JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

Groundwater Evaluation, Trace Elemental Assessment and their Regional Implications for shallow Aquifer of Ganga Alluvial Plain around Lucknow, northern India

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Abstract

A total of 109 groundwater samples were collected from the shallow alluvial aquifer of the Ganga Alluvial Plain during May - June, 2010 and were analyzed for their suitability of drinking and irrigation purposes. Geochemically, the groundwater belongs to the Ca-Mg-HCO_3 facies with neutral pH. Natural background levels were established as [HCO_3 (299), Cl (2.7), F (0.26), NO_3 (0.57), SO_4 (5.92), Ca (7.35), Mg (10.93), K (1.32),Na (9.97) in mg/l] and [Si (3.53), Al (66), As (0.37), Ba (142), B (31), Cd (0.06), Cr (1.00), Cu (0.50), Fe (257), Pb (0.20), Mn (45.0), Ni (2.30), P (15), Rb (0.56), Sr (300), Zn (2.0) in µg/l].The urban groundwater is revealed by high enrichment factors of Cu, Al, NO_3, Cl, Rb, Fe, Sr, Zn, Ba and Pb. The chemical ratios of [Cl/F]/Cl and [Na+K]/NO_3 indicate the migration of sewage cum domestic effluents into the shallow groundwater. The contamination with trace elements (Al, As, Cr, Cu, Pb, Ni and Cd) may be associated with the distribution of unplanned solid waste disposal processes in both rural and urban sites. The present case study provides the basic understanding for the need of urgent protection of the groundwater resource through waste management plans for the whole Ganga Alluvial Plain in northern India.

1. Introduction

Our basic health problems are commonly associated with lack of 'clean drinking water' that vary dramatically from region to region depending on geography, climate and economic development etc. In the search of 'clean water', the escalating contamination of surface water bodies has shifted tremendous pressure on groundwater resources during the last few decades[1,2,3] . The overexploitation of groundwater resources due to rising demand and reduced annual recharge has brought severe constraints leading to contamination. Alluvial aquifers (a linear hydro-geochemical units) are highly vulnerable to drinking water contamination due to their shallow nature and high permeability[4]. These drinking groundwater contaminants are implicated in causing human cancer[5]. Government's development plans are linked with the factors responsible for migration of these groundwater contaminants and have implications on the health of 500 million of people living across the alluvial plain.

India has 4% of the world's freshwater resources and, unfortunately, its one-third population does not have access to safe drinking water. On the other hand, it was estimated that about 21% of all communicable diseases are related to water. More than this, nearly 1.5 million children under the age of 5 die every year due to water-borne diseases[6]. The Government of India implemented several developmental programs in order to provide people with better prospects for economic development and improvement of common people by utilizing uncontaminated groundwater resources. The Ministry of Rural Development is mandated to provide safe drinking water in all rural habitations through countrywide as a path of National Drinking Water Program (NDWP). This program has helped in overcoming the problem of bacteriological contamination in drinking water to large extent[7]. Under this program, mass scale installation of India Mark-II handpumps shifted drinking water source from surface water to shallow groundwater. In the similar way, the Ministry implemented United Nations sponsored Central Rural Sanitation Program (CRSP) to improve the quality of life in rural areas. It is a community-led and people oriented program commenced in 1999. The habitants developed cesspools and septic systems to dispose their sewage waste on a residence-by residence basis. In 2001, only 22% of rural families have assessed to household toilets and due to success of this program it reaches 63% in 2010[7]. The Ministry of Urban Development implemented National Urban Renewal Mission (NURM) scheme to meet the challenge of rapid urbanization of India. The main thrust was on the development of infrastructure relating to drinking water supply including sanitation, sewerage, and solid waste management etc[7].

In northern India, the Ganga Alluvial Plain (GAP) is located between the Himalaya in the north and peninsular India in the south. It has an outstanding geomorphic feature characterized by its low elevation (<300 m above mean sea level), low relief (20-35 m) and high population density (>500 persons/km^2). It is one of the densely populated and highly agriculture based regions in the world (Fig 1a). The groundwater resource of GAP constitutes an important source of water used for drinking, agricultural and industrial purposes. Several urban centers such as Delhi, Kanpur, Lucknow, Allahabad and Varanasi etc. have developed along rivers of the GAP.

Researchers investigated heavy metals (Al, As, Cu, Fe, Mn, Mo, Ni, Pb, Se, Sn, Vn and Zn) and organo-chlorine pesticides in the drinking water of Lucknow urban centre at 100 locations[8]. Few scientist have studied hydro-geochemical parameters for the groundwater of Varanasi and concluded that the majority of groundwater belong to the order of Na>Ca>Mg>K cationic and HCO_3>Cl>SO_4 anionic concentrations[9]. Researchers have reported that ~10% groundwater samples exceeded the Bureau of India Standards limit of NO_3 and F contaminations in the shallow and unconfined groundwater aquifers of Kanpur area[10]. Few other researcher have reported that concentrations of total dissolved solids, hardness, alkalinity, Cl, F, SO_4, Ca, Mn, Pb, Cr and Fe exceeded their respective permissible limits in ~ 19% of the groundwater samples collected from dug wells, borewells and handpumps at Unnao[11]. However, the records of dissolved major and trace elements/constituents in the shallow groundwater of the GAP are limited.

Geographically, Lucknow is located on the banks of the Gomati River in central part of the GAP (Figure 1 a and b). Its rural as well as urban parts have been in continuous natural and developmental processes due to constant increase in population with prominent physical and chemical changes in its groundwater. There is a growing recognition of scientific need to intermingle the socio-economic development programs with environmental risks to human health. Present research study has been planned to provide the quality evaluation and trace elements assessments of the shallow groundwater of Lucknow. The main objectives are (1) to determine the concentration of dissolved major and trace elements/constituents in the shallow groundwater collected from upper aquifer of Lucknow, (2) to establish the natural background level of these major and trace elements/constituents, (3) to assess the groundwater suitability for drinking and irrigation purposes and (4) to assess controlling factors of the groundwater quality.

Monitoring area: Lucknow

Lucknow monitoring area (LMA) is situated between 80° 45' to 81° 05' N and 26° 40' to 27° 00' E and covers about 1300 km^2 of the alluvial plain. The growth pattern of its urban population and area is exponential in nature and highlights that the size of urban population is continuously increasing from 1980 onwards (Figure 1c). According to the 2011 census, Lucknow district has an approximate population of 4.6 million living 63% in urban and 34% in rural areas with a population density of 1,815 person/km^2. The population growth rate of Lucknow over the decade 2001-2011 was recorded 25.8% and has been classified as one of the top 10 fastest growing cities in India. The rising population, urbanization processes, agriculture activities and other associated anthropogenic actions are creating environmental impact on its water resources; particularly quantitative and qualitative aspects of the Lucknow groundwater resource.

The climate of Lucknow is humid sub-tropical type and is characterized by four distinct seasons: the summer season (March-May) followed by the monsoon season (June-September), the post-monsoon season (October-November) and the winter season (December-February). Figure 2(a) displays the mean monthly variation of rainfall, minimum and maximum temperature in Lucknow area[12]. Precipitation during the monsoon season is the main source of the groundwater recharge activity of the GAP. The environmental isotopic studies suggested that groundwater around Delhi area is being recharge by surface water during the summer and winter seasons, while recharge is associated with precipitation during the monsoon and the post-monsoon seasons[13]. Singh and his co-workers in 2010 studied dynamics of Arsenic (As) mobilization in fluvial environment of the Ganga Plain. Thirty-six water samples were collected from the river and its tributaries at low discharge during winter and summer seasons and were analysed by ICP-MS. Dissolved As and Fe concentrations were found in the range of 1.29–9.62 and 47.84–431.92 µg/L, respectively. The results show arsenic concentrations in the river water are likely to follow the seasonal temperature variation and reach the level of World Health Organization's permissible limit (10 µg/L) for drinking water in summer season[14]. Researchers have also studied the significant contribution of the Ganga Alluvial Plain and its impact on barium flux of the Ganga River System[15].

Lucknow exhibits two geomorphic features, namely regional upland surface and the Gomati River Valley. The regional upland surface shows flat topography characterized by low relief along with entrenched river valleys. It also show vast area without any drainage network of streams and a variety of alluvial features namely abandoned channels, lakes and ponds etc. The Gomati River Valley is a 20-m deep entrenched alluvial valley in the regional upland surface. It shows two well developed river terraces along the active river channel. Many urban locations such as Hussainabad, Kaiserbagh and Lucknow University are situated within the river valley. Geologically, these features are essentially composed of unconsolidated alluvial sediments derived from the Himalayan region by the weathering and erosion processes. The alluvial deposits are made up of inter-layered 1-2 m thick fine sand and silty mud deposits with extensive discontinuous calcrete horizon[16]. These deposits comprise several aquifer zones, broadly occurring in the various depth ranges. The first or topmost sandy aquifer lies between 8 to 112 m below ground level known as unconfined aquifer. This sandy aquifer mainly supports all handpumps and shallow tubewells in LMA and fulfils nearly 45% and 100% demand of the drinking water supply to the urban and rural population, respectively. Based on the available lithological data of exploratory tubewells from Central Ground Water Board, Mehrotra in 2004 presented a lithological cross section as shown in Figure 2b and the position of shallow aquifer[17]. Figure 2c displays the groundwater contour map showing the elevation of the piezometric surface with respect to mean sea level during the summer season of 1987. The groundwater flows from the surrounding upland regional surface towards the Gomati River to make the rivers influent characteristic[17]. The shallow groundwater resources of LMA, therefore, are being mostly tapped to fulfill the drinking water demand. According to data obtained from Lucknow Jal Sansthan reports, the gap between demand of 600 million liters per day and supply of 480 million liters per day is filled by private borewells. The shallow depth to water level is restricted to flood plains or nearby Gomati River and deeper depth in the central part of LMA which clearly indicated the extensive groundwater withdrawal from the uppermost aquifer[17]. The groundwater level in the monitoring area occurs at shallow depth. In 1986, the groundwater level was recorded at 10.28 m below ground level. Due to increasing demand of drinking water supply by growing pressure of human population, the level was lowered at 19.28 m below ground level in 2000. Thus in 14 years, the groundwater level had declined by 9 m at the rate of 0.64 m/year as shown in Figure 2d.

In the urban part of Lucknow, there are nearly 28 significant drains discharging their urban waste into the Gomati River which are also not systematically connected with sewerage system. Major drains such as G H Canal (modified urban drain), Kukrailnadi (modified urban drain), Sarkata Nala etc. carry bulk of city's sludge and discharge it into Gomati River. The estimated quantity of sewage generated by the city during December 2001 was 461 million liters per day[12]. There is a poor state of existing sewerage system as 60% of city may be choked or broken[12]. Thus, there is a large gap between generation, collection and treatment of wastewater. As a result, a large part of uncollected, untreated waste water finds its way either to the nearby water bodies or gets accumulated on the surface or sub-surface environment.

