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Groundwater quality in Ghaziabad district, Uttar Pradesh, India: Multivariate and health risk assessment

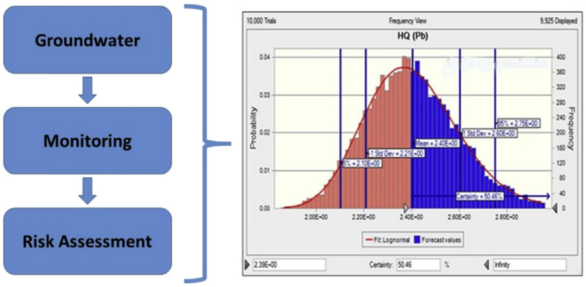
Mayuri Chabukdhara [a, b, *], Sanjay Kumar Gupta [b], Yatharth Kotecha [b], Arvind K. Nema [b]

[a] *Department of Environmental Biology and Wildlife Sciences, Cotton College State University, Guwahati, Assam 781001, India*
[b] *Environmental Engineering Laboratory, Department of Civil Engineering, Indian Institute of Technology, Hauz Khas, New Delhi 110 016, India*

HIGHLIGHTS

- Groundwater in urban & peri-urban regions of Ghaziabad district were monitored.
- Sources, status of metal pollution and associated risks were assessed.
- PCA showed mixed origin for Pb, Cd, Zn, Fe & Ni, natural origin for Cu and Mn.
- FCA indicated serious level of metal pollution in urban regions.
- Findings suggest health risk of metals to the children over prolonged period.

GRAPHICAL ABSTRACT



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ABSTRACT

This study aimed to assess the quality of groundwater and potential health risk due to ingestion of heavy metals in the peri-urban and urban-industrial clusters of Ghaziabad district, Uttar Pradesh, India. Furthermore, the study aimed to evaluate heavy metals sources and their pollution level using multivariate analysis and fuzzy comprehensive assessment (FCA), respectively. Multivariate analysis using principle component analysis (PCA) showed mixed origin for Pb, Cd, Zn, Fe, and Ni, natural source for Cu and Mn and anthropogenic source for Cr. Among all the metals, Pb, Cd, Fe and Ni were above the safe limits of Bureau of Indian Standards (BIS) and World Health Organization (WHO) except Ni. Health risk in terms of hazard quotient (HQ) showed that the HQ values for children were higher than the safe level ($HQ = 1$) for Pb (2.4) and Cd (2.1) in pre-monsoon while in post-monsoon the value exceeded only for Pb ($HQ = 1.23$). The health risks of heavy metals for the adults were well within safe limits. The finding of this study indicates potential health risks to the children due to chronic exposure to contaminated groundwater in the region. Based on FCA, groundwater pollution could be categorized as quite high in the peri-urban region, and absolutely high in the urban region of Ghaziabad district. This study showed that different approaches are required for the integrated assessment of the groundwater pollution, and provides a scientific basis for the strategic future planning and comprehensive management.

1. Introduction

Groundwater, which is considered relatively free of waterborne pathogens, is one of the most valuable freshwater sources being used for the drinking purposes throughout the world. The quality of

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[*] Corresponding author.
E-mail address: mayuri_chabukdhara@yahoo.co.in (M. Chabukdhara).

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water is identified in terms of its physical, chemical, and biological parameters (Sargaonkar and Deshpande, 2003). The contamination of groundwater is of serious concern (Crévecoeur et al., 2011). In developing countries, lack of access to clean drinking water is adversely affecting the general health and life expectancy of a population (Nash and McCall, 1995). The cultural shift of using groundwater instead of surface water for drinking in South and Southeast Asia resulted in a decrease of waterborne diseases, however, it has resulted in an increase chronic exposure to naturally occurring inorganic toxic substances (Bacquart et al., 2015).

Owing to the toxicity, persistence, and high bio-accumulative potential, heavy metal pollution of water is of serious environmental concern (Pekey et al., 2004). Severe human health implications such as cardiovascular and skeletal diseases, infertility, and neurotoxicity etc. are associated with the exposure of heavy metals to the human beings (WHO, 2011). Exposure of metals to the human beings are results numerous liver and kidney problems moreover such group of toxicants is considered as a genotoxic carcinogen (Knight et al., 1997; Loubieres et al., 1999; Strachan, 2010). Some of the metals are essentially required in traces for the growth and functions of living organisms, however, exposure to higher concentrations are toxic for human and aquatic life (Ouyang et al., 2002). The elevated level of toxic metals in the groundwater poses substantial risks to local resource users and to the natural environment (Sang et al., 2008). In addition to geogenic sources, metal pollution in groundwater have been triggered due to rapid industrialization and urbanization followed by indiscriminate, uncontrolled and unplanned disposal of wastes, intensive agricultural practices, leaching and percolation from heavily contaminated sites (Sharma and Al-Busaidi, 2001; Srinivasa and Govil, 2007; Kavcar et al., 2009). Further, currently, there is no regulatory criterion of metals concentrations in groundwater in India.

