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Hydrogeochemical zonation for groundwater management in the area with diversified geological and land-use setup

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ABSTRACT

Despite its limited aerial extent, the National Capital Territory (NCT) Delhi, India, has diversified geological and topographical setup. A geochemical assessment of prevailing conditions of aquifer underlying the NCT was attempted and further classified into different hydrogeochemical zones on the basis of statistical and analyses and its correlation with land use, geological and climatic setting. Mineral phase study and isotopic analyses were used for the verification of performed clustering. Saturation indices (SI) calculated using the geochemical modelling code PHREEQC were used to distinguish the characteristics of four zones, as saturation states of the water does not change abruptly. Four different hydrogeochemical zones were statistically identified in the area: (1) intermediate (land-use-change-impacted) recharge zone, (2) discharge (agriculture-impacted) zone, (3) recharge (ridge) zone, and (4) recharge floodplain (untreated-discharge-impacted) zone. The distinctiveness of hydro-geochemical zones was further verified using stable isotopic (^{2}H and ^{18}O) signature of these waters. GIS-based flow regime in association with long-term geochemical evidences implied that these zones are being affected by different problems; thus, it necessitates separate environmental measures for their management and conservation. The study suggested that in a diversified urban setup where the complex interactions between anthropogenic activities and normal geochemical processes are functioning, hydrogeochmical zoning based on the integration of various techniques could be the first step towards sketching out the groundwater management plan.

1. Introduction

Any environmental component (atmosphere, lithosphere, hydrosphere, pedosphere, biosphere) has its share of pollution source (common or specific), the effect of which can be global, regional or local (Belousova and Proskurina, 2008). Sustainable water management in order to meet the relentlessly growing drinking water demand of urban population, especially in the developing countries, is among the most indispensable environmental issues. Further, in the present era of high population growth, rapid urbanisation and climate change, the unpredictable frequency and intensity of rainfall makes it difficult to plan any precise water management and storage schemes (Kumar et al., 2011). Therefore, dependence on groundwater has increased substantially. Considering the gradual increase of impervious zones and limited drainage efficiency in many highly urbanised cities like the National Capital Territory (NCT) of Delhi, India, hydrogeochemical zoning based on prevailing groundwater quality, land-use, soil type, natural topographical surface condition, available pollution sources, and water–mineral equilibrium is the first step towards sustainable urban water management. Recently, some studies demonstrated the importance of geomorphological features in regulating various contaminants in groundwater (Nas and Berktay, 2006; Kannel et al., 2008; Papacostas et al., 2008; Quicksall et al., 2008; Kim et al., 2009). Others suggest the importance of hydrological condition, i.e., aquifer disposition, land-use, and recharge rate, for the determination of groundwater contamination susceptibility (Kelly, 1997; Cey et al., 1999; Kraft et al., 1999; Petry et al., 2002; Chae et al., 2004; Stute et al., 2007; Aziz et al., 2008). However, most of the studies were carried out in alluvium plain with more or less uniform land-use (mostly agriculture). The groundwater susceptibility under diversified geological setup and urban land-use is still poorly understood, and

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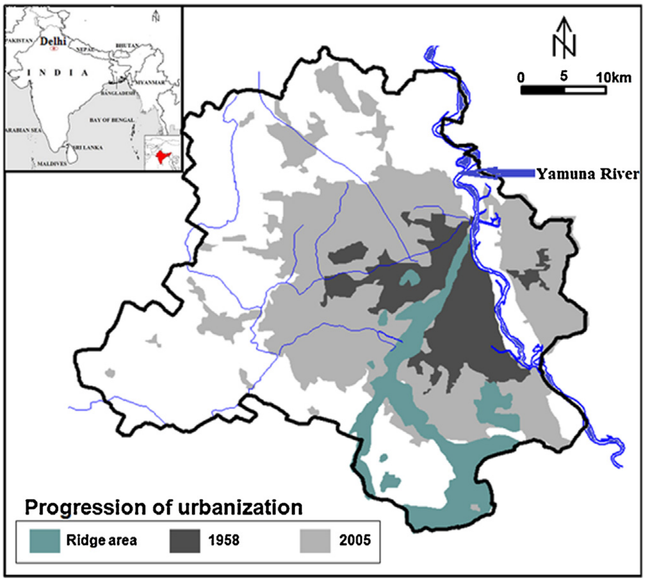

Fig. 1. Land-use change in Delhi over time shown through progression of urbanisation. Thin lines in the map show drains and canals.