In Lucknow study area, the shallow character and high permeability of the alluvial aquifers make them highly vulnerable to contamination from various anthropogenic activities along with some developmental plans. The NDWP uses the groundwater resource to provide the safe drinking water in the both urban and rural parts of LMA (Figure 3a). The CRSP disposes the domestic cum sewage waste water below the ground surface mainly in the rural part (Figure 3b). Figure 3c displays recent photograph showing process of the replacement of old sewer pipelines in the heart of Lucknow urban centre. Due to uniform administrative planning, these developmental programs, therefore, may be linked with the shallow groundwater resource of the GAP at regional scale.

2. Material and Methods

For the evaluation of groundwater quality from shallow aquifer of Lucknow, the central GAP, Survey of India, toposheets no. 63B/13, 63B/14, 63F/1 and 63F/2 (of 1:50,000 scale) were used to identify the availability and accessibility of the sampling locations. The sampling map was prepared with a grid interval of 2 minute for latitude and longitude as shown in Figure 4. The study area have been covered in 100 blocks of which 76 blocks are from rural area and 24 blocks from urban area of LMA (Lucknow Monitoring Area). Each 2-minutes block represents one groundwater sampling site for the present study from India Mark-II handpumps (shallow aquifer – 100 nos. – L01 to L100) and tubewells (deeper aquifer – 09 nos. – T01 to T09) used for drinking water and irrigation purposes, respectively.

Water samples from handpumps and tubewells were collected from each site during May-June, 2010 at the beginning of the monsoon season (Figure 2a). Basic information of study area along with sampling details has been presented in Table 1. Two sets of samples were obtained at each location. Sampling has been done in high density polyethylene bottles, which were carefully rinsed three times before use. The samples were collected without trapping air bubbles in it and stored in clean sample box. One set of samples were collected as natural (non-acidified) and another set of samples were acidified in the field with supra-pure HNO_3 for analyses of major constituents/ elements and trace elements, respectively[18]. In order to avoid any contamination, samples bottles were transferred to polyethylene bags to avoid direct contact. The physico-chemical parameters (pH, conductivity, total dissolved solids and temperature) of groundwater were determined at field sampling sites by using pre-calibrated portable field kit of *HANNAH* company.

The bicarbonates (HCO_3^-) were determined by titration using hydrochloric acid (total alkalinity measured) and the turn over point was determined using methyl orange indicator (m- value). The concentration of bicarbonate is equivalent to m-value. The concentration of Cl is estimated by titrimetric method[18]. Selected constituents such as NO_3, SO_4, PO_4, F were detected using Ion-Chromatograph, DX-500 of Dionex instrument at the Wadia Institute of Himalayan Geology, Dehradun. The samples were analyzed against salt standards. For selected major and trace elements analyses, all the samples were filtered through a Millipore membrane filter (0.45 µm) and were analyzed by Inductively Coupled Plasma-Mass Spectrophotometer, ELAN DRC II Perkin Elmer SCIEX, at Institute Instrumentation Centre, Indian Institute of Technology Roorkee. All chemicals of analytical grade and Milli-Q water were used during analysis. Each sample was analyzed in duplicate and mean values were taken as the result. The samples were analyzed against certified standards and reliability of the procedures has been assured by several measurements with careful standardization, use of blanks, uniformity in replicate analysis and re-analysis of selected samples.

3. Results and discussion

The purpose of this study was to focus on the anthropogenic influence on the shallow groundwater resources of the GAP. The characteristic of shallow groundwater of LMA was chemically evaluated by proposed Piper diagram[19] (Figure 5), Stiff diagram[20] (Figure 6 a), Modified Collins diagram (Figure 6 b) and Chadha plot[21] (Figure 6 c). The Natural Background Level (NBL) derived from the lowest five concentrations of major/trace elements in all tubewell samples. The elemental profile and enrichment factors have been calculated for the clear understanding of the impact of urbanization processes on the groundwater resource. The N-S and NE-SW profiles, representing the rural section and rural-urban section of the LMA were used for elemental profile. The enrichment factors were calculated by the ratio of average values of major constituents/trace elements concentrations in groundwater of urban and rural area. Based on the geographical characteristics of the GAP and the results of present case study, an empirical model has been proposed to understand the dynamics of contaminants migration into the groundwater resources.

3.1 Distribution of major and trace elements/constituents

Physico-chemical analyses indicate that pH of the shallow groundwater of the LMA is characterized by neutral to slight alkaline in nature (pH = 7.2 to 8.1). The total dissolved solid (TDS) ranges from 82 to 460 mg/l in handpumps and from 139 to 300 mg/l in tubewells samples. Table 1 & Table 2 lists the results of the chemical analysis and physico-chemical parameters of major dissolved elements/constituents in all of the groundwater samples. The range average values of dissolved major elements/constituents in the shallow groundwater from handpumps and are HCO_3 (183 – 564 mg/l; 318 mg/l), Cl (0.7 – 302.4 mg/l; 17.1 mg/l), F (0.1 – 1.8 mg/l; 0.54 mg/l), NO_3 (0.1 – 155.8 mg/l; 6.86 mg/l), SO_4 (0.16 – 250.23 mg/l; 18.13 mg/l), Ca (3.2 – 23.2 mg/l; 7.25 mg/l), Mg (7.2 – 39.2 mg/l; 16.89 mg/l), K (0.9 – 37.7 mg/l; 2.3 mg/l), Na (2.5 – 106.7 mg/l; 18.38 mg/l) and Si (2.73 – 6.03 mg/l; 4.61 mg/l).

Results of the dissolved trace elements in all groundwater samples were presented in Table 3. The ranges and average values of dissolved trace elements Al (14 – 6596 µg/l; 247 µg/l), As (0.21 – 4.46 µg/l; 0.65 µg/l), Ba (31 – 513 µg/l; 152 µg/l), B (13 – 315 µg/l; 45 µg/l), Cd (0.05 – 3.37 µg/l; 0.19 µg/l), Cr (0.83 – 8.90 µg/l; 1.85 µg/l), Cu (0.59 – 297.2 µg/l; 7.87 µg/l), Fe (138 – 4649 µg/l; 843 µg/l), Pb (0.06 – 34.27 µg/l; 4.14 µg/l), Mn (1.4 – 863.9 µg/l; 102.5 µg/l, Ni (1.12 – 41.9 µg/l; 3.79 µg/l), P (12 – 236 µg/l; 25 µg/l), Rb (0.08 – 11.37 µg/l; 0.88 µg/l), Sr (119 – 1890 µg/l; 496 µg/l) and Zn (19 – 2260 µg/l; 333 µg/l) were found in the groundwater samples from handpumps. The average values of dissolved Al (319 µg/l), As (0.53 µg/l), Ba (165 µg/l), B (46 µg/l), Cd (0.07 µg/l), Cr (1.46 µg/l), Cu (1.22 µg/l), Fe (347 µg/l), Pb (0.26 µg/l), Mn (73.9 µg/l), Ni (2.59 µg/l), P (17 µg/l), Rb (1.40 µg/l), Sr (421 µg/l) and Zn (4 µg/l) were found in the groundwater samples from tubewells. The summary of analytical data of major and trace elements/constituents along with permissible limits for drinking water purpose as recommended by World Health Organization[22] are presented in Table 4.

3.2 Shallow Groundwater Characteristic

The Piper diagram consists of three distinct fields: two triangular fields and a diamond shaped field[19]. In the triangular fields, the percentage values of cations (Ca, Mg and Na) and anions (HCO_3, SO_4 and Cl) were plotted, separately as shown in Figure 5. The chemical data of major dissolved cations and anions in meq/l were used. Hydro-geochemical facies of groundwater can be distinguished by the position of their plots occupying in certain sub-areas of the diamond-shaped field. The shallow groundwater of the LMA belongs to Ca-Mg-HCO_3 hydro-geochemical facie and dominates with Ca and Mg cationic species and HCO_3 anionic species.

Figure 6 a shows the chemical composition of the groundwater samples represented in Stiff diagram[20]. Magnesium and Ca are the major cations while HCO_3 dominates as major anion. The bar represents the dominance of Mg-Ca cations (~70%) and bicarbonate anion (~90%). The Mg and Ca species may be attributed to the groundwater from weathering of silicate minerals present in the alluvium sediments of the GAP. The HCO_3 anionic species may be derived from the dissolution of silicate minerals by the carbonic acid. Modified Collins diagram represents the relative proportions of the ionic balance of major constituents of cations and anions in the groundwater samples as shown in Figure 6 b. Chadha in 1999 proposed a rectangular plot to express the primary character of water including temporary and permanent hardness[21]. In this plot, the differences in milliequivalent percentage between alkaline earths (Ca + Mg) and alkali metals (Na + K), expressed as percentage reacting values, are plotted on x-axis, and the differences in milliequivalent percentage between weak acidic anions (CO_3 + HCO_3) and strong acidic anions (Cl + SO_4) are plotted on y-axis. Majority of the shallow groundwater samples falls in the sub-field of the Ca + Mg - HCO_3 water type with temporary hardness as shown in Figure 6 c. Ion balance is an important parameter for data quality assessment. The significant correlation was observed between total anions (bicarbonate + chloride + sulphate) and total cations (calcium + magnesium + sodium + potassium). It is represented in Figure 6 c with a significant value (r^2=0.67).

The analytical results also show a wide variation in the dissolved concentrations of major and trace elements/constituents of the shallow groundwater. For spatial distribution, Cl, NO_3, Ba and P have been selected for the present study as shown in Figure 7. Chloride is a major element of natural waters and is generally considered a good tracer of salinity-increase sources. The main anthropogenic sources are urban, industrial and agricultural waste-waters. However, no health-based guideline value has so far been proposed by WHO for Cl in drinking water[23]. Nevertheless, Cl concentration above 250 mg/l in natural water can give rise to a noticeable taste. In LMA, Cl concentrations vary from 0.7 to 302.4 mg/l. The high concentrations (>100 mg/l) were recorded at Aishbagh (L-45), Telibagh (L-57) and Garhi (L-60) locations in the study area (Figure 7 a). Under natural conditions, the NO_3 level in drinking water is generally < 2 mg/l and often lowers than 0.2 mg/l. The presence of high level NO_3 in groundwater indicates contamination by extraneous sources like sewage, domestic waste and fertilizer etc. In the study area, the concentration of NO_3 in groundwater varies high from 0.01 to 155.76 mg/l. North-south spatial distribution pattern shows pockets of high NO_3 concentrations in the groundwater of urban and rural areas at Hussainabad (L-44), Alambagh (L-46) and Bijnaur (L-48) locations (Figure 7 b).

