Submarine groundwater discharge in the Indian context

In India, the demand for freshwater resources is increasing every year because of population rise and rapid economic development. This warrants the imminent need for better evaluation of all the available sources of freshwater and their discharge–recharge mechanisms for planning sustainable development strategies in the country. Among different sources, groundwater constitutes about 97% of the earth's liquid freshwater in the hydrologic cycle. It has now been realized that as part of the hydrologic cycle, a significant amount of groundwater flows directly into the sea through porous rocks and sediments[1]. This component is called submarine groundwater discharge (SGD). In a study carried out in the southern United States using ^{226}Ra as tracer[2], it was reported that the contribution of SGD in the coastal waters of the area could be comparable to the observed discharge from rivers[3]. Although India has an extensive coastline of about 7500 km, except selected case studies[4–10], no systematic efforts have hitherto been made to assess SGD flux to its receiving coastal waters. As the country is undergoing rapid economic development in the recent years, it is high time that the scientific community make efforts to estimate the quantity and quality of SGD flux to the Indian seas for planning and development of its freshwater potential.

The SGD component is temporally and spatially variable, as interaction between multiple forcing mechanisms varies at any given location and time. Hydraulic gradient influenced by topography and aquifer permeability are the main factors that determine the flux of SGD to the sea. The groundwater that is discharged to the sea along with surface (river) water as base flow is not considered within the ambit of SGD, as this water component could have originated far inland (meteoric groundwater) and transported to the coastal zone along with the fresh surface water before mixing with the sea water in the estuarine environment. On the other hand, SGD is characterized as subterranean estuary, where tide plays a different role.

The increasing population density and changing agricultural practices in the coastal areas of the country have led to the release of excessive quantities of nutrients and other contaminants into its coastal environments. This, in many cases, has led to eutrophication of the coastal waters, red tide, mud bank formation, algal bloom, methane emission, beach accretion, etc. The coastal seepage and submarine discharges are critical to the water balance and sea water quality. The aquifer discharge supports wetlands and brackish water habitats to maintain biodiversity and fishery nursery areas in the coastal region. Though the different components of the water budget are known in India (Figure 1), the component of water flowing into the oceans in the form of SGD is yet to be quantified on a national level.

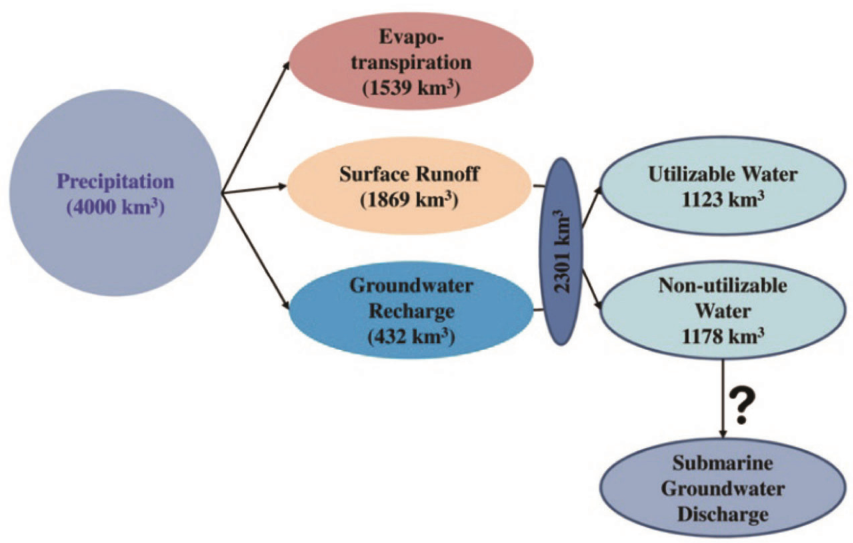

Figure 1. Water budget of the Indian subcontinent. (Source: Central Planning Commission Report, 2010)

In this context, the National Centre for Earth Science Studies (NCESS), Thiruvananthapuram, which is functioning under the Ministry of Earth Sciences, Government of India, is spearheading a national network project to understand the role of submarine groundwater discharge in the productivity of the Arabian Sea and the Bay of Bengal, and also to estimate the quantity of freshwater that can be tapped sustainably from coastal aquifers with barest minimum environmental impacts to the coastal/nearshore aquatic ecosystems.

