333.2 Bq/m^3 with an average of 219.49 Bq/m^3.

Nutrients in pore water

Inside the harbor, porewater ammonia varies from 0 to 3.8µmol/L with an average of 0.44 µmol/L, and outside the harbor, it varies from 8.1 to 131.8 µmol/L with an average of 37.83 µmol/L. Nitrite (NO_2) varies from 0 to 13.7 µmol/L inside the harbor with an average of 4.07 µmol/L and it varied between 0 to 20.4 µmol/L outside the harbor with an average of 4.15 µmol/L. Nitrate (NO_3) varies from

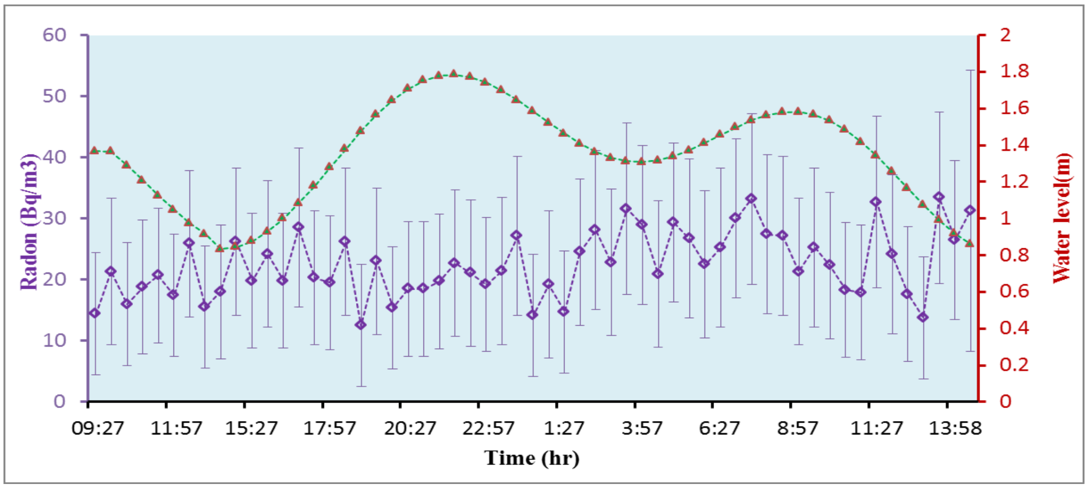

Fig. 3: Variation of radon concentration with water level (March 2018)