The concentration of Ba ranges from 31 to 513µg/l with an average value of 152 µg/l. The maximum concentration was recorded at Hussainabad (L-44). Figure 7 c shows high Ba concentration contour in the LMA. The concentration of P in the groundwater widely ranges from 12 to 236 µg/l with an average value of 25 µg/l. High values were recorded in several rural locations such as Bazidnagar (L-02), Mithinagar (L-03), Kudha (L-07) and urban location Khurramnagar (L-64). Three isolated high P concentration contours are located along the Gomati River channel that may linked with the movement of groundwater of the study area as shown in Figure 7 d.

Inter-elemental correlation is commonly used to establish the relation between independent and dependent variables. The most significant correlation were observed between Na-SO_4 (r^2=0.70), Na-Cl (r^2=0.51), Cl-SO_4 (r^2=0.58), Rb-Al (r^2=0.81), Rb-Cu (r^2=0.58) and Cu-Al (r^2=0.68). Cl and SO_4 show a good trend of increasing concentration with increasing Na suggesting same source and can be used as pollution indicators for anthropogenic input. A good correlation of Cu with Rb and Al indicates presence of Cu through uncontrolled, active waste dumps. No other significant correlations were observed in the shallow groundwater of the LMA.

3.3 Groundwater quality assessment

3.3.1 Drinking suitability

The international standards of World Health Organization were considered for the evaluation of groundwater suitability for drinking purpose[19, 22] and data is compared and summarized in Table 4. Figure 8 a displays pie diagrams showing the groundwater samples (%) crossing WHO drinking water limits by Al, F, Pb, Ba, NO_3, Ni and Cd etc. Fluoride element have both lower (<0.6 mg/l) and upper (>1.5 mg/l) limits of concentration with identified beneficial and harmful health effects. The concentration of F in the groundwater indicates that 6% of the samples are exceeding the upper limit with maximum value 1.8 mg/l at L-59 location (Table 1). The recommended desirable and permissible limits of Na concentration in drinking water are 50 and 200 mg/l, respectively[23]. About 96% of groundwater samples were below the desirable limits (Table 4). One percent of total groundwater samples exceed the permissible limit of Cl (>250 mg/l). Only 3% of groundwater samples exceed the desirable limit of NO_3 (>45 mg/l). The isolated high concentration of NO_3 were reported in rural (150 mg/l at L-48) as well as urban (156 mg/l at L-44 and 108 mg/l at L-46) locations. This reveals the percolation of domestic cum sewage waste water upto ~30 m depth into the upper alluvial aquifer of the study area. In the distribution of dissolved Al, 19% of total samples were observed exceeding the guideline value (>200 µg/l) of drinking water. Dissolved trace metals Pb, Ni and Cd were reported 11%, 3%and 1% of samples exceeding WHO guideline values, respectively. Dissolved concentrations of K, As, Cu and Zn elements were reported below the WHO permissible limits of drinking water.

3.3.2 Irrigation suitability

Major and trace elements distribution affects the suitability of groundwater for the use of irrigation purpose as well. Therefore, these hydro-geochemical parameters of groundwater samples collected from tubewells were used to calculate Wilcox Classification, Sodium Percent, Sodium Adsorption Ratio for the evaluation of shallow groundwater quality for irrigation suitability. Electrical conductivity and sodium content are important parameters used in the classification of irrigation water as sodium reacts with soils to reduce its permeability. Sodium content is usually expressed in percent of Na. High Na percent causes deflocculation and impairment of the tilth and permeability of soils[24]. Sodium percentage in groundwater of the LMA ranges between 1.44 to 2.99. The permissible limit of maximum Na percent for irrigation water is 60[25]. The plot of electrical conductivity and Na percent data on Wilcox diagram (Figure 8 b) shows that sodium percent is within the recommended value[25]. The groundwater quality of the LMA is classified as excellent for irrigation purposes as shown in Figure 8 b. Salinity hazard is also used to define the quality of irrigation water and is expressed by Sodium Adsorption Ratio. It is quantified by the dissolved proportion of sodium to calcium and magnesium ions in given groundwater samples. The values of Sodium Adsorption Ratio ranged between 0.32 and 3.04 meq/l in the shallow groundwater in the LMA.

The classification of irrigation waters with respect to Salinity and Sodium Hazards is represented (Figure 8 c) in the United States Salinity diagram[26]. The classification indicates that the salinity hazard with low salinity water (C1) can be used for irrigation on most soils. Medium salinity water (C2) can be used if a moderate amount of leaching occurs. High salinity water (C3) cannot be used on soils even with restricted drainage. Very high salinity (C4) is not suitable for irrigation under ordinary conditions, but may be used occasionally under very special circumstances. The soils must be permeable, adequately drain, irrigation water applied in excess to provide considerable leaching and suitable for very salt tolerant crops. Wilcox in 1955 defined that Sodium Hazard describes low sodium water (S1) can be used for irrigation on almost all soils with little danger of harmful levels of exchangeable sodium[25]. Medium sodium water (S2) will present an appreciable sodium hazard in fine-textured soils having high cation-exchange capacity especially under low - leaching conditions unless gypsum is present in the soil. This water may be used on coarse - textured or organic soils with good permeability. High sodium water (S3) may produce high levels of exchangeable sodium in most soils and will require special soil management, good drainage, high leaching and organic matter additions. Very high sodium water (S4) is generally unsatisfactory for irrigation purposes, except at low and perhaps medium salinity[25]. Plot of the analytical data on the diagram illustrates the Electrical Conductivity as a salinity hazard and Sodium Adsorption Ratio as an alkalinity hazard as shown in Figure 8 c. Result shows that all groundwater samples fall in the category of C1S1 indicating low salinity and low alkali water, except one sample falling in C2S1 category indicating medium salinity and low alkali water (Figure 8 c). It can be concluded that groundwater collected from tubewells of the LMA can be used for irrigating most of the soils and crops with minor probability of exchangeable sodium.

3.4 Natural Background Levels (NBL)

The concentrations of major and trace elements/constituents varies by more than six orders of magnitude ranging from <0.1 µg/l to <500mg/l in the shallow groundwater of Lucknow monitoring area (Table 4). The NBL values for major constituents/trace elements were established as HCO_3 (299 mg/l), Cl (2.7 mg/l), F (0.26 mg/l), NO_3 (0.57 mg/l), SO_4 (5.92 mg/l), Ca (7.35 mg/l), Cd (0.06 µg/l), Mg (10.93 mg/l), K (1.32 mg/l), Na (9.97 mg/l), Si (3.53 mg/l), Al (66 µg/l), As (0.37 µg/l), Ba (142 µg/l), B (31 µg/l), Cr (1.00 µg/l), Cu (0.50 µg/l), Fe (257 µg/l), Pb (0.20 µg/l), Mn (45.0 µg/l), Ni (2.30 µg/l), P (15 µg/l), Rb (0.56 µg/l), Sr (300 µg/l) and Zn (2 µg/l).The values are compared with pristine values/natural background levels and data table has been accomplished. The pristine values are taken from the deep borewell samples.

The enrichment factor of tubewell and handpump groundwater is calculated by considering the above established NBLs as a reference and data was presented in bar diagram as shown in Figure 9 a & b. The significant enrichment of Cl, NO_3, SO_4, Al, Cu, Pb, Rb, Zn and Cd constituents/elements were observed in the shallow groundwater. The bar diagram clearly indicates the migration and movement of these contaminants by various anthropogenic activities into the shallow groundwater aquifer in the both rural and urban areas of the LMA. Constituents /elements such as Cl (~ 7.60), NO_3 (~ 18.93), SO_4 (~ 6.46) and Al (~ 10.00) show significant enrichment in the groundwater of tubewells; whereas Cu (~16), Pb (~21), Zn (~168) and Cd (~3) show detrimental enrichment in the groundwater of handpumps. The enrichment of NO_3 in both the groundwater of tubewells (~19 times) and handpump (~11 times) is the clear indication of the anthropogenic influences on the shallow groundwater as shown in Figure 9 a & b.

To study the influence of the anthropogenic activities on the groundwater resource, the enrichment factor is again calculated by considering the established NBL values. The bar diagram clearly shows the urban groundwater has higher enrichment factors of elements such as Cl, NO_3, SO_4, Al, Cu, Pb, and Zn than the rural ground waters (Figure 9 b). At the same time, the rural ground waters show higher enrichment factors of elements such as F, K, As, Mn, Ni, P, and Cd than the urban ground waters. This clearly indicates that the anthropogenic processes are responsible for mobilization of elements (Cl, NO_3, SO_4, Al, Cu, Pb, and Zn) in the urban area and elements (F, K, As, Mn, Ni, P, and Cd) in the rural area.

3.5 Urban vs. rural influence

Elemental profiles across the N-S and NE-SW sections were used to understand the urban vs. rural influences on the chemical characteristics of groundwater (Figure 10 a & b). Figure 10a displays the isolated and multiple peaks of high concentrations of Cl, NO_3 and SO_4. The enrichment factors were also calculated as the ratio of average major constituents/trace elements concentrations in groundwater of urban versus rural areas. The significant enrichments in Cu (3.8 times), Al (3.4 times), NO_3 (2.9 times), Cl (2.2 times), Rb (1.7 times), Fe (1.5 times), Sr (1.5 times), Zn (1.4 times), Ba (1.3 times) and Pb (1.2 times) constituents/elements were recorded in the urban groundwater as displays in bar diagram of Figure 10 b. The elemental profiles and enrichment factors clearly represent the impact of urbanization on its shallow groundwater resources in the NMA.

3.6 Sources of groundwater contamination

In the LMA, the groundwater contamination may occur either through diffused sources or point sources. Chloride, SO_4, NO_3 and Na are mostly derived from agricultural fertilizers, animal wastes, industrial and municipal sewage[27]. To assess the influence of major contaminants in overall scenario of the study area, and established NBLs of NO_3, SO_4, Na and Cl have been selected. Groundwater sampling sites having concentration higher than these NBLs are classified as contaminated sites either by sewage effluents or by domestic effluents and may be by both effluents. On overview, 31 sites (12 belong to urban area) were classified as contaminated with sewage-cum domestic effluents in the study area (Figure 11 a). Majority of trace elements are considered to be toxic at higher concentrations and even some are lethal at very low concentrations. Among various trace elements, the present study revealed that Pb, Mn, Ni and Cd concentrations exceed the desirable limits at many locations of the study area. Fairly high values of trace elements Cu (297.18µg/l), Zn (660µg/l), Ba (167 µg/l), Pb (34.27µg/l), Mn (262.8µg/l), Ni (9.08µg/l) and Cd (0.27µg/l) were reported at Khurramnagar (L-64) location in the urban area. It is the site formerly used as unlined urban waste landfill site for couple of years in 90's. Figure 11 b displays spatial distribution of sites contaminated with trace elements (Al, As, Cr, Cu, Pb, Ni and Cd) in both rural and urban parts of the LMA.