The key conduits of SGD along the east and west coasts of peninsular and island regions include fractured Deccan trap rocks, contact zones between country rock and weathered horizons, regional joints and shear zones, Cenozoic sedimentary formations, limestone/karst tunnels, offshore springs, submerged palaeochannels, etc. In addition to the discharge through top unconfined/ phreatic aquifer systems, single or multiple zones of confined aquifers up to a depth of 500 m or more are also considered as favourable zones for exchanging flux. Deciphering three-dimensional geometry of such potential zones is the prime task of the Mission-SGD Programme funded by the Ministry of Earth Sciences, Govt of India. The programme is planned to be implemented with active participation and support of premier R&D organizations and universities in the country. The widely used methods to assess SGD are satellite image processing, thermal imaging, temperature/ salinity/isotope tracer techniques, hydrogeological surveys, resistivity surveys, seepage meter measurements, ground penetrating radar observations, carbon–nutrient flux determination, airborne geophysical surveys, shallow seismic surveys and aquifer modelling. A comprehensive assessment of the SGD component of the water cycle is essential in the context of climate change that would not only affect the hydrology of the coastal lowlands, but also the life and prosperity of the coastal communities at large.

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Invasion of biofouling mussel *Mytilopsis* Conrad, 1857 (Bivalvia: Dreissenacea) in the Cochin backwaters, southwest coast of India

The black-striped mussel, *Mytilopsis sallei* is an invasive biofouling bivalve native to the tropical and subtropical waters of the western Atlantic, which extends from Colombia to the Gulf of Mexico[1–4]. It is generally believed that their distribution towards the West Africa coast and beyond has been through attachment to the hull of ships since the 16th century. Later they were introduced to the Eastern Pacific via the Panama Canal, Fiji, Japan, Taiwan, Hong Kong, China, Philippines, Thailand, Singapore, Malaysia and India through ballast waters and also by attachment to the hull of ships. This species is reported to have invaded Indian waters through Visakhapatnam harbour during 1960s (ref. 5), and further reported from Mumbai harbour during 1975 (refs 6, 7).

Here we report on the occurrence of *Mytilopsis* sp. from the southwest coast of India (near Cochin harbour: 9°50′43.9″N, 76°17′17.2″E). During the study, the basic water quality parameters were measured using a standard multiparameter instrument (model: Eutech PC 450). Water column temperature was 27°C with 5 ppt salinity and 5.8 mg/l dissolved oxygen. Population density was estimated by quadrate method. The estimated population density of *Mytilopsis* sp. in Ezhupunna region of Vembanad Lake, Kerala, was 748 ind.m^{-2} (Figure 1). Specimens were identified based on key characters and other morphological features[8]. The right valve of the bivalve was slightly larger and overlapped the left valve. The shell colour was light yellowish-brown, while the juvenile mussels showed light and dark bands veering alternately to the right and left. The highly variable shell morphology of this species makes morphological identification difficult[9]. Therefore, a tissue sample from the specimen was subjected to molecular examination for species-level confirmation. A live individual was put in hot water for a few minutes and then preserved in 100% ethyl alcohol[10]. Prior to DNA extraction, the alcohol-preserved sample was hydrated at 26°C in 1 ml sterile distilled water for 10–12 h. Genomic DNA from the macerated tissue was extracted using the Qiagen DNeasy Blood and Tissue Kit (Germany, Catalog No: 69504) by following the spin column procedure. The polymerase chain reaction (PCR) mixture contained 25 μl Master Mix (Takara Clontech EmeraldAmp® GT PCR Master Mix), 1 μl reverse primer, 1 μl forward primer, 8 μl template DNA and 15 μl nuclease free water. The universal end primers 18S F (5′-CTGGTTGATCCTGCCAGT-3′) and 18S R (5′-TAATGATCCTTCCGCAGG-TTCACCT-3′) were used for amplifying 18S ribosomal RNA gene. Amplification was carried out in a thermal cycler (Agilent Technologies, model no. Sure cycler 8800). The protocol for amplification started with denaturation at 95°C for 1 min, annealing at 55°C for 2 min and extension at 72°C for 3 min; 30 cycles were performed. Amplified products were run on agarose gel (1.2%) electrophoresis. An intense band was developed, which was purified and sent for sequencing (SciGenom Labs Pvt Ltd, Ernakulam, Kerala). The acquired sequences were assembled by BioEdit 7.0.9 (ref. 11) and later aligned by ClustalX (ref. 12). A 757 base-pair length of ribosomal RNA gene sequence was developed in respect of *M. sallei* and submitted to the NCBI database with accession number KY013490. Two other sequences of *M. sallei* were obtained from NCBI for constructing a phylogenetic tree (maximum likelihood). The sequences of *M. sallei* specimens were arranged in a single clade with a high bootstrap value (100%). The selected out-group *Congeria kusceri* exhibited a divergent array (Figure 2). The sequences of *M. sallei* exhibited an intraspecific sequence divergence of 0%, which confirmed that the sequence obtained from the current geographic position (KY013490) clearly matched with those from Lam Tsuen River, Hong Kong, China (JX099476, JX099477)[4]. This result leads to the confirmation of bioinvasive occurrence of *M. sallei* in the Cochin backwaters. Five specimens,