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Short communication

Geographic information systems and multivariate analysis to evaluate fecal bacterial pollution in coastal waters of Andaman, India[☆]

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ABSTRACT

Urbanization of coastal areas in recent years has driven us to consider a new approach for visually delineating sites that are contaminated with fecal bacteria (FB) in the coastal waters of the Andaman Islands in India. Geo-spatial analysis demarcated harbor, settlement, and freshwater/discharge influenced zones as hot spots for FB, while the open sea was demarcated as a cold spot. The land use types, such as developed and agriculture, with more anthropogenic activities increasing the FB counts while open sea showed the least FB. Box whisker plot indicated an increasing FB trend in the coastal waters during monsoon. Furthermore, principal component analysis revealed 67.35%, 78.62% and 70.43% of total variance at Port Blair, Rangat and Aerial bays, respectively. Strong factor loading was observed for depth (0.95), transparency (0.93), dissolved oxygen (0.93) and fecal streptococci (0.85). Distance proximity analysis revealed that fecal contaminations diluted significantly ($P < 0.05$) at the distance of 2.1 km toward the deeper or open sea water. This study demonstrates the effectiveness of an integrated approach in identifying the sources of fecal contamination and thus helping in better monitoring and management of coastal waters.

1. Introduction

Coastal waters are susceptible to fecal bacterial pollution from sewage mixing in streams/rivulets, excreta of birds and animals, and from other poorly understood environmental reservoirs such as soils and sands which can add fecal bacteria (Boehm et al., 2009). Fecal wastes are carriers of many infectious pathogens which pose a major threat to human health (Harwood et al., 2005). Approximately 120 million gastrointestinal infections and numerous skin diseases are recorded globally due to fecal pollution in coastal waters (Viau et al., 2011). The United States Environmental Protection Agency (USEPA, 2012) has recommended *Escherichia coli* and fecal coliform as fecal indicator bacteria (FIB) which cause water quality impairments. In addition to the above, fecal streptococci has also been suggested as a fecal pollution indicator (Slanetz and Bartley, 1964) in conjunction with either the coliforms or fecal coliforms to establish the source of pollution (Barbaro et al., 1969; Geldreich and Kenner, 1969). In marine environments, microbes are primarily removed by the filter feeding systems of shellfish (Rodrigues et al., 2011; Campos et al., 2013) and/or diluted from coastal bays by tidal variations and differential FIB sensitivities to salinity due to osmotic shock and radiation (McLaughlin et al., 2007; Rippy et al., 2013).

Tidal variation and river flow affect the bacterial concentration in coastal bays (Rodrigues et al., 2011). The semi-enclosed bays differ from the oceanic environment, providing shelter to many marine flora and fauna. Further, physical factors, such as geomorphology of the coastal bay, depth and prevailing water currents, are major variables affecting coastal waters (Jonge et al., 2002). The population in the coastal area depends on these water-bodies for navigation, transportation and fishing (Jha et al., 2013; Sahu et al., 2013; Dheenan et al., 2014; Meena et al., 2015). These bays

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become polluted due to fecal contamination through point and non-point sources and thus cause serious concerns for the public, as well as for the environment. Hence, public health and environmental protection needs to be addressed through efficient detection, prediction and management of FB pollution. Fecal bacterial contamination of coastal waters is a manifestation of the interplay between many environmental processes and thus a systematic approach is required to investigate the sources. Although, hot spot analysis has been widely used for crime mapping (Ratcliffe and McCullagh, 1999; Harries, 1999) its usage for fecal bacteria contamination (Jent et al., 2013) in coastal waters is limited. This study proposes an innovative approach which combines hot spot, distance proximity and principal component analysis (PCA) in a comprehensive manner to visually delineate the FB polluted zones.

Hot spot and PCA are useful tools to explore and identify the spatio-temporal variations and potential pollution sources in coastal waters (Zhou et al., 2007; Huang et al., 2011). Galvin et al. (2013) used the geographical information system (GIS) based hot spot analysis to find out the spatial diffusion patterns of infectious microbes. This tool identifies statistically significant spatial clusters of high (hot spots) and low FB values (cold spots) and thus aiding in the coastal environment management. The objectives of the present study are 1) to estimate FIB and related physicochemical parameters in coastal bays, 2) to develop a hot spot map of FIB, and 3) to establish the role of distance proximity analysis in the diffusion of fecal pollution.