3.7 Chemical indicators of sewage contamination

The presence of NO_3 in sewage effluents and Na and K in domestic effluents is uniformly documented in the scientific literature. In the present study, NO_3 and Cl values of the shallow groundwater were synchronized with the values reported in sewage discharge in the Ganga River at Varanasi[28]. Chloride is one of the major inorganic elements found in waste waters. To establish an approach for tracing the source of groundwater contamination either by sewage or some other, variations of Na+K/NO_3 and Cl/F ratio were examined. These ratios can, therefore, be a useful inorganic tracer for identification of the origin of sewage contamination in the groundwater. The Cl/F ratio ranges from 0.58 to 11023 in the shallow groundwater of the LMA. Figure 12a displays scatter diagram showing Cl versus Cl/F ratio of the shallow drinking groundwater and clearly indicates that in some of the urban and rural locations drinking groundwater were contaminated with sewage effluents. Hence, the Cl/F ratio can be used as chemical tracer for sewage contamination in the groundwater of the GAP. Figure 12 b displays scatter diagram showing NO_3 versus Na+K of the shallow drinking groundwater. It can be established that the most of the groundwater samples was belong to group 3 indicating the chemical modifications of the groundwater of the LMA by sewage and domestic effluents.

3.8 Groundwater contaminants migration modeling

In this section, we proposed a generalized model for groundwater contaminants in the shallow aquifer of the GAP under the present hydrogeological and climatic conditions (Figure 13).The GAP is an alluvial plain having shallow depth of groundwater level (~10 m) and saturated zones are made up of sandy loam which easily helps to percolate monsoon precipitation and contaminants from the sub-surface to the shallow aquifer zone. Large scale installation of India Mark-II handpumps perceived to provide safe drinking water; whereas unlined septic tanks and unplanned dumping sites make the sub-surface (~5 to 10 m) of alluvial plain vulnerable to groundwater contaminants. Recently available data indicates that the LMA does not treat about 90% of its sewerage in its urban area and does not have any plan for its rural area. Lucknow city also generates nearly 1,000 tones of municipal solid waste and only half of it can be transported to open unlined dumping sites located around the urban-rural interface. At the same time, groundwater contaminants can also enter into the shallow aquifer through percolation and by infiltration during the monsoon season. The flow of sewage cum domestic effluents via silt dominated natural porous media is the key path of contaminant migration in the shallow aquifer. High NO_3, SO_4, Cl and P values in the groundwater clearly indicates the migration of effluents in the saturated zone and their impact on groundwater resource in the rural as well as urban areas of the LMA.

4. Conclusions

In the GAP region, the shallow groundwater is classified as of good quality from the perspective of irrigation suitability. However, the contaminants such as F, NO_3, Al, Ba, B, Pb, Mn, Ni and Cd show higher values than the recommended guidelines of WHO in case of drinking water suitability. The government's development plans act as either sources or factors responsible for migration of the groundwater contaminants. Hence, relevant hydrological processes governing the mobilization of groundwater contaminants in the alluvial aquifer of the GAP need to be identified for groundwater quality and trace elements assessment. Thus, long term development, planning and management programs of the GAP region need immediate environmental audit to protect the groundwater quality concerning the health of millions of people in future.

5. Acknowledgements

This paper is from the doctoral thesis of NS who is thankful to Council of Scientific and Industrial Research (CSIR), New Delhi for financial assistance in the form of Senior Research Fellowship [No. 9/107(340)/2010)]. We give special thanks to Profs M. Singh and S. Singh for their valuable comments by which manuscript is benefitted. We convey our deep sense of gratitude to Profs. I. B. Singh and M. P. Singh for their encouragement. We thank all residents at the sampling sites for their kindness shown to us during field survey for this study. Special thanks are due to Dr. A. K. Singh, Dr. (Mrs.) Swati and Mr. Rohit Kuvar for their assistance during sample collection. Manuscript was benefited by comments and suggestions of Dr. S. Sensarma.

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Table 1 Sampling details and results of major dissolved constituents/elements in shallow groundwater samples collected from India Mark II handpump (L-01 to L-100; n=100) and tubewell (T-01 to T-09; n=09) in Lucknow monitoring area of the central Ganga Alluvial

Sample code	Date (dd/mm/yy)	Longitude	Latitude	HCO_3 (mg/l)	Cl (mg/l)	F (mg/l)	NO_3 (mg/l)	SO_4 (mg/l)	Ca (mg/l)	Mg (mg/l)	K (mg/l)	Na (mg/l)	Si (mg/l)
HANDPUMPS													
L-01	27.05.10	80°46′30″	26°58′40″	250	12.9	1.63	26.92	10.21	3.51	20.64	2.79	15.47	3.79
L-02	27.05.10	80°46′00″	26°57′00″	275	1.8	0.25	0.12	6.23	5.83	13.09	1.52	10.32	4.96
L-03	27.05.10	80°47′00″	26°55′00″	290	1.3	0.17	2.05	1.09	6.64	16.43	1.44	8.17	5.29
L-04	27.05.10	80°45′40″	26°53′20″	339	2.9	0.26	4.62	4.70	4.70	24.08	1.90	14.99	5.02
L-05	27.05.10	80°45′30″	26°51′40″	290	1.5	0.51	0.01	18.20	6.93	19.25	1.90	8.26	5.04
L-06	04.06.10	80°46′20″	26°48′40″	372	1.5	0.20	0.01	0.73	5.71	27.84	2.07	17.62	5.39
L-07	04.06.10	80°46′00″	26°47′20″	351	11.6	0.36	0.96	27.86	6.20	26.48	2.54	34.73	5.42
L-08	04.06.10	80°46′20″	26°45′20″	342	25.8	0.34	0.01	19.94	7.15	21.77	2.11	30.83	5.90
L-09	04.06.10	80°45′20″	26°42′20″	247	1.1	0.17	4.37	1.03	5.24	13.35	1.34	9.73	5.47
L-10	04.06.10	80°46′20″	26°41′20″	308	14.5	0.20	0.22	27.10	6.63	17.00	1.82	22.48	5.37
L-11	27.05.10	80°48′00″	26°58′20″	351	2.3	0.30	0.01	1.97	5.59	20.83	2.17	13.26	5.45
L-12	27.05.10	80°47′20″	26°57′20″	247	2.0	0.27	1.39	1.05	5.94	12.96	1.55	7.96	5.56
L-13	27.05.10	80°47′30″	26°54′20″	381	1.2	0.44	1.17	6.08	6.69	22.60	1.43	11.48	5.80
L-14	27.05.10	80°48′20″	26°53′20″	354	2.1	0.45	2.33	4.16	6.41	23.04	1.78	22.75	5.68
L-15	27.05.10	80°47′40″	26°51′30″	320	7.5	1.17	13.09	28.02	5.58	27.65	2.08	15.24	5.09
L-16	04.06.10	80°48′00″	26°48′30″	253	6.2	0.47	2.49	4.75	5.70	16.90	2.84	14.55	5.35
L-17	04.06.10	80°48′20″	26°47′20″	256	17.0	0.11	1.41	14.83	8.18	16.91	2.09	25.96	6.03
L-18	04.06.10	80°48′40″	26°44′40″	345	21.0	0.45	2.63	19.71	7.82	20.58	2.31	22.13	5.61
L-19	04.06.10	80°47′20″	26°43′20″	275	9.7	0.93	5.06	10.94	4.70	18.46	3.22	24.96	4.96
L-20	04.06.10	80°47′20″	26°40′20″	244	1.1	0.95	0.01	0.56	3.57	13.33	0.90	18.93	5.26
L-21	27.05.10	80°49′20″	26°58′40″	195	1.9	0.34	15.21	1.05	6.68	15.19	1.38	9.50	5.27
L-22	27.05.10	80°50′20″	26°56′20″	183	51.3	0.12	33.96	99.72	9.47	28.22	2.50	49.81	5.09
L-23	27.05.10	80°50′40″	26°55′20″	320	6.1	0.32	3.05	4.83	8.24	15.77	1.76	13.23	5.50
L-24	27.05.10	80°50′30″	26°52′40″	320	0.9	1.46	0.22	12.06	6.98	20.71	1.57	9.90	5.03
L-25	04.06.10	80°49′30″	26°50′40″	488	13.2	0.43	5.57	24.62	7.34	24.99	2.39	48.15	5.46
L-26	04.06.10	80°49′30″	26°48′40″	275	1.0	0.72	0.28	0.64	5.98	24.49	2.57	26.53	5.19
L-27	04.06.10	80°50′20″	26°47′30″	336	1.1	0.44	0.01	2.02	5.97	15.28	1.55	29.08	5.37
L-28	07.06.10	80°50′40″	26°44′30″	275	7.4	0.37	3.89	7.16	7.63	18.80	2.69	19.47	5.49
L-29	07.06.10	80°50′40″	26°43′20″	366	2.0	0.25	0.26	5.75	6.53	24.53	1.90	18.22	5.23
L-30	07.06.10	80°50′20″	26°41′30″	250	0.7	0.28	1.15	0.16	6.33	11.03	1.78	7.87	5.31

L-31	26.05.10	80°51′20″	26°59′30″	192	6.3	0.31	2.54	6.74	5.44	9.25	1.12	5.05	4.84
L-32	26.05.10	80°52′30″	26°56′20″	320	0.9	0.23	0.01	0.62	7.92	13.04	2.13	10.15	5.52
L-33	27.05.10	80°51′20″	26°54′30″	381	1.2	0.25	0.01	0.36	5.96	20.86	2.44	15.52	5.01
L-34	27.05.10	80°52′00″	26°52′30″	305	5.4	0.42	0.30	5.15	7.20	16.07	1.79	10.11	5.06
L-35	04.06.10	80°52′30″	26°50′40″	366	2.9	0.36	0.43	2.34	5.72	17.95	2.09	18.67	4.60
L-36	04.06.10	80°51′30″	26°48′20″	311	1.5	0.43	1.78	1.39	6.21	15.21	1.51	10.31	4.88
L-37	07.06.10	80°51′20″	26°46′20″	275	83.5	0.04	1.24	9.15	13.24	35.72	3.64	21.71	5.36
L-38	07.06.10	80°52′00″	26°45′20″	275	35.4	0.92	3.02	21.76	8.72	17.91	1.89	9.93	4.82
L-39	07.06.10	80°52′20″	26°42′40″	287	1.1	0.24	2.06	0.74	7.26	12.79	1.49	9.05	5.55
L-40	07.06.10	80°52′20″	26°40′40″	275	24.0	0.21	3.70	26.03	9.77	16.97	1.60	14.40	5.46
L-41	26.05.10	80°53′40″	26°58′40″	397	3.4	0.38	0.01	1.84	9.53	16.78	2.52	10.12	5.15
L-42	26.05.10	80°53′30″	26°57′40″	317	7.4	0.34	0.36	2.15	8.70	14.77	1.86	9.29	5.12
L-43	27.05.10	80°54′00″	26°55′20″	305	2.6	0.17	0.10	1.55	7.82	10.99	1.62	7.89	4.80
L-44	27.05.10	80°54′20″	26°52′20″	317	58.1	0.26	155.76	16.38	8.81	27.50	3.01	29.19	4.43
L-45	08.06.10	80°54′20″	26°50′40″	305	110.2	0.01	4.74	57.54	23.23	38.81	2.87	44.94	4.83
L-46	08.06.10	80°54′30″	26°48′40″	275	50.5	0.09	107.56	55.16	13.93	28.16	2.31	15.20	5.11
L-47	07.06.10	80°53′30″	26°46′30″	287	43.9	0.50	8.15	10.88	9.48	23.44	2.21	9.45	4.97
L-48	07.06.10	80°54′30″	26°44′40″	305	80.4	0.35	150.16	231.11	15.04	39.15	37.68	71.35	4.51
L-49	07.06.10	80°54′40″	26°43′40″	311	6.0	1.54	0.10	3.60	8.73	13.80	2.75	14.59	4.70
L-50	07.06.10	80°54′00″	26°40′30″	320	10.4	0.99	8.02	29.55	10.35	16.78	2.15	21.31	5.13
L-51	26.05.10	80°56′30″	26°59′20″	259	9.5	1.50	0.01	4.94	7.48	14.25	1.84	7.43	4.22
L-52	26.05.10	80°55′30″	26°56′40″	275	2.9	1.41	1.40	8.25	7.72	15.17	1.83	10.74	4.57
L-53	28.05.10	80°56′00″	26°54′40″	229	6.0	0.60	0.01	3.57	7.95	7.48	1.73	8.11	4.21
L-54	28.05.10	80°55′40″	26°53′20″	259	38.8	0.93	0.01	13.15	6.12	12.81	2.16	14.98	4.07
L-55	09.06.10	80°56′20″	26°51′40″	305	29.3	0.41	3.38	64.01	5.74	18.31	1.70	28.93	3.67
L-56	07.06.10	80°55′20″	26°48′30″	336	22.0	0.47	8.92	21.59	9.41	18.96	2.31	15.28	4.72
L-57	07.06.10	80°56′40″	26°47′00″	397	111.3	0.85	23.76	22.44	13.59	27.81	2.45	31.08	5.04
L-58	07.06.10	80°56′30″	26°45′20″	305	2.4	0.01	0.01	11.56	7.75	13.40	1.78	10.77	5.32
L-59	07.06.10	80°55′30″	26°42′40″	275	4.0	1.80	0.01	2.20	6.54	9.31	1.45	9.15	4.08
L-60	07.06.10	80°55′40″	26°41′00″	473	302.4	1.05	3.96	250.23	10.37	30.69	3.22	106.67	4.25
L-61	26.05.10	80°55′20″	26°59′40″	320	17.8	0.95	6.10	8.07	7.97	17.43	2.41	11.71	4.51
L-62	27.05.10	80°57′20″	26°56′40″	320	2.7	0.39	0.01	0.64	8.09	14.31	1.84	11.06	4.44
L-63	27.05.10	80°57′40″	26°55′20″	397	4.3	0.64	0.01	6.83	7.30	14.07	1.60	11.45	4.27
L-64	28.05.10	80°50′00″	26°53′20″	305	4.4	0.31	0.01	1.59	6.20	11.86	2.13	13.48	5.17
L-65	08.06.10	80°57′20″	26°50′40″	427	39.3	0.26	13.49	38.05	6.09	19.73	1.80	33.76	3.82
L-66	08.06.10	80°58′20″	26°48′40″	336	1.9	0.65	2.06	1.47	6.99	12.47	1.59	11.83	4.51
L-67	08.06.10	80°58′20″	26°47′40″	305	7.4	0.32	1.82	4.01	8.39	11.16	1.70	16.54	4.53

L-68	07.06.10	80°57′30″	26°44′40″	320	1.1	0.42	0.01	0.74	7.35	11.36	1.51	10.35	4.30
L-69	07.06.10	80°57′30″	26°42′40″	195	1.0	1.69	0.01	12.23	4.83	7.17	1.36	2.90	3.63
L-70	07.06.10	80°58′40″	26°40′40″	259	27.8	0.30	3.07	16.28	8.38	12.29	1.92	10.08	4.60
L-71	26.05.10	80°59′30″	26°40′20″	275	3.3	0.37	0.01	3.15	7.01	13.36	1.59	9.64	3.83
L-72	26.05.10	80°59′30″	26°57′20″	290	1.8	0.38	0.01	10.19	7.21	9.63	1.68	5.98	3.93
L-73	28.05.10	81°00′20″	26°54′30″	336	7.5	0.74	0.01	5.65	8.38	15.84	1.63	9.05	4.39
L-74	28.05.10	80°59′30″	26°52′30″	336	12.1	0.27	0.01	8.19	6.79	13.03	1.86	13.39	4.15
L-75	28.05.10	81°00′20″	26°51′30″	259	1.9	0.49	0.01	1.60	4.51	9.41	1.51	7.85	3.84
L-76	08.06.10	80°59′30″	26°48′40″	488	13.9	0.43	0.83	60.61	3.17	13.12	1.38	52.13	3.20
L-77	08.06.10	81°00′20″	26°46′20″	351	1.5	0.52	0.01	1.16	5.46	15.28	1.60	11.10	3.97
L-78	08.06.10	80°59′40″	26°45′30″	381	3.8	0.36	0.24	22.86	6.92	12.64	5.61	16.33	4.09
L-79	07.06.10	81°00′30″	26°42′30″	305	1.1	0.22	0.12	0.49	7.28	10.77	1.48	6.38	4.41
L-80	07.06.10	81°00′20″	26°41′30″	336	41.3	0.21	9.78	77.38	11.61	12.08	2.28	29.20	4.10
L-81	26.05.10	80°1′30″	26°59′20″	336	49.8	0.27	0.01	13.04	12.11	12.96	2.41	32.51	4.30
L-82	26.05.10	81°2′20″	26°56′30″	348	5.4	0.52	0.01	6.45	9.79	20.11	1.92	7.28	4.04
L-83	28.05.10	81°1′40″	20°54′40″	275	1.2	1.74	0.01	10.55	5.97	12.63	1.74	8.17	3.91
L-84	28.05.10	81°2′30″	26°52′20″	244	63.0	0.13	0.01	34.76	9.08	15.88	1.87	13.20	3.76
L-85	28.05.10	81°2′40″	26°51′20″	290	2.1	0.41	0.01	1.11	5.80	12.41	1.76	8.23	4.04
L-86	08.06.10	81°2′20″	26°48′30″	305	3.5	0.45	0.01	2.01	5.70	11.72	1.47	8.65	3.96
L-87	08.06.10	81°2′40″	26°46′40″	427	5.7	0.38	5.61	13.56	7.10	15.07	2.03	17.58	3.84
L-88	08.06.10	81°2′30″	26°44′40″	326	0.8	0.49	0.01	0.87	3.21	11.72	1.12	20.59	3.19
L-89	07.06.10	81°2′00″	26°42′20″	458	12.0	0.42	2.16	6.00	3.49	13.35	1.07	37.37	3.31
L-90	07.06.10	81°2′20″	26°41′20″	412	1.6	0.37	0.01	1.45	5.84	15.25	1.73	17.76	3.89
L-91	26.05.10	81°4′20″	26°59′40″	381	9.3	0.23	0.01	9.55	5.65	14.21	2.19	21.16	3.62
L-92	26.05.10	81°4′20″	26°56′30″	305	1.1	1.06	0.01	15.34	6.42	13.78	1.38	5.40	3.20
L-93	28.05.10	81°4′20″	26°55′30″	214	1.1	1.45	0.01	7.62	4.02	8.08	1.18	2.49	2.73
L-94	28.05.10	81°3′40″	26°53′30″	317	4.0	0.33	3.66	3.30	6.45	11.18	1.53	7.89	3.82
L-95	28.05.10	81°3′40″	26°51′00″	320	0.9	0.49	0.07	0.89	4.43	11.51	2.22	9.51	3.59
L-96	08.06.10	81°4′30″	26°48′30″	305	0.9	1.14	0.01	0.41	3.88	10.95	1.18	9.59	3.47
L-97	08.06.10	81°4′20″	26°46′40″	247	0.9	0.24	1.35	0.72	5.11	8.21	0.99	4.48	3.63
L-98	07.06.10	81°4′20″	26°45′20″	366	3.8	0.32	1.72	3.87	6.04	13.05	1.85	9.75	4.04
L-99	07.06.10	81°3′20″	26°43′40″	564	46.8	0.43	9.58	144.74	5.65	22.22	1.73	76.79	3.69
L-100	07.06.10	81°3′30″	26°41′30″	458	2.3	1.73	0.01	2.25	3.47	10.85	1.54	42.11	3.51
TUBEWELLS													
T-01	27.05.10	80°46′30″	26°58′40″	320	1.3	0.33	0.09	5.02	7.35	12.22	1.43	8.48	4.12
T-02	04.06.10	80°46′40″	26°48′40″	320	1.7	0.49	0.01	4.39	8.32	10.48	1.88	9.71	4.37
T-03	07.06.10	80°52′20″	26°42′40″	342	2.8	0.26	1.40	7.44	7.10	9.86	1.41	20.23	3.78

T-04	07.06.10	80°55′40″	26°41′00″	503	58.7	0.42	0.33	100.50	7.48	16.68	2.28	71.88	3.90
T-05	27.05.10	80°57′20″	26°56′40″	351	5.8	0.43	2.38	4.23	7.49	15.26	1.91	16.06	4.19
T-06	07.06.10	81°00′20″	26°41′30″	259	2.0	0.18	1.00	33.10	8.74	9.98	1.54	8.59	3.13
T-07	26.05.10	81°02′10″	26°56′40″	275	7.0	0.30	17.21	10.17	7.82	14.82	0.98	7.47	3.67
T-08	08.06.10	80°02′40″	26°45′40″	381	8.4	0.52	8.33	8.52	7.35	16.33	1.65	16.47	3.79
T-09	08.06.10	81°03′10″	26°43′30″	320	8.6	0.23	14.91	9.19	7.99	12.13	1.26	15.61	3.30

Plain, northern India. Refer Fig. 4 for location of all sampling sites. All units are in mg/l.

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Table 2: Results of physical parameters in groundwater samples collected from India Mark II handpumps (n=100) and tubewells (n=09) from Lucknow area. (TDS= Total Dissolved Solids, EC= Electrical Conductivity)

S.No.	Sample Code	pH	TEMP	TDS	EC
1	L-01	7.9	29.1	122	182
2	L-02	7.7	28.7	112	167
3	L-03	7.6	28.3	119	178
4	L-04	7.7	29.6	125	187
5	L-05	7.6	27.0	132	197
6	L-06	7.4	28.2	159	237
7	L-07	7.5	28.9	175	261
8	L-08	7.4	29.2	176	263
9	L-09	7.7	28.0	108	161
10	L-10	7.4	28.4	151	225
11	L-11	7.7	29.2	131	196
12	L-12	7.7	29.4	102	152
13	L-13	7.5	29.0	145	216
14	L-14	7.5	28.6	160	239
15	L-15	7.6	28.4	150	224
16	L-16	7.6	28.4	131	196
17	L-17	7.3	28.7	171	255
18	L-18	7.4	28.4	176	263
19	L-19	7.7	28.4	145	216
20	L-20	7.8	28.0	104	155
21	L-21	7.8	29.1	114	170
22	L-22	7.6	29.8	253	378
23	L-23	7.6	29.2	134	200
24	L-24	7.7	28.6	135	201
25	L-25	7.4	28.6	206	307
26	L-26	7.6	29.1	163	243
27	L-27	7.6	28.1	154	230
28	L-28	7.7	27.8	152	227
29	L-29	7.7	28.9	157	234
30	L-30	7.8	28.4	105	157
31	L-31	7.9	28.0	87	130
32	L-32	7.5	28.3	127	190
33	L-33	7.6	28.0	145	216
34	L-34	7.6	28.7	132	197
35	L-35	7.8	28.5	150	224
36	L-36	7.6	28.6	123	184
37	L-37	7.6	28.2	294	439
38	L-38	7.7	27.9	154	230
39	L-39	7.7	28.1	123	184
40	L-40	7.6	27.4	168	251
41	L-41	7.5	28.0	151	225

42	L-42	7.5	28.0	142	212
43	L-43	7.7	28.7	120	179
44	L-44	7.6	29.6	248	370
45	L-45	7.2	28.2	460	687
46	L-46	7.3	27.9	250	373
47	L-47	7.6	27.5	180	269
48	L-48	7.2	27.9	459	685
49	L-49	7.5	28.7	150	224
50	L-50	7.5	27.9	190	284
51	L-51	7.8	27.5	131	196
52	L-52	7.3	27.8	147	219
53	L-53	7.7	28.2	118	176
54	L-54	8.0	28.8	136	203
55	L-55	8.0	27.8	189	282
56	L-56	7.6	27.2	184	275
57	L-57	7.2	27.9	282	421
58	L-58	7.7	28.0	127	190
59	L-59	7.8	27.9	120	179
60	L-60	7.2	27.8	444	663
61	L-61	7.6	27.7	141	210
62	L-62	7.6	28.2	154	230
63	L-63	7.6	28.4	149	222
64	L-64	7.8	28.2	133	199
65	L-65	7.5	28.2	206	307
66	L-66	7.4	28.4	142	212
67	L-67	7.3	27.9	166	248
68	L-68	7.5	28.7	135	201
69	L-69	8.0	28.3	82	122
70	L-70	7.6	28.3	155	231
71	L-71	7.7	27.6	139	207
72	L-72	7.8	27.8	122	182
73	L-73	7.6	27.5	166	248
74	L-74	7.6	28.6	151	225
75	L-75	7.8	28.4	101	151
76	L-76	7.5	28.2	207	309
77	L-77	7.5	27.6	167	249
78	L-78	7.4	27.2	160	239
79	L-79	7.7	27.7	128	191
80	L-80	7.4	27.1	216	322
81	L-81	7.6	28.1	180	269
82	L-82	7.7	27.1	136	203
83	L-83	8.0	27.7	111	166
84	L-84	7.7	29.7	193	288
85	L-85	7.8	28.2	122	182
86	L-86	7.7	28.1	125	187
87	L-87	7.5	27.3	167	249
88	L-88	7.8	27.8	125	187
89	L-89	7.8	28.3	175	261
90	L-90	7.6	28.3	152	227
91	L-91	7.6	28.1	162	242
92	L-92	7.8	27.0	128	191
93	L-93	8.1	27.0	85	127

94	L-94	7.6	28.4	135	201
95	L-95	7.8	27.8	117	175
96	L-96	7.7	27.4	108	161
97	L-97	7.7	27.5	98	146
98	L-98	7.6	27.7	133	199
99	L-99	7.5	28.0	302	451
100	L-100	7.8	28.2	160	239
101	T-01	7.5	28.4	140	209
102	T-02	7.4	27.9	142	212
103	T-03	7.5	27.8	149	222
104	T-04	7.5	27.8	300	448
105	T-05	7.4	28.6	161	240
106	T-06	7.8	27.2	139	207
107	T-07	7.5	26.3	146	218
108	T-08	7.3	27.4	160	239
109	T-09	7.4	27.2	167	249

Table 3 Results of trace elements in shallow groundwater samples collected from India Mark II handpump (L-01 to L-100; n=100) and tubewell (T-01 to T-09; n=09) in Lucknow monitoring area of the central Ganga Alluvial Plain, northern India. Refer Fig. 4 for location of all sampling sites. All units are in μg/l.

Sample code	**Al**	**As**	**Ba**	**B**	**Cr**	**Cd**	**Cu**	**Fe**	**Pb**	**Mn**	**Ni**	**P**	**Rb**	**Sr**	**Zn**
	(μg/l)	**(μg/l)**	**(μg/l)**	**(μg/l)**	**(μg/l)**	**(μg/l)**	**(μg/l)**	**(μg/l)**	**(μg/l)**	**(μg/l)**	**(μg/l)**	**(μg/l)**	**(μg/l)**	**(μg/l)**	**(μg/l)**
L-01	184	1.00	118	41	2.38	0.41	3.33	258	4.16	4.2	2.49	31	0.78	809	21
L-02	122	4.46	207	19	2.43	0.29	3.16	1601	0.94	223.6	3.28	236	0.40	156	32
L-03	300	1.07	108	18	2.93	3.37	11.64	538	17.18	36.1	21.56	69	0.55	187	494
L-04	118	0.53	184	31	2.14	0.67	3.44	311	3.74	13.7	5.83	27	0.44	457	134
L-05	264	0.34	111	20	2.41	0.37	3.69	1239	4.47	48.0	26.64	24	0.43	278	324
L-06	81	0.51	59	33	2.10	0.15	1.39	912	1.98	63.4	5.94	21	0.33	625	310
L-07	548	0.77	117	54	3.38	0.38	9.54	575	6.99	194.9	41.90	81	0.27	636	210
L-08	96	0.43	91	43	2.84	0.15	3.30	3267	4.25	152.9	7.09	18	0.18	365	334
L-09	69	0.43	77	19	2.00	0.10	2.13	311	1.13	15.0	2.95	19	0.08	192	60
L-10	1942	0.70	153	23	3.28	0.16	100.75	1156	5.30	91.9	5.11	46	4.16	275	1010
L-11	128	0.82	116	26	2.40	0.14	5.80	270	1.56	79.6	2.00	44	0.40	431	277
L-12	48	0.95	108	16	2.36	0.13	3.16	377	0.85	127.6	2.27	29	0.61	173	30
L-13	127	0.46	91	24	2.13	0.74	2.84	271	4.92	46.3	2.27	23	0.47	321	1229
L-14	49	0.61	110	32	2.42	0.14	4.89	519	1.67	39.8	2.55	16	0.20	316	107
L-15	62	0.81	152	24	2.54	0.17	1.69	399	0.75	32.9	2.06	22	0.39	732	164
L-16	600	0.68	45	24	2.60	0.11	2.55	648	1.70	88.6	2.69	23	0.77	436	26
L-17	45	0.72	130	24	2.74	0.08	2.26	630	0.57	113.7	2.82	16	0.21	217	28
L-18	79	0.71	130	35	2.67	0.13	2.37	794	2.93	116.4	2.88	19	0.33	307	234
L-19	69	1.02	232	45	2.77	0.14	1.45	243	1.70	283.6	1.66	24	0.25	419	354
L-20	159	0.96	59	46	2.86	0.13	0.82	173	1.78	24.7	1.57	36	0.27	376	204
L-21	92	0.90	96	21	5.09	0.12	6.94	268	4.56	1.4	2.36	40	0.55	288	156
L-22	66	1.91	179	63	1.84	0.08	7.14	713	1.52	178.4	2.72	39	1.20	610	75
L-23	258	0.40	106	27	3.69	0.19	5.40	663	4.23	24.2	2.93	30	0.46	296	532
L-24	46	0.33	117	25	1.37	0.12	1.88	564	0.86	19.8	2.13	17	0.18	368	65