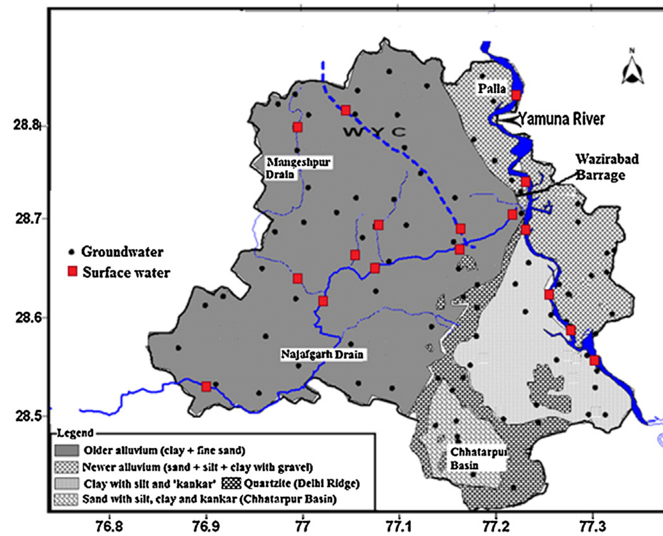

Fig. 2. Sampling locations (marked with dots) and general geological map of National Capital Territory (NCT) – Delhi, India. Curved lines are showing different drains (thick line indicates Najafgarh drain, dotted lines shows Western Yamuna Canal (WYC) while thin lines for minor drains).

its importance for groundwater management is not yet properly evaluated in detail.

In this study, with an extended and bigger time series data base of 3 years, an attempt has been made to classify one of the fastest growing mega cities (Delhi, India) in the World (Economic Survey of Delhi, 2005–2006) into different hydrogeochemical zones. The scale and magnitude of land transformation in Delhi was never as rapid and unplanned as that in the last decade of twentieth century, which has increased the severity of the drinking water problem (CGWB, 2003). Land-use in Delhi (Fig. 1), as in any other cities in the world, has a major influence on groundwater recharge, water use, and water quality (Datta et al., 1997; Chae et al., 2004; Rao et al., 2007; Kumar et al., 2006, 2009a, 2009b, 2011). In the presence of diverse landform features and rapid land-use change, it is difficult to identify groundwater resources that can be exploited as sustainable drinking water supplies. The water management issues are further complicated by undocumented groundwater extraction and the presence of various diffuse pollution sources. Therefore, it is important to differentiate and understand the hydrogeochemical zones of the aquifers, water–mineral equilibrium conditions, and seasonal hydrogeochemical cycles in detail for planning any future development schemes.

The main issues that are addressed in the present paper include: (1) delineation of various hydrogeochemical zones in the region, (2) formulation of management options for each zone, and (3) evaluation of distinctiveness of each zone through evaluation of the fluid–rock equilibrium state using PHREEQC and isotopic signatures. The results of this study elucidated the effectiveness of integrated use of different techniques and tools like cluster analyses, stable isotope tracers, geochemical modelling and GIS for the hydrogeochemical zoning of any diversified urban setup. Finally, the paper evaluates the capability of major ion chemistry and statistical techniques to delineate hydrogeochemical zones in a complex geological and urban setup.

2. Site description

Delhi has an area of 1483 km^2, which lies between 28°24′17″ N and 28°53′00″ N latitude and 76°50′24″ and 77°20′37″ E longitude (Fig. 2). The Delhi region is a part of the Indo-Gangetic Alluvial Plains with elevation ranging from 198 m to 263 m above mean sea level. The main seasonal climatic influence is the monsoon rainfall, typically from June to September. The mean annual rainfall in NCT Delhi is 612 mm with large year-to-year variations. About 81% of the rainfall occurs in three months of July, August and September (CPCB, 2001).

2.1. Geomorphology

Physiographically, the region shows four major units (Fig. 2): (a) the Delhi ridge consisting of quartzite rocks, (b) Chhatarpur alluvial basin that is occupied by the alluvium derived from the adjacent quartzite ridge, (c) Alluvial plains on eastern and western sides of the ridge, and (d) the Yamuna River flood plain deposits (CGWB, 2003; Kumar et al., 2006). The alluvium formations within the territory are either due to recent sedimentation processes termed as Newer Alluvium or due to the sediment deposited earlier, termed as Older Alluvium. The newer alluvium is distributed mainly in the Ridge region, the floodplain of Yamuna and the Chhatarpur closed basin. It is marked by the absence of permanent vegetation because of active sedimentation or erosion processes. The rest of the area is covered by the older alluvium. The thickness of the alluvium increases in the direction away from the Ridge (Seth and Khanna, 1969). A dense network of lined canals exists in the north-western part of the state. A number of micro watersheds originate from the quartzite ridge.

2.2. Hydrogeology

The aquifer system of the newer alluvium is mostly unconfined. A generalised geological succession with their hydrological condition and groundwater production potential is published elsewhere (Kumar et al., 2006). The aquifer system of newer alluvium can sustain tube wells with yield ranging from 1400 to 2800 L/min (lpm). Transmissivity of the new alluvium aquifer system varies from 730 to 2100 m^2/day, with hydraulic conductivity varying between 13 and 60 m/day. Wherever the proportion of 'Kankar' (granules of calcium carbonate) is high, the beds form moderately permeable granular zones with transmissivity varying from 130 to 350 m^2/day. The specific yield and storage values are expected