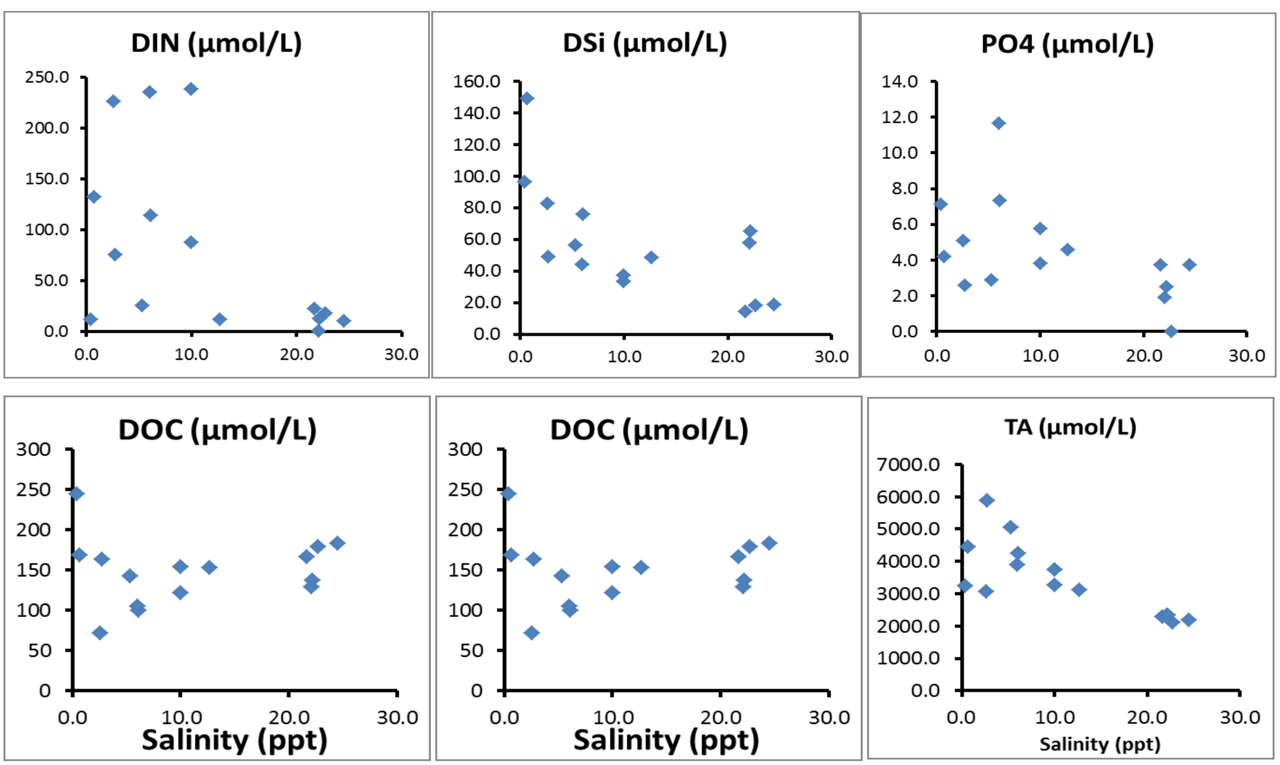

Fig. 4: Plots of nutrient concentrations and Total Alkalinity vs salinity for the pore water: (a) DIN; (b) SiO_3; (c) PO_4 (d) DOC (e) DIC and (f) TA

0 to 237.9 μmol/L inside the harbor with an average of 91.64 μmol/L and from 0 to 47 μmol/L outside the harbor with an average of 9.39 μmol/L. Phosphate varies from 0 to 11.6 μmol/L inside the harbor with an average of 4.99 μmol/L and 2.5 to 4.6 μmol/L outside the harbor with an average of 3.34 μmol/L. Silicate varies from 14.3 to 96.4 μmol/L inside the harbor with an average of 47.86 μmol/L

and from 48.4 to 149.3 μmol/L outside the harbor with an average of 73.62 μmol/L. Inside the harbor pore water, organic carbon content varies from 72 to 245 μmol/L, and outside the harbor, it varies from 138 to 169 μmol/L. The inorganic carbon content of porewater varies from 1410 to 3764 μmol/L and outside harbor it varies from 1754 to 5566 μmol/L. Fig. 4 shows plots of nutrient concentrations versus salinity in porewater.

DISCUSSION

Submarine groundwater discharge

The calculation for the SGD seepage rate is done based on Burnett and Dulaiova, (2003); Burnett et al., (2008); Jacob et al., (2009), and Dulaiova et al., (2010). Figure 3 displays the variation of radon with time, the water level at the location of radon time series varies between 0.6m to 1.8m. Pore water radon concentration is considered as the end member for radon in calculating SGD flux. Inside the harbor, the breakwaters and groins restrict the exchange with the outer system. The average SGD seepage in the harbor is calculated to be 53.l9+/-16.7cm/day. It varies from 0.93+/-1.9 cm/day during high tide to 159.035+/-49.85 cm/day during low tide. The variation in the SGD rate implies its dependence on the tide and water level fluctuation (Fig. 5). The SGD flux is calculated to be 13.25×10^4 m^3/day based on the discharge rate and seepage face.

The region covering the headland of Elathur (laterite cliff) in the north to the Kallayi tidal inlet in the south exhibits a positive hydraulic gradient favoring the occurrence of SGD in the Vellayil Harbor (George et al., 2018). The positive terrestrial hydraulic gradient drives SGD (Xinya et al., 2009; Swarzenski et al., 2007; Simonds et al., 2008). Harbor and its nearby region are deposited with newly accreted sediments of recent coastal alluvium (sand) which is formed from the regression of the coastal line (Rafeeque et al., 2020). According to the report by UNESCO (2004), the seepage through permeable sediments like sand may be less; however, its contribution will be large for the reason that it flows through a wider area. The evidence reveals more towards the non channelized flow of groundwater discharge along Vellayil harbor as its presence can't be detected visually in any form like diffused flow or spring, and the driving force of this flow to this harbor environment is found to be hydraulic gradient (George et al., 2018), supported by the topography and the underlying geology and tidal force (Fig 5). Non-channelized flows are usually recirculated groundwater discharge than freshwater (UNESCO, 2004) and so SGD along Vellayil Harbor could be recirculated which is driven either by a combination of hydraulic gradient and tidal forcing or simply either one of these.