2. Materials and methods

2.1. Description of study area and sample collection

The Andaman Islands consist of land with several bays and are spread over a 350 km stretch from north to south, receiving heavy rainfall (3035 mm/year) for eight months of the year (Indian Meteorological Department (IMD), Port Blair). The Andaman Islands have three important bays (Fig. 1): Aerial Bay (AB) at North Andaman; Rangat Bay (RB) at Middle Andaman and Port Blair Bay (PBB) at South Andaman. Port Blair is the capital city of Andaman and Nicobar (A & N) Islands and its bay covers a 30 km^2 area which is influenced by heavy navigational, anthropogenic activities and land based runoff. Rangat Bay is a small semi-enclosed bay with an area of 6.55 km^2 located on the eastern side of Middle Andaman, surrounded by villages, mangroves and creeks. Aerial Bay is one of the main ports of the North Andaman Islands with a water spread of approximately 55 km^2. These bays are used for inter-island boat service, mainland bound shipping and fishing activities.

Surface seawater samples were collected from these bays in high and low tides during the period from 2010 to 2011. In total, 252 samples were collected from 42 sampling locations during pre-monsoon, monsoon and post-monsoon seasons.

2.2. Environmental parameters

The sampling stations were selected based on the prevailing environment and land use pattern around the bays. The seawater samples were collected from the freshwater discharge (FW), mangrove (MN), human habitation (HB), jetty/harbor (JT) and open sea (OS). Surface seawater samples were collected with the help of a GO-FLO (Model 1080) water sampler for analysis of physicochemical parameters such as dissolved oxygen (DO), biochemical oxygen demand (BOD) and total suspended solids (TSS). The GO-FLO sampling bottle features a close-open-close operation (hydrostatic pressure activated) which flushes until closed by standard GO Devil messenger (model 1000-MG). The GO-FLO sampling bottle avoids sample contamination, loss of sample on the deck and exchange of water from different depths. Water temperature (WT), salinity and pH were measured *in situ* using a calibrated multi-parameter water quality instrument (Hanna, Model: HI9828). A secchi disc with graduated markings was used to measure the transparency and depth. The DO and BOD was measured using Winkler's titration method (Winkler, 1888). The TSS was determined by filtering 1 L of seawater in pre-dried and pre-weighed (Millipore GF/C) filter paper (APHA, 1995).

2.3. Microbial analyses of seawater

Surface seawater samples were collected in sterile bottles for the estimation of fecal coliforms (FC), fecal streptococci (FS) and total heterotrophic bacteria (THB). These samples were transported to the laboratory in an ice box and analyzed within 4 h. USEPA filtration methods 1604 and 1600 were followed to quantify the FC and FS (USEPA, 2002a, 2002b), respectively. Total heterotrophic bacterial counts were estimated using Zobell Marine Agar (ZMA) by the spread plate method and total colonies observed were expressed as Colony Forming Units (CFU) per 100 mL. All physicochemical and bacteriological samples were analyzed in triplicate and quality control procedures (USEPA, 2012) were followed by using careful procedural standardization and blank measurements.

2.4. Statistical analysis

Statistical analyses, such as Pearson correlation, Analysis of Variance (ANOVA) and PCA, were performed on physicochemical and bacteriological data using SPSS software (version 17). Correlation is a simplified statistical tool to establish the relationship between two variables and also show the degree of dependency of one variable to the other (Belkhiri et al., 2010). The PCA reduces the dimensionality of the data set from a large number of variables into a smaller number of underlying factors (principal components or PCs), without losing information (Helena et al., 2000; Ahmad et al., 2013). Kaiser–Meyer–Olkin (KMO) measurement was performed to examine the suitability and sampling adequacy of the data. Box-plot graphs were also prepared for physicochemical and bacteriological data using SPSS software (version 17).

2.5. Hot spot analysis

The latitude and longitude of the sampling locations were recorded by a global positioning system (GPS; Garmin eTrex Vista-H, ±3 m). A geo-database of the above mentioned physicochemical and bacteriological parameters with geo-coordinates was developed in Microsoft Excel and imported into ArcGIS® 9.3.1 software (ESRI, 2009). The dataset was processed in ArcGIS 9.3.1 using the hot spot analysis tool. This tool created an output feature class with a z-score and p-value for each input feature class. The point features generated z-scores and p-values, which statistically distinguished the hot and cold spots. The inverse distance weighted (IDW) interpolation technique was used for developing thematic (Facchinelli et al., 2001; Wang, 2006) layers using the point features generated through hot spot analysis for FC and FS. The IDW uses the measured values surrounding the prediction location and assumes that each measured point has a local influence that decreases with distance (Mueller et al., 2004; Wang, 2006; Xie et al., 2011). Spatial autocorrelation in GIS helps understand the degree to which one object is similar to other nearby objects and was performed using Moran's I (Index) tool available in ArcGIS (Gu et al., 2012). To determine the hot and cold spots, indicated by red and blue, respectively, on thematic map, the following equations were used in the analysis: