Spatial distribution of various parameters in groundwater of Delhi, India

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Abstract: The present study analyzed the spatial variability in groundwater quality and depth in National Capital Territory (NCT) of Delhi, India. The study classified the parameters into five distribution classes viz., low, moderately low, moderate, moderately high, and high. Spatial variability maps were generated using kriging tool in ArcGIS environment. Primary data collected seasonally during 2012–2014 were used for the generation of maps. Physico-chemical parameters were correlated with each other and groundwater depth. All the parameters were found to be negatively correlated with groundwater depth. Spatial distribution maps showed that maximum concentration of most parameters was found in the northern parts of the study area, while maximum depth was reported from the southern part. Maximum area of around 59% of total area of Delhi has low electrical conductivity, TDS, and hardness values. With groundwater depth improving toward north Delhi, groundwater quality is found to be improving toward south parts of Delhi.

Subjects: Earth Sciences; Environment & Agriculture; Environmental Studies & Management

Keywords: groundwater; Delhi; depth; water quality; Kriging; Environmental sustainability engineering

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PUBLIC INTEREST STATEMENT
Groundwater is one of the cleanest freshwater resources available on earth and is considered as the most threatened resources. Since groundwater is non-uniformly distributed throughout the world, its availability and quality are of the major concern for urban and agricultural areas. The present work was conducted in National Capital Territory (NCT) of Delhi, one of the fast-growing capital cities of the world. Through the study, trend of groundwater depth and quality throughout the study area were found by collecting samples from certain sites. The study highlighted the depleting groundwater resources in southern parts of Delhi and deteriorating quality in northern parts instead of shallow water depth. Thus, the work can help authorities and planners to manage urban activities, especially urban and agricultural activities, to preserve groundwater resources and prevent its abuse.
1. Introduction

Groundwater is one of the most important sources of water for various human activities. With deteriorating surface water quality, there is an increasing reliance on groundwater resources in urban and rural areas. Thus, groundwater quality and quantity are continuously under threat due to abuse of resources. Problems of falling groundwater table and deteriorating groundwater quality have become a common problem throughout the world. According to State of India’s Environment’s (2015) report, India is one of the largest consumers of groundwater resources, distributed unevenly in the country. In India, there is lack of scientific data due to incomplete understanding in recharge and discharge processes of underground water and are mostly approximated. The number of groundwater withdrawal structures has increased rapidly leading to overexploitation and depletion of the resource (Singh & Singh, 2002). Das (2011) reported that the uneven alluvium region of Delhi is a potential groundwater reservoir of the city and diverse geology and topography of the area have significant control on movement of groundwater. With continuous and high influx of population, the capital of India is facing acute water shortage and groundwater is fulfilling about 50% of the water requirement (CGWB, 2006).

Estimation of groundwater quality and depth is vital for planning sustainable management of this vital natural resource, and thus requires handling of large amount of spatial and non-spatial data. Geographical Information System (GIS) is an important tool for dealing with such types of data (Chaudhary, Kumar, Roy, & Ruhal, 1996; Goyal, Chaudhary, Singh, Sethi, & Thakur, 2010; Sarma, Sarma, & Barik, 2012). Goovaerts (2000) stated that geostatistics was developed to deal with problems of spatially autocorrelated data (Moukana & Koike, 2008). Sarangi, cox, and Madramootoo (2005) attempted geostatistical techniques to know groundwater pollution and depth at unsampled locations. Kriging methods are considered for mapping spatial variations using spatial correlations between sampled points (Ella, Melvin, & Kanwar, 2001).

The present work is an attempt to find out the spatial variability in values of various physico-chemical parameters and depth of groundwater in NCT of Delhi using kriging interpolation tool of ArcGIS. The study was taken up as a reference from work by Dash, Sarangi, and Singh (2010) with primary data collected during 2012–2014.

2. Study Area

The National Capital Territory of Delhi lies between 28°24′15″ and 28°53′00″ N latitudes and 76°50′24″ and 77°20′30″ E longitudes with a total geographical area of 1,483 km². Delhi region is a part of the Indo-Gangetic Alluvial Plains, at an elevation ranging from 198 to 220 m above mean sea level (Dash et al., 2010). Physiographically, the region shows four major variations: (a) The Delhi ridge, which is a prolongation of Aravalli hills consisting of quartzite rocks, extending from the southern part of the territory to the western bank of Yamuna for a stretch of about 35 km. (b) The Chattarpur Alluvial basin, covering an area of about 48 km², is occupied by alluvium derived from the adjacent quartzite ridge. (c) Alluvial plains on the eastern and western sides of the ridge; and (d) Yamuna flood plain deposits (Kumar, Ramanathan, Rao, & Kumar, 2006). The primary source of groundwater in Delhi is from the southwest monsoon rainfall which occurs during the months of July–September (Datta & Tyagi, 1996).

For the present study, a total eight sites were selected based on the four land covers in Delhi viz., protected forest, trees outside forest, maintained park, and settlement area. Two sites under each land cover category were selected (Figure 1) for analysis.

3. Material and Methods

A total of 48 samples of groundwater were collected from the 8 selected study sites for physico-chemical analysis. Groundwater samples were collected in polyethylene bottles from tube wells and hand pumps after pumping the water for 10 min. Samples were collected during October 2012–June 2014, seasonally, for post-monsoon, winter, and summer. Groundwater depth was measured using Piezometers installed by Central Groundwater Board (CGWB). Groundwater temperature, pH, and
Electrical Conductivity (EC) were measured on-site using digital meters. Groundwater samples were collected in polyethylene containers and were analyzed for TDS, hardness (total, calcium, and magnesium), alkalinity, acidity, chloride, nitrate, sulfate, fluoride, sodium, and potassium according to the standard procedures given in APHA Standard Methods (1998). From all the physico-chemical parameters studied, nine parameters were selected for the present study using Principal Component Analysis (PCA). PCA and correlation of data were conducted by SPSS 19 software. Data acquired were used for generation of spatial variability maps by ArcGIS 10.2 software.

3.1. Kriging
Spatial interpolation techniques are used to find out values at points where data have not been estimated. Kriging is a geostatistical method for spatial interpolation. Kriging being a local and stochastic method of interpolation is better from deterministic methods in assessing prediction error with estimated variances (Chang, 2012). This method was used for generation of maps which is an advanced and unique interpolation technique that helps derive a predictive value for an unmeasured location. It is based on regionalized variable theory, which assumes that the spatial variation in the data being modeled is homogeneous across the surface. Kriging assumes that the distance or direction between sample points reflects a spatial correlation that can be used to explain variation in the surface. Kriging interpolation method suffers limitations in the case of outliers and non-stationarity in the data (Weise, 2001).

Two following tasks are necessary to make a prediction by kriging:
• Uncover the dependency rules
• Make the predictions
Thus, kriging goes through two steps to realize these two tasks:

(a) It creates variograms and covariance functions to estimate the statistical dependence values that depend on the model of autocorrelation.

(b) It predicts the unknown values.

Ordinary kriging which has been applied in the present study provides interpolated or kriged values from equations that minimize the variance of the estimation error. The coefficients of the linear combination known as weights depend on: (i) the distance between the sample point and the estimated point and (ii) the spatial structure of the variable. Ordinary kriging is based on the assumption that the mean of the process is constant and invariant within the spatial domain. This is expressed as:

\[ z(x) = \mu + \epsilon(x) \]

where, \( \mu \) is an unknown constant and generally considered the mean value of the regionalized variable; \( z(x) \) is the value of regionalized variable at any location \( x \) with stochastic residual \( \epsilon(x) \) with zero mean and unit variance (Dash et al., 2010).

4. Results and Discussion

Based on the PCA, nine physico-chemical parameters were selected for the present study (Belkhiri, Boudoukha, & Mouni, 2011; Choi et al., 2005), which are the contributing factors in the groundwater quality of NCT of Delhi. They are Electrical Conductivity (EC), TDS, total hardness, calcium, magnesium, sulfate, chloride, sodium, and potassium (Table 1). The varied ranges of all these parameters are considered as high, moderately high, moderate, moderately low, and low (Table 2).

About 60% of the area comprises low EC value (846.2 km\(^2\)) distributed partly in the districts of North, North West, North East, South, South West, East, Central, and New Delhi with EC value less than 1208 \(\mu S/cm\). An area of 47.4 km\(^2\) of North and North West districts recorded EC more than 3274.28 \(\mu S/cm\) (Figure 2(a)). According to Kazemi and Mohammadi (2012) EC values of more than 2000 \(\mu S/cm\) indicate salinization of aquifer (Gupta & Sarma, 2014). High electrical conductivity in groundwater may also be attributed to ion exchange and solubalization in the aquifer medium (Sanchez-Perez & Tremoliers, 2003; Sharma, Sarma, & Mahanta, 2012). According to Todd (2014), solution from rock materials is the primary source of soluble salts in groundwater. Similarly, TDS and hardness also show 59.8 and 58.8% of total area covered under low concentration values of less than 1163.38 mg/l and 382.35 mg/l, respectively (Figure 2(b) and 2(c)). Approximate areas under moderately low, moderate, moderately high, and high concentrations for EC, TDS, and hardness are also similar (Table 3). Similar trends for EC and TDS were also reported by Saka, Akiti, Osae, Appenteng, and Gibrilla (2013). Strong

| Table 1. Descriptive statistics of groundwater parameters |
|---------------------------------|---------------|---------------|---------------|
| Parameters                      | Minimum       | Maximum       | Mean          |
| E.C. (\(\mu S/cm\))             | 322           | 5090          | 1437.89       |
| TDS (mg/L)                      | 284           | 5862          | 1323.44       |
| Hardness (mg/L)                 | 120           | 1594          | 428.38        |
| Calcium (mg/L)                  | 8.02          | 108.22        | 32.34         |
| Magnesium (mg/L)                | 29.07         | 459.17        | 120.05        |
| Sulfate (mg/L)                  | 18.11         | 343.92        | 128.72        |
| Chloride (mg/L)                 | 25.56         | 1824.7        | 349.36        |
| Sodium (mg/L)                   | 23            | 1150          | 205.88        |
| Potassium (mg/L)                | 2             | 21            | 7.65          |
| Depth (mbgl)                    | 0.83          | 60.85         | 14.94         |
positive correlation among EC, TDS, and total hardness justifies the distribution of these parameters in groundwater of Delhi (Table 4). Similar correlations were also reported by Srivastava and Ramanathan, (2008) and Gupta and Sarma (2013). High salinity values restrict the use of water for

Table 2. Classification of groundwater parameter values in five distribution classes

| Parameters       | Low         | Moderately Low | Moderate | Moderately High | High        |
|------------------|-------------|----------------|----------|-----------------|-------------|
| E.C. (μS/cm)     | <1208       | 1208-1896.85   | 1896.85-2585.56 | 2585.56-3274.28 | >3274.28    |
| TDS (mg/L)       | <1163.38    | 1163.38-1888   | 1888-2613 | 2613-3339       | >3339       |
| Hardness (mg/L)  | <382.35     | 382.35-582.86  | 582.86-783.37 | 783.37-983.87   | >983.87     |
| Calcium (mg/L)   | <24.71      | 24.71-31.38    | 31.38-38.05 | 38.05-44.72     | >44.72      |
| Magnesium (mg/L) | <85.53      | 85.53-133.9    | 133.9-182.3 | 182.3-230.8    | >230.8      |
| Sulfate (mg/L)   | <71.25      | 71.25-110.47   | 110.47-149.69 | 149.69-188.90  | >188.90     |
| Chloride (mg/L)  | <343.52     | 343.52-634.81  | 634.81-928 | 928-1217.19    | >1217.19    |
| Sodium (mg/L)    | <171.95     | 171.95-281.42  | 281.42-390.88 | 390.88-500.35  | >500.35     |
| Potassium (mg/L) | <5.41       | 5.41-7.99      | 7.99-10.56 | 10.56-13.14    | >13.14      |
| Depth (mbgl)     | <12.9       | 12.9-23.04     | 23.04-33.14 | 33.14-43.24    | >43.24      |
drinking purpose. Calcium concentration between 31.38 mg/l and 38.05 mg/l under moderate class has maximum coverage of 527.2 km² (35.5%) distributed in parts of North, North West, South, South West, and New Delhi districts. While for magnesium, maximum area of 577.8 km² covering 39% of total area reported moderately low range of 85.53 mg/l to 133.9 mg/l. Parts of South, South West, and New Delhi districts have low magnesium concentration of less than 85.53 mg/l (Figure 2(e)). Sulfate in Delhi groundwater was reported in the range 18 mg/l–343 mg/l, out of which 168.8 km² area is with more than 228.12 mg/l and 231.7 km² (15.6%) areas having sulfate less than 71.25 mg/l (low range). Maximum area of Delhi (31.5%) was reported to have moderate sulfate concentration of 110.47–149.69 mg/l in groundwater. Craig and Anderson (1979), Miller (1979), and Kumar, Sharma, Ramanathan, Rao, and Kumar (2009) reported breakdown of organic substances from soil and leachable sulfate from anthropogenic activities are sources of sulfate in groundwater. Chloride concentrations are found to be low throughout Delhi with the average value of 349.36 mg/l. Only 1.7% of total area is reported to have high chloride value (more than 1508.37 mg/l) while 1010.6 km² and 268.3 km² areas are reported under low and moderately low concentrations of chloride, respectively. Similarly for sodium, maximum parts of Delhi have low sodium contents (171.95 mg/l) except few small pockets in the districts of North and North West having high sodium concentration. Dissolution activity of clay, gravel, feldspar, and kankar enhances the sodium concentration in groundwater (Kumar et al., 2009). According to CPCB (Central Pollution Control Board, 2008) report, high sodium in Delhi can be due to base exchange phenomenon. Strong correlation between sodium and chloride shows the same source of origin for the ions (Belkhiri & Mouni, 2013; Saka et al., 2013). Saka et al. (2013) also reported correlation of TDS with sodium and chloride. Potassium content is found less in Delhi with average concentration of 7.65 mg/l. An area of 13.8 km² of North and North West districts has potassium content more than 15.72 mg/l (Figure 2(i), Table 3).

Groundwater depth in Delhi varies from 0.83 meters below ground level (mbgl) to 60.85 mbgl (Figure 3). Low groundwater depth of less than 12.9 mbgl was recorded from about 35.6% of the total area and depth higher than 53.34 mbgl was recorded from only 3% of the area. Depth was

### Table 3. Area in sq. km under each distribution class of groundwater parameter values in Delhi

| Classes          | EC    | TDS  | TH   | Ca   | Mg   | Sulfate | Chloride | Na   | K   | Depth |
|------------------|-------|------|------|------|------|---------|----------|------|-----|-------|
| Low              | 846.2 | 886.8| 872  | 82.1 | 547.2| 231.7   | 1010.6   | 85.3 | 347.3| 528.5 |
| Moderately Low   | 330.2 | 306  | 369.6| 424.3| 577.8| 391.1   | 268.3    | 317.4| 590.7| 600.7 |
| Moderate         | 140.2 | 130.5| 116.8| 527.2| 201.3| 467.2   | 96.5     | 129.1| 261.1| 150.5 |
| Moderately High  | 119   | 114.4| 96.1 | 371.2| 120.3| 224.2   | 82.2     | 127.2| 145.4| 157.8 |
| High             | 47.4  | 45.3 | 28.5 | 78.2 | 36.2 | 168.8   | 25.4     | 54.3 | 138.5| 45.5  |
| Total Area       | 1483  | 1483 | 1483 | 1483 | 1483 | 1483    | 1483     | 1483 | 1483 | 1483  |

### Table 4. Correlation table for groundwater parameters and depth

|            | EC    | TDS  | Hardness | Calcium | Magnesium | Sulfate | Chloride | Sodium | Potassium | Depth |
|------------|-------|------|----------|---------|-----------|---------|----------|--------|-----------|-------|
| EC         | 1.00  | 0.98 | 0.90     | 0.33    | 0.66      | 0.75    | 0.95     | 0.83   | 0.79      | −0.43 |
| TDS        | 0.98  | 1.00 | 0.89     | 0.37    | 0.65      | 0.74    | 0.94     | 0.86   | 0.79      | −0.41 |
| Hardness   | 0.90  | 0.89 | 1.00     | 0.45    | 0.75      | 0.59    | 0.79     | 0.75   | 0.75      | −0.44 |
| Calcium    | 0.33  | 0.37 | 0.45     | 1.00    | 0.19      | 0.94    | 0.94     | 0.94   | 0.79      | 0.48  |
| Magnesium  | 0.66  | 0.65 | 0.75     | 0.19    | 1.00      | 0.49    | 0.68     | 0.57   | 0.48      | −0.45 |
| Sulfate    | 0.75  | 0.74 | 0.59     | 0.09    | 0.49      | 1.00    | 0.63     | 0.61   | 0.76      | −0.62 |
| Chloride   | 0.95  | 0.94 | 0.94     | 0.43    | 0.68      | 0.63    | 1.00     | 0.77   | 0.71      | −0.35 |
| Sodium     | 0.83  | 0.86 | 0.79     | 0.32    | 0.57      | 0.61    | 0.77     | 1.00   | 0.73      | −0.34 |
| Potassium  | 0.79  | 0.79 | 0.75     | 0.36    | 0.48      | 0.76    | 0.71     | 0.73   | 1.00      | −0.39 |
| Depth      | −0.43 | −0.41| −0.44    | 0.19    | −0.45     | −0.62   | −0.35    | −0.34  | −0.39     | 1.00  |
found to be improving toward north from the south, which may be attributed to River Yamuna as a source of recharge. Lowering of depth toward north Delhi may also be due to increase in hydraulic gradient toward northeast as reported by Dash et al. (2010). Kumar, Ramanathan, and Keshari (2009a) also supported the role of River Yamuna through western Yamuna canal as groundwater recharge source in parts of North, North West, East and North East districts. Moderately low levels of groundwater from 12.9 mbgl to 23.04 mbgl were reported from 600.7 km² covering parts of North West, West, South West, and Central districts. Areas of South Delhi include ridge parts which are considered as recharge zones for groundwater, but face uncontrolled groundwater extraction, leading to deeper water levels (Gupta & Sarma, 2014). Chatterjee et al. (2009) also found deep water table in the ridge area.

All the parameters reported highest values from north and northwest parts of the NCT of Delhi, while groundwater depth recorded maximum values from South Delhi. High nutrient concentrations in northern part of the study area were also recorded by Kumar et al. (2009). Groundwater depth was also found to be negatively correlated with all the physico-chemical parameters, thus justifying the good quality of water at sites with deep groundwater table. Hu et al. (2005), Dash et al. (2010) and Gupta and Sarma (2013) also reported high salinity in areas with minimal groundwater depth.

5. Conclusion
Being an important source of water supply, groundwater quality and depth are among the major issues of concern in an urban capital like NCT of Delhi, India. Knowledge of spatial distribution of physico-chemical parameters and depth of groundwater is a basic requirement for planning and management of resources. Kriging interpolation is one of the advanced geostatistical tools to study the spatial distribution of any parameter based on some spatial values available. The spatial variability maps of groundwater quality parameters and depth show the increase of all the physico-chemical parameters from north to south, while groundwater depth decreases from south to northern parts of Delhi. Thus, information obtained from the maps generated using kriging can be useful to delineate areas in NCT of Delhi under various categories of water availability or different water quality classes for planning, management, and policy-making.
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