Nutrient flux associated with SGD

The nutrient concentration varies with chemical reactions like denitrification, precipitation, dissolution of minerals, and desorption during its traverse to the nearshore water (Lee et al., 2012). Here, we assume that such changes have not occurred between the sampling locations of porewater and discharge for calculating the nutrient flux. The nutrient concentration of the pore water of the intertidal zone is measured inside the harbor and outside the harbor, and its average is used as the end member for nutrient flux estimation using SGD flux. The DIN flux to harbor through SGD is 1.07×10^4 mol/day, DIP is 5.83×10^2 mol/day, DSi is 0.74×10^4 mol/day, DIC is 3.79×10^5 mol/day and DOC is 1.96×10^4 mol/day. The streamflow is absent into the Vellayil harbor and so the nutrient transport is either through the subsurface flows like SGD or through

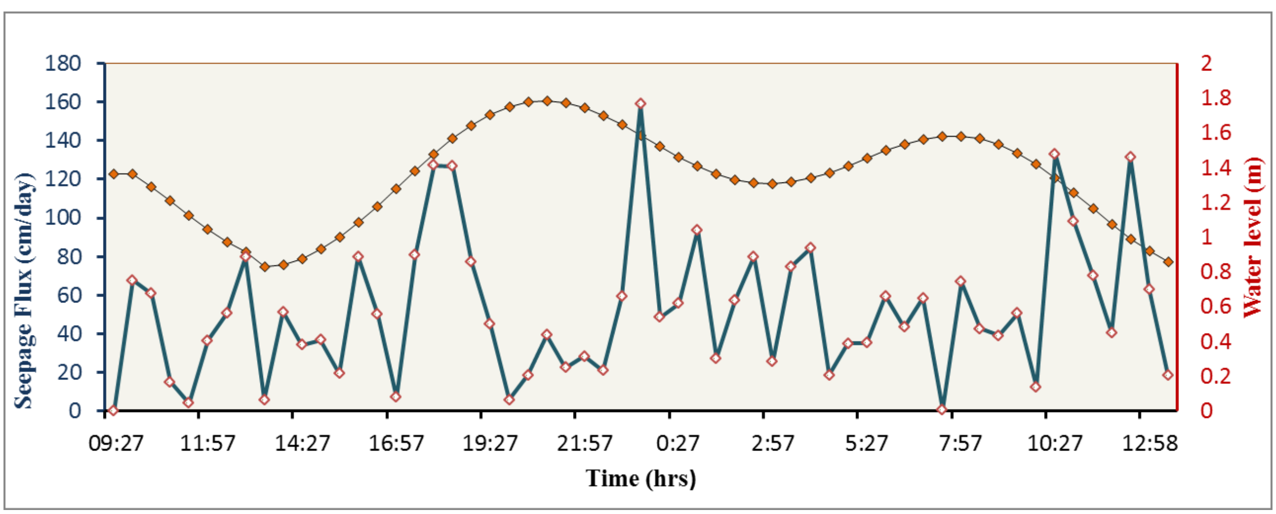

Fig. 5: Variation of SGD seepage with water level (March 2018)

anthropogenic depositions. The flux proves that SGD is an important pathway for nutrient discharge in the nearshore regions of Kozhikode. The contribution of SGD in adding nutrients to the harbor has not been considered much in the nutrient budget evaluation of the SW coast of India.