L-25	50	0.50	189	50	1.55	0.14	8.22	1202	7.22	35.2	2.36	18	0.61	767	311
L-26	54	0.54	292	58	1.12	0.14	3.44	215	4.75	43.5	3.12	18	0.47	1185	311
L-27	43	0.46	155	89	1.04	0.07	2.17	616	2.81	33.0	2.45	12	0.37	428	30
L-28	807	0.69	138	41	1.63	0.10	7.01	696	10.62	98.5	2.97	41	1.52	533	36
L-29	39	0.38	31	41	1.17	0.14	2.36	693	2.29	112.1	1.88	22	0.08	672	45
L-30	66	0.76	61	20	4.11	0.11	10.25	3252	12.22	36.1	6.44	26	0.20	257	516
L-31	91	0.97	59	13	1.81	0.10	6.53	296	2.13	4.2	2.22	25	0.58	119	101
L-32	58	0.46	173	21	1.04	0.08	1.02	457	0.96	85.1	2.06	18	0.78	233	133
L-33	1349	0.47	170	50	1.69	0.07	4.30	513	4.04	130.2	3.76	27	2.11	535	1407
L-34	71	0.71	158	26	2.24	0.08	6.00	1223	3.27	27.5	2.46	20	0.48	410	109
L-35	34	0.41	153	53	1.03	0.11	1.04	466	3.93	48.3	1.95	18	0.48	625	492
L-36	67	0.56	175	32	1.15	0.10	7.27	258	5.45	19.9	4.17	27	0.48	414	215
L-37	28	0.74	225	38	1.13	0.07	1.83	691	0.42	59.4	3.95	15	0.13	1434	33
L-38	231	0.36	137	29	1.10	0.10	1.82	497	2.22	53.0	2.56	15	0.31	420	219
L-39	44	0.46	46	25	3.40	0.06	2.74	3193	7.71	38.9	4.19	17	0.17	603	126
L-40	58	0.32	57	33	1.14	0.08	2.74	497	1.02	107.9	2.68	16	0.14	454	53
L-41	33	4.07	155	26	0.89	0.08	1.27	351	1.62	138.1	2.49	24	2.96	304	430
L-42	34	0.78	163	25	1.05	0.16	3.22	285	3.60	98.4	3.29	26	0.92	230	493
L-43	41	1.50	112	22	1.63	0.16	7.48	412	12.05	40.8	2.87	46	0.60	171	537
L-44	39	0.45	513	66	1.06	0.09	8.41	613	1.39	84.1	2.65	19	0.85	1890	125
L-45	35	1.04	456	42	1.30	0.23	4.06	1040	3.64	169.1	6.18	16	0.39	718	1657
L-46	36	0.46	229	39	1.30	0.09	7.04	1322	2.99	115.5	4.13	18	0.40	1229	216
L-47	29	0.31	244	41	0.97	0.07	1.73	645	1.27	59.1	2.60	15	0.54	1351	64
L-48	53	0.61	90	216	1.11	1.24	4.99	1180	10.44	340.7	4.64	20	1.99	528	1376
L-49	45	0.86	145	53	1.20	0.71	1.26	874	16.68	107.4	2.57	22	0.39	304	936
L-50	30	0.33	95	30	1.94	0.12	2.93	592	2.28	29.2	3.02	30	0.38	632	62
L-51	36	0.67	166	20	2.68	0.07	1.13	866	0.94	85.3	3.00	19	1.81	373	78
L-52	14	0.4	191	26	3.4	0.10	0.66	254	0.06	181.	2.36	18	0.68	353	24

		9			8					2					
L-53	32	0.38	243	26	2.49	0.15	0.73	1211	0.50	310.0	2.35	19	0.59	231	100
L-54	37	0.56	121	36	1.19	0.09	1.32	678	0.84	49.5	1.91	14	0.61	470	100
L-55	418	0.48	74	54	3.13	0.88	10.28	1962	11.59	51.0	2.67	20	1.01	651	1254
L-56	68	0.39	57	31	2.20	0.24	2.99	588	2.60	97.7	3.78	15	0.42	552	476
L-57	40	0.51	72	32	1.09	0.10	3.92	824	1.02	77.4	4.27	17	0.56	981	90
L-58	4228	0.73	133	25	3.80	0.11	4.41	1850	3.98	129.5	5.46	42	7.47	314	1633
L-59	371	0.32	70	29	1.17	0.10	1.11	411	0.43	38.5	2.12	17	0.62	331	84
L-60	81	0.86	47	123	1.13	0.14	4.12	620	1.04	216.5	3.25	17	1.08	1000	250
L-61	816	0.61	250	39	2.33	0.16	6.91	1225	4.53	91.6	3.46	26	1.13	476	46
L-62	43	0.54	156	31	7.41	0.10	4.76	3932	4.38	191.6	4.83	23	0.38	391	140
L-63	60	0.72	196	29	1.54	0.11	1.18	419	6.31	222.6	2.23	25	0.83	372	693
L-64	6596	0.30	167	36	8.90	0.27	297.18	4649	34.27	262.8	9.08	50	11.37	410	660
L-65	227	0.32	255	99	1.66	0.09	10.98	1034	3.87	66.2	3.18	18	0.98	914	318
L-66	117	0.55	136	41	2.73	0.36	34.85	3015	16.72	99.0	4.05	20	0.26	537	591
L-67	25	0.31	142	44	0.98	0.09	12.52	1627	3.54	78.5	2.57	14	0.34	433	64
L-68	37	0.37	150	26	0.97	0.10	1.94	324	1.73	37.6	2.64	16	0.29	348	477
L-69	31	0.45	49	26	1.02	0.15	0.81	331	1.80	42.5	1.51	15	0.14	211	151
L-70	25	0.47	62	25	1.05	0.07	1.62	376	0.85	93.2	2.55	14	0.19	356	36
L-71	42	0.38	126	24	1.06	0.06	5.73	463	3.28	89.3	3.41	12	0.51	356	73
L-72	35	0.50	194	22	0.90	0.08	2.01	400	1.51	104.9	3.61	17	2.74	234	236
L-73	96	0.46	192	30	1.01	0.09	2.02	707	1.79	143.4	3.12	16	0.61	461	121
L-74	28	0.45	149	40	0.87	0.07	0.69	1339	2.66	55.8	2.15	19	0.65	338	617
L-75	25	0.58	102	26	0.98	0.11	1.14	267	1.22	14.9	1.93	16	0.26	325	113
L-76	35	0.53	146	184	1.15	0.07	3.18	205	1.07	31.6	1.89	17	0.62	542	53
L-77	39	0.41	200	54	0.98	0.07	1.15	233	1.02	23.7	1.72	16	0.48	658	238
L-78	44	0.38	333	55	1.29	0.20	11.16	1170	17.79	444.5	2.47	26	0.56	442	935
L-79	117	0.33	99	27	0.97	0.07	0.59	308	1.50	51.8	2.32	14	0.43	468	299

L-80	33	0.47	279	55	1.07	0.06	6.25	587	4.57	814.2	3.54	15	0.27	305	31
L-81	29	0.52	291	59	1.12	0.06	6.59	611	4.79	863.9	3.67	15	0.27	306	22
L-82	32	1.38	214	34	1.35	0.05	3.26	1557	2.02	177.1	3.77	18	4.25	521	76
L-83	39	0.72	144	25	1.08	0.08	1.05	718	1.59	127.0	2.01	31	0.82	301	180
L-84	230	0.68	155	24	1.09	0.15	6.47	470	3.54	110.1	4.58	21	1.33	459	639
L-85	39	0.42	207	28	0.92	0.07	0.71	573	1.01	75.9	2.43	17	0.58	382	133
L-86	27	0.55	170	35	1.05	0.11	3.76	1230	3.03	49.5	1.85	19	0.35	373	180
L-87	31	0.58	353	50	1.03	0.21	3.89	424	5.33	25.2	2.33	19	0.82	474	689
L-88	207	0.47	111	82	1.07	0.07	1.84	305	2.18	27.2	1.20	19	0.77	503	149
L-89	500	0.51	192	120	1.26	0.06	3.45	406	0.54	13.9	1.52	18	1.34	575	19
L-90	30	0.34	260	78	0.83	0.07	0.77	635	2.04	48.1	2.15	14	0.71	663	803
L-91	22	0.24	217	67	0.90	0.06	0.69	1013	0.93	62.9	1.86	14	0.37	525	149
L-92	23	0.21	177	24	0.87	0.07	0.82	356	1.65	64.8	2.24	16	2.16	334	146
L-93	39	0.45	98	22	1.62	0.10	1.22	2230	29.25	77.6	2.12	20	0.97	206	2260
L-94	40	0.46	110	27	1.05	0.07	1.23	518	2.16	45.3	2.75	17	0.42	306	131
L-95	27	0.39	100	49	0.95	0.12	0.91	394	2.84	15.8	1.67	15	0.45	508	161
L-96	31	0.28	43	33	0.86	0.08	0.79	244	1.03	28.8	1.28	17	0.48	567	130
L-97	29	0.49	70	19	1.08	0.12	1.67	731	1.25	14.6	1.72	17	0.16	167	61
L-98	36	0.46	199	31	0.90	0.20	1.11	443	1.85	30.2	2.43	16	0.34	580	494
L-99	395	0.45	72	181	1.26	0.13	5.35	699	1.89	42.8	3.92	18	1.28	1307	254
L-100	32	0.43	183	315	0.94	0.16	1.19	138	1.40	12.9	1.12	14	0.33	1036	228
T-01	27	0.55	182	54	1.04	0.07	0.56	229	0.35	123.0	2.19	21	0.40	315	14
T-02	31	0.26	139	32	0.85	0.08	0.32	281	0.14	72.0	2.44	15	0.23	407	1
T-03	180	0.92	160	36	0.93	0.06	0.78	288	0.21	61.2	2.22	17	1.03	370	2
T-04	318	0.71	201	122	1.06	0.10	1.73	320	0.26	117.6	2.46	14	1.14	691	3
T-05	52	0.61	191	43	0.84	0.07	0.57	243	0.16	116.5	2.28	14	0.66	464	2
T-06	523	0.72	134	34	1.16	0.06	0.59	443	0.33	67.6	3.16	20	4.60	189	3
T-07	41	0.3	122	20	2.2	0.04	0.33	241	0.11	0.3	2.39	13	0.47	378	1

		4			9										
T-08	1170	0.31	195	34	2.23	0.07	2.04	631	0.44	81.7	3.34	19	2.34	734	3
T-09	531	0.38	158	43	2.78	0.06	4.08	448	0.37	25.3	2.81	19	1.69	242	2

Table 4 Maximum, minimum and average of physical parameters, major and trace dissolved elements/constituents of the shallow groundwater from Lucknow monitoring area. WHO (1993) limits of drinking water quality are also given. The values of Natural Background Level are based on the lowest 5 values of tubewell samples. [NAD = No Adequate Data to permit recommendation of a health-based guideline value, Temp. = Temperature, TDS = Total Dissolved Solids, EC = Electrical Conductivity]

