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Multivariate statistical analysis and geochemical modeling for geochemical assessment of groundwater of Delhi, India

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ABSTRACT

Groundwater is the most important source of drinking waters supply in the National Capital Territory (NCT) of, New Delhi, India. A diverse geological and topographical set up along with the fast growing population and anthropogenic activities has created a need of groundwater quality assurance for drinking and domestic water supply in the region. The major hydro-geochemical process and impacts of anthropogenic activities can be deciphered using multivariate statistical analysis, conventional graphical plots and saturation indices. Groundwater samples were collected from 170 locations spread over entire region and were analysed for a total of 12 water quality physico-chemical parameters. It is observed that the groundwater is neutral to alkaline in nature with electrical conductivity (EC) value ranging from 460 to 8980 μs/cm. Chemometric analysis was performed along with geochemical modeling. The 3 clusters obtained through HCA were clearly differentiated based on their chemical characteristics i.e. concentration of major ions. High concentration of nitrate (NO_3^-) and fluoride (F^-) exceeding WHO standards was found in 29% and 27% of the water samples respectively. It is observed that semi-arid climatic conditions along with rock-water interaction, weathering and ion-exchange are the major factors controlling groundwater quality in the region. Oversaturation of fluorite and gypsum has resulted into high concentration of F^- in study area. It is found that the results from statistical and geochemical models compliment the findings using conventional plots and are able to decipher comprehensive geochemistry of groundwater in the region.

1. Introduction

Groundwater is a major concern for the community as it is the most important and reliable source of freshwater supply on earth. Groundwater is a renewable and finite natural resource, vital for man's life, socio-economic development and a valuable component of the ecosystem, vulnerable to natural and human impacts (Singh et al., 2011a). In general groundwater is considered to be safe than surface water in terms of microbial contamination because of the unique filtration capacity of soil matrix above the aquifer, however it also induces geogenic contaminants at times. Groundwater quality in an area is a function of physico-chemical parameters that are greatly influenced by natural processes such as intermixing of water, water chemistry in recharge area, flowpath, rock-water interaction, climatic conditions along with geological formations and anthropogenic activities (Barbecot et al., 2000; Belkhiri et al., 2010; L-Ruiz et al., 2015). Natural processes such as recharge and discharge, precipitation or dissolution of aquifer minerals, ion-exchange, oxidation-reduction, residence time and mixing of water has a great influence on groundwater quality (Reghunath et al., 2002). Anthropogenic activities such as over withdrawal of groundwater, leaching of fertilizers and accidental spillages also influences the quality of groundwater. The contamination in groundwater persists for longer duration due to low flow rate of groundwater in aquifer system. Chemical characteristics of groundwater determine the suitability of water for domestic, agricultural or industrial use (Mondal et al., 2010; Li et al., 2012; Roques et al., 2014; Kumar and Singh, 2015). Increased population, unplanned landuse practices and high water supply demands has deteriorated both the quality and quantity of groundwater (Hamilton and Helsel, 1995; Machiwal and Jha, 2015; Liu et al., 2016). In recent past, studies have been conducted using different methods including multivariate statistical analysis (Yidana and Yidana, 2010; Singh et al., 2011b; Machiwal and Jha, 2015), geochemical modeling (L-Ruiz et al., 2015; Suma et al., 2015; Singh et al., 2012; Yidana et al.,

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2008), stable isotopes (Barbieri et al., 2005; Carucci et al., 2012), redox indicator, structural equation modeling (Belkhiri and Narany, 2015) to investigate the geochemical evolution and hydrochemical processes controlling the chemical characteristics of groundwater. Statistical analysis do not necessarily establish cause and effect relationships, but collates the information in a compact format by removing data redundancy as the first step in the complete analysis and thus assist in generating hypothesis for the interpretation of various hydrochemical processes (Guler et al., 2002). Multivariate analysis of geochemical data operates on the concept that each aquifer zone has its own unique groundwater quality signature, based on the chemical characteristics of the sediments that surround it (Singh and Mukherjee, 2015). Inverse geochemical modeling involves a mass balance model which is used to quantify the reactions and thus the chemistry of groundwater in its flowpath and rock-water interaction (Barbieri et al., 2005; Carucci et al., 2012; Yidana et al., 2008; Appelo and Postma, 2005). Contaminants such as nitrate (NO_3^-) and fluoride (F^-) have an adverse impact on human health. High concentration of NO_3^- in groundwater may cause methemoglobinemia, pre-mature birth and blue baby syndrome, whereas high concentration of F^- may cause lack of enamel formation, moulting of teeth, bone fragility and at the severe stage it may cause bilateral lameness and stiffness of gait (Edmunds and Smedley, 2005; Singh et al., 2011a; Singh et al., 2013a)

With the above background an attempt has been made to decipher the geochemistry of groundwater using statistical and geochemical models and to determine and understand the fate of contaminants such as F^- and NO_3^- as these are harmful from public health perspective.