Ghaziabad is one of the fastest growing cities in India that houses more than 300 industrial units. The information of ground water contamination Ghaziabad city has been merely reported in previous studies (Singh et al., 2012, 2014; Kumari et al., 2013). The present study focuses on a comprehensive evaluation of heavy metals contaminations in groundwater in and around the urban-industrial regions and peri-urban regions of Ghaziabad, Uttar Pradesh, India using various approaches. More specifically, the objectives of the study are: (1) to assess the distribution of selected heavy metals (Cu, Cr, Pb, Cd, Zn, Mn, Fe and Ni) in groundwater; (2) to identify possible sources of contaminations by multivariate analysis; (3) to estimate non-carcinogenic health risk *via* consumption; and lastly (4) to evaluate the level of heavy metal pollution in groundwater using fuzzy comprehensive assessment model based on fuzzy set theory.

2. Materials and methods

2.1. Study area description

Ghaziabad district in Uttar Pradesh, India is situated in the center of the Ganga-Yamuna doab and is one of the fastest growing industrial cities of the India. The agriculture is dominated in the peri-urban area of the Ghaziabad district whereas the urban areas are mostly dominated by small scale industries. The climate of this region is tropical to temperate with extreme temperature conditions in summer and winter. During the summer season, the temperature remains in between 43 °C and 30 °C, whereas, in winter it fluctuates from 25 °C to 5 °C. The soil range from pure sand to stiff clays and the aquifer material is medium to a coarse-grained sand exception being a trans-Hindon area (CGWB, 2009). Huge numbers of small-scale, medium, as well as heavy industries including textiles, galvanizing/electroplating, diesel engines, distilleries, picture tubes and glassware, paint and varnish industries, lead reprocessing, automobile pistons, rings, steel, pharmaceuticals, and pesticide etc are situated in the Ghaziabad (Chabukdhara and Nema, 2012a,b). Groundwater in the region is used for irrigation, domestic and industrial purposes.

2.2. Groundwater sampling

The groundwater samples were collected from 22 different sites from both peri-urban and urban regions of Ghaziabad district during pre-monsoon (May) and post-monsoon (November) season in 2010 (Fig. 1). The annual the rainfall is around 80–85% between July to September due to the southwest monsoon (CGWB, 2009). The mean annual rainfall in this region is 732 mm varying spatially in different sub-regions of the district. Based on the locations, groundwater samples were collected from 4 sites in peri-urban region (GW-1, 20, 21 and 22) and 18 sites in urban region (GW-2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, and 19). The description of sampling sites is provided in Table S1 (Supplementary Material). The water samples were collected in pre-cleaned 1000 ml plastic bottles from hand-pumps and borewells. The collected samples were stored airtight ice-cold containers and transported to the laboratory within 6 h of collection.

2.3. Analytical analysis

All the physico-chemical analysis was performed following the standard methods (APHA, 1998). For metal analysis in water, water samples (50 ml) were digested with 10 ml of concentrated HNO_3 at 80 °C until the solution became transparent (APHA, 1998). The solution was filtered through Whatman No. 42 filter paper and was diluted to 50 ml with ultrapure water. The metal analysis was carried out by a double-beam atomic absorption spectrophotometer (ECIL 4141, India).

2.4. Reagents and standards

The analytical grade (AR) chemicals were used throughout the study without further purification. All the metal standard solution was prepared by successive dilution of certified standards (1000 mg L^{-1}) procured from E-Merck, Germany. All the experiments were carried out in triplicate. Only ultrapure water was used for the preparation all the standards and reagents.

2.5. Quality control

The analytical data quality was guaranteed through the implementation of laboratory quality assurance and quality control methods, including the use of standard operating procedures, calibration with standards, analysis of reagent blanks, matrix spikes, recovery of known additions, and analysis of replicates. All analysis was carried out in triplicate, and the results were expressed as the mean. The reagent blanks were monitored throughout the metal analysis and used to correct the analytical results. The detection limit was defined as three times the standard deviation from the mean blank.

2.6. Data analysis

The data were analyzed using a statistical package SPSS® (Window Version 17.0) and with XlStat, an add-in package of Microsoft Excel 2011. The multivariate analysis such as correlation analysis and principal component analysis (PCA) was used for source analysis following the methods explained elsewhere