Urbanization and its impacts on groundwater and nutrient discharges

In the urban sprawl of Kozhikode, urbanization has greatly affected the groundwater scenario. Kozhikode district is 38.25% urbanized (Census of India, 2001) and the population growth rate is 7.20% (Census of India, 2011).Vellayil Harbor is a tourist attraction of Kozhikode district for its beautiful beach and situated very close to Kozhikode beach, 1.5 to 2 km, which is yet another tourist spot. Urbanization along the coastal zone disrupts the groundwater recharge, as buildings, roads, paved walkways, etc. have taken over the place of soil through which infiltration occurs. Eventually, the recharge to the zone of saturation through the vadose zone reduces and badly impacts the coastal aquifer. The level of groundwater falls and weakens the groundwater movements to the oceans. The amount of groundwater discharged is less, as compared with other locations, but nutrient discharge is comparable. According to Jesiya (2019), the Kozhikode urban zone faces severe space constraints for proper leach pits. When the number of people living per unit area increases there occurs a lack of proper sanitation facilities and pits which pollute groundwater (Jesiya 2019). The proximity of the sanitation facility to the drinking water source led to high nitrate and bacterial contamination in the coastal aquifers (Jesiya 2019). This ultimately stresses the aquifer through pollution. Basak and Nazimuddin, (1993) and Salaj et al. (2018b) confirmed that the lateral flow of groundwater through the coastal urban aquifers of Kozhikode can transport contaminants within as well as around the aquifer systems. Accordingly, the number of nutrients in groundwater increases tremendously, resulting in high SGD-associated nutrient flux. The nutrient discharged through SGD is one of the main contributors to the nutrient budgets of coastal water (Costa et al., 2006; Garcia-Solsona et al., 2008).

Role of nutrients through SGD in the primary production

Net primary productivity in the coastal zone can be enhanced through nutrients derived from SGD (Kim et al. 2011; Luo et al., 2014). In this system, the N:P ratio (17.87) is almost similar to the Redfield ratio (16) indicating that both nitrogen and phosphorus get reduced in tandem during phytoplankton growth. A slight increase in the N:P ratio here is the effect of growing urbanization. In a few years when the trend in urbanization grows higher, the N:P ratio through SGD will increase tremendously as an increase in urbanization can lead to a higher level of N:P ratios (Santos et al., 2014). Consequently, nutrients discharged through SGD become the main factor for the balanced growth of phytoplankton (Dodds and Whiles, 2019). Analogous conditions of the N:P ratio is observed during upwelling also (Tyrrell, 2019). Coastal upwelling occurs during SW monsoon along the coasts of Southwest coast of India (Banse, 1959; Darbyshire, 1967; Johannessen et al., 1981; Lathipha and Murthy, 1985; Maheswaran, 2000; Muni Krishna, 2007; Rao et al., 2004; Sharma, 1978) involving the offshore transport of surface water and its replacement by cold, nutrient-rich subsurface water (Muni Krishna 2008). Nevertheless, the sampling season for the current study is Pre-monsoon (March), which is a non-upwelling season for the SW coast of India, accordingly, SGD-derived nutrient flow supports the primary productivity in the nearshore region of the Kozhikode urban segment.

CONCLUSION

The present study in the Vellayil Harbor located in the Kozhikode city limits focused on assessing the urbanized coastal aquifer for the groundwater discharge through the subsurface flow and its contribution to the nutrient budget using the radon mass balance model. The spatial distribution of radon concentration indicated its mixing inside the harbor water rather than identifying a point location of discharge. The SGD flux into the harbor was calculated as 13.25×10^4 m^3/day and is found to be less when compared with other regions of submarine discharge along the Kozhikode coast. SGD through this region is expected to be a combination of fresh groundwater and recirculated seawater where hydraulic gradient and tidal forcing are suspected to act as the drivers. Our study indicated that as the pollutant discharge to the groundwater is high it can lead to its disposal to the marine environment through SGD impairing the natural balance of the marine ecosystem. Thus, SGD through the urbanized coastal aquifer of Kozhikode coast acts as a contributor of nutrient fluxes to the harbor and to sea and influences its primary productivity, nutrient budget and nutrient cycling. Unchecked disposal of wastes, improper sanitation, and drainage can lead to increased nutrient discharge leading to unbalanced ecological coexistence with development. Appropriate waste disposal and aquifer management through regular monitoring and action plans are recommended in Kozhikode City to maintain a sustainable coastal environment and to ensure the availability of safe sanitation and drinking water. Also, this work contributes to the judicial management of sanitation and groundwater of Kozhikode City for ensuring sustainable management of the urbanized coastal aquifer.

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