2. Material and methods

2.1. Study area

The national capital city of India, New Delhi is situated between 28°23′17″N–28°53′00″N latitude and 76°50′24″E–77°20′37″E longitude (Fig. 1). The study region covers around 1480 km^2 of area and the altitude varies from 213 m to 305 m from mean sea level. The climate is of semi-arid nature and average rainfall of Delhi is 714 mm, most of the rainfall (81%) occurs in monsoon season. The study area is a part of Gangetic alluvial plain as River Yamuna passes through the eastern part of the city. Geologically the study area is composed of older

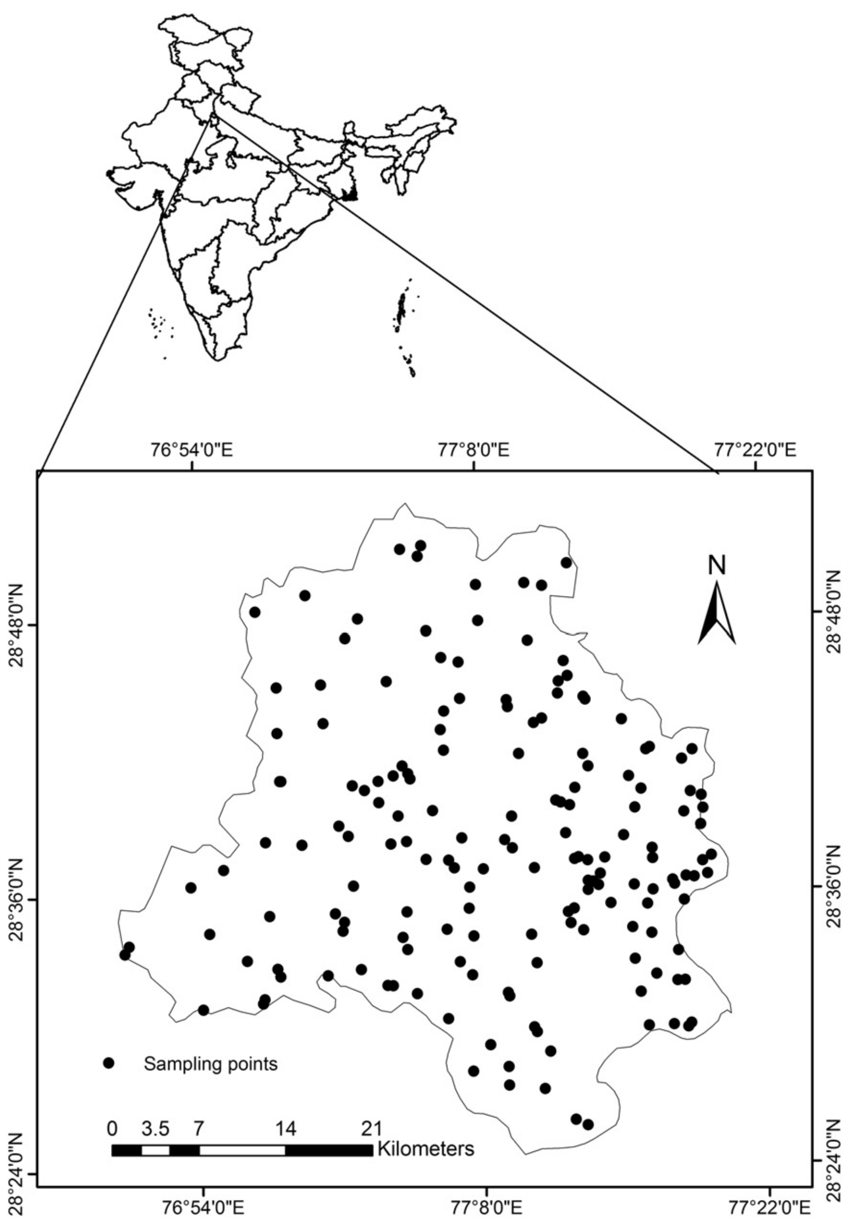

Fig. 1. Study area along with sampling locations.