Statistical Parameters	Handpumps					Tubewells			Pristine (n=05)	WHO (1993)
	Total (n=100)			Urban (n=24)	Rural (n=76)	(n=09)				
	Min.	Max	Avg.	Avg.	Avg.	Min	Max	Avg.	Avg.	Acceptable Limit
Physical Parameters										
pH	7.20	8.10	7.60	7.60	7.60	7.30	7.80	7.50	NAD	NAD
Temp. (°C)	27.00	29.80	28.20	28.30	28.20	26.30	28.60	27.60	NAD	NAD
TDS (mg/l)	82.00	460.00	160.00	182.40	153.20	139.00	300.00	167.00	NAD	NAD
EC (µS/cm)	122.00	687.00	239.00	272.00	229.00	207.00	448.00	249.00	NAD	NAD
Major Elements/ Constituents										
HCO_3 (mg/l)	183.00	564.00	318.00	313.00	319.00	259.00	503.00	341.00	299.00	NAD
Cl (mg/l)	0.70	302.40	17.10	29.40	13.20	1.30	58.70	10.70	2.70	250.00
F (mg/l)	0.01	1.80	0.54	0.45	0.57	0.18	0.52	0.35	0.26	1.50
NO_3 (mg/l)	0.01	155.76	6.86	13.70	4.69	0.01	17.21	5.07	0.57	50.00
SO_4 (mg/l)	0.16	250.23	18.13	19.46	17.71	4.23	100.50	20.28	5.92	500.00
Ca (mg/l)	3.17	23.23	7.25	8.36	6.90	7.10	8.74	7.74	7.35	NAD
Mg (mg/l)	7.17	39.15	16.89	17.8	16.59	9.86	16.68	13.09	10.93	NAD
K (mg/l)	0.90	37.68	2.30	2.0	2.39	0.98	2.28	1.59	1.32	NAD
Na (mg/l)	2.49	106.67	18.38	18.6	18.29	7.47	71.88	19.39	9.97	200.00
Si (mg/l)	2.73	6.03	4.61	4.4	4.65	3.13	4.37	3.81	3.53	NAD
Trace Elements										
Al (µg/l)	14.00	6596.00	247.00	530.00	157.00	27.00	1170.00	319.00	66.00	200.00
As (µg/l)	0.21	4.46	0.65	0.53	0.69	0.26	0.92	0.53	0.37	10.00
Ba (µg/l)	31.00	513.00	152.00	181.00	143.00	122.00	201.00	165.00	142.00	300.00
B (µg/l)	13.00	315.00	45.00	45.00	45.00	20.00	122.00	46.00	31.00	300.00
Cd (µg/l)	0.05	3.37	0.19	0.16	0.20	0.04	0.10	0.07	0.06	3.00
Cr (µg/l)	0.83	8.90	1.85	1.80	1.84	0.84	2.78	1.46	1.00	50.00
Cu (µg/l)	0.59	297.18	7.87	17.90	4.70	0.32	4.08	1.22	0.50	2000.00
Fe (µg/l)	138.00	4649.00	843.00	1130.00	753.00	229.00	631.00	347.00	257.00	NAD
Pb (µg/l)	0.06	34.27	4.14	4.70	3.90	0.11	0.44	0.26	0.20	10.00
Mn (µg/l)	1.40	863.90	102.50	92.20	105.70	0.30	123.00	73.90	45.0	500.00
Ni (µg/l)	1.12	41.90	3.79	3.40	3.90	2.19	3.34	2.59	2.30	20.00
P (µg/l)	12.00	236.00	25.00	21.00	26.00	13.00	21.00	17.00	15.00	NAD
Rb (µg/l)	0.08	11.37	0.88	1.30	0.75	0.23	4.60	1.40	0.56	NAD
Sr (µg/l)	119.00	1890.00	496.00	624.00	456.00	189.00	734.00	421.00	300.00	NAD
Zn (µg/l)	19.00	2260.00	333.00	420.00	306.00	1.00	14.00	4.00	2.00	3000.00

Figures:

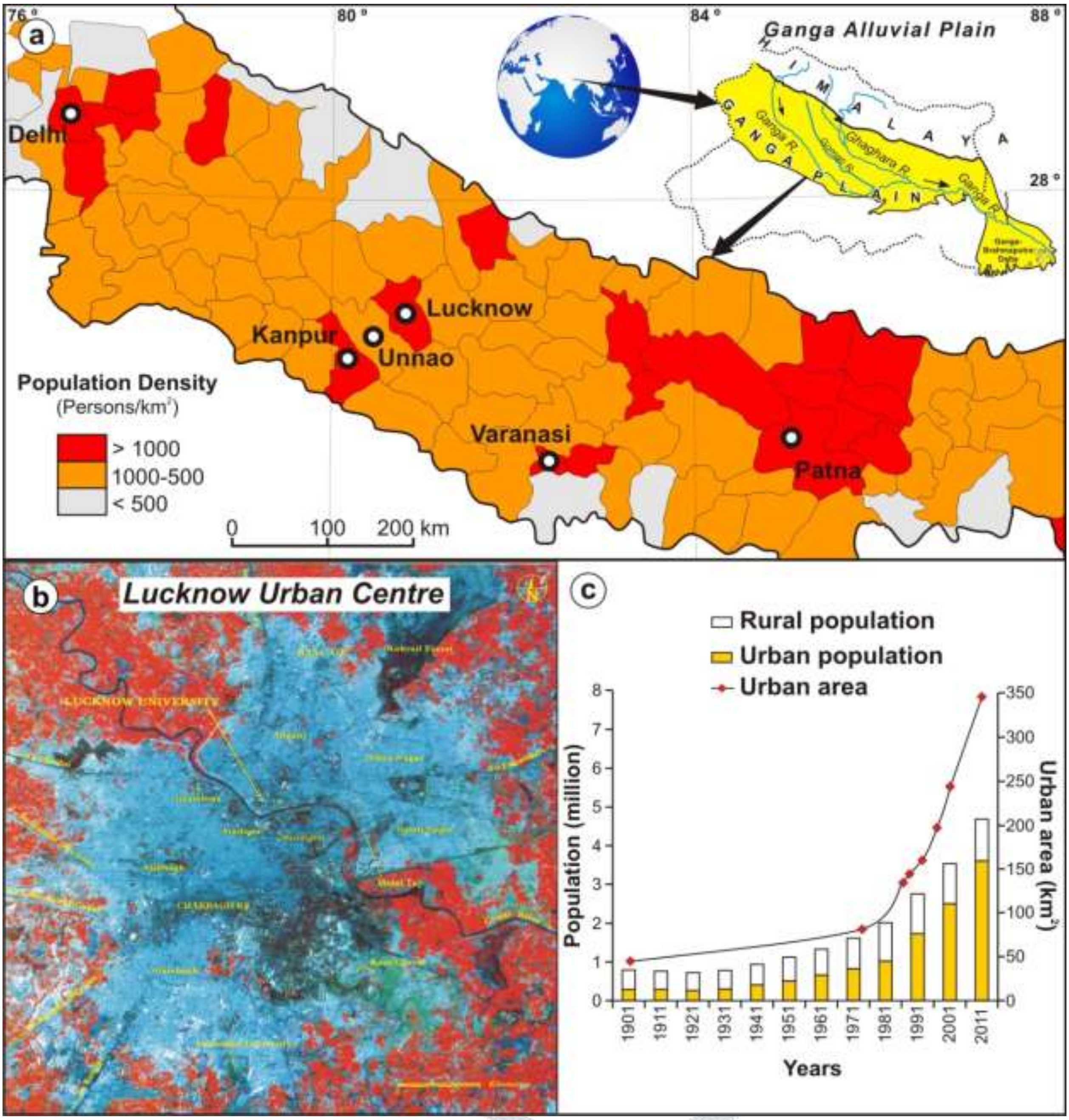

Figure 1: figure displays the Ganga Alluvial Plain in northern India, highlighting Lucknow Monitoring area (a) low elevation ([<300m above mean sea level), low relief (20-30m), high population density (>500 person/sqkm) (b) displays Lucknow monitoring area located on the banks of the Gomati river in central part of the GAP(c) bar graph shows size of increasing of urban population from 1980onwards

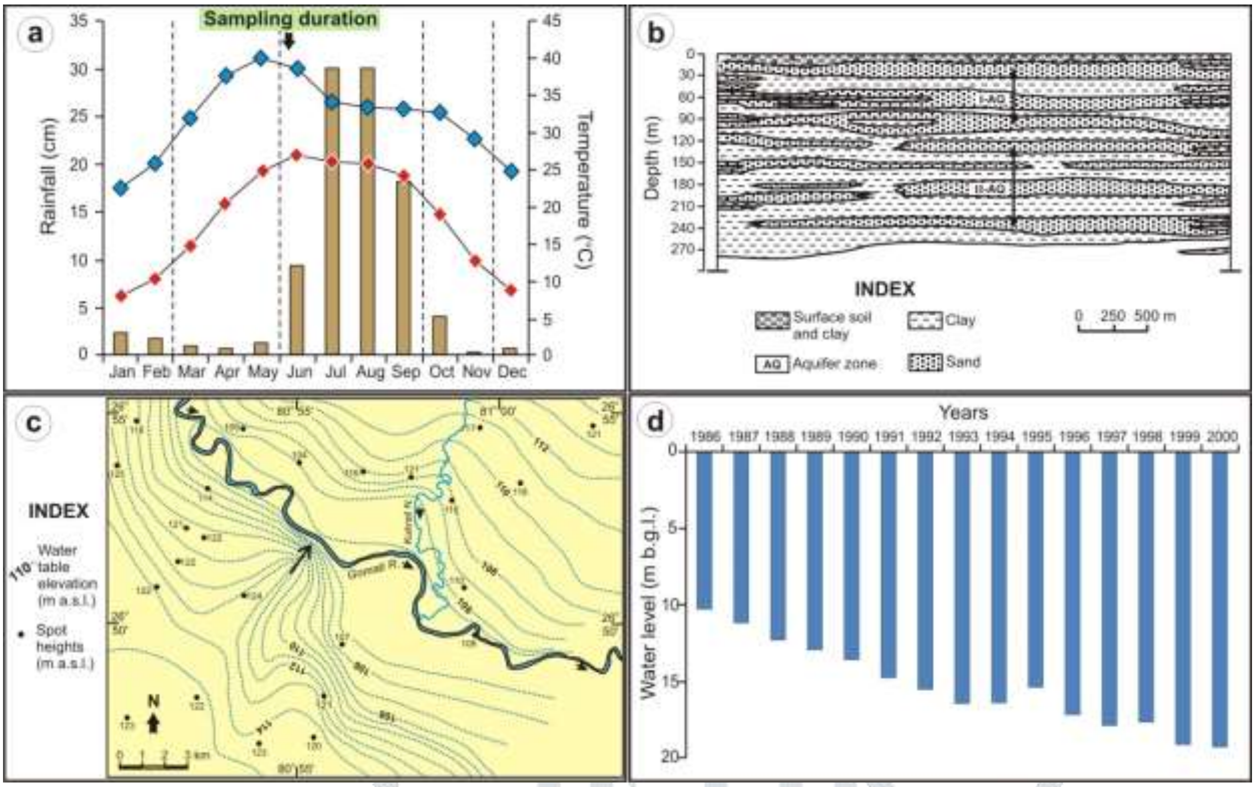

Figure 2: (a) The mean monthly variation of rainfall, minimum and maximum temperature in Lucknow area (CPCB2002)(b) Lithological cross section of alluvial aquifer (2004Mehrotra)(c) displays contour map showing the elevation of piezometric surface with respect to mean sea level during summer season in 1987 (d) graph showing groundwater decline data of 14years by 9m at 0.65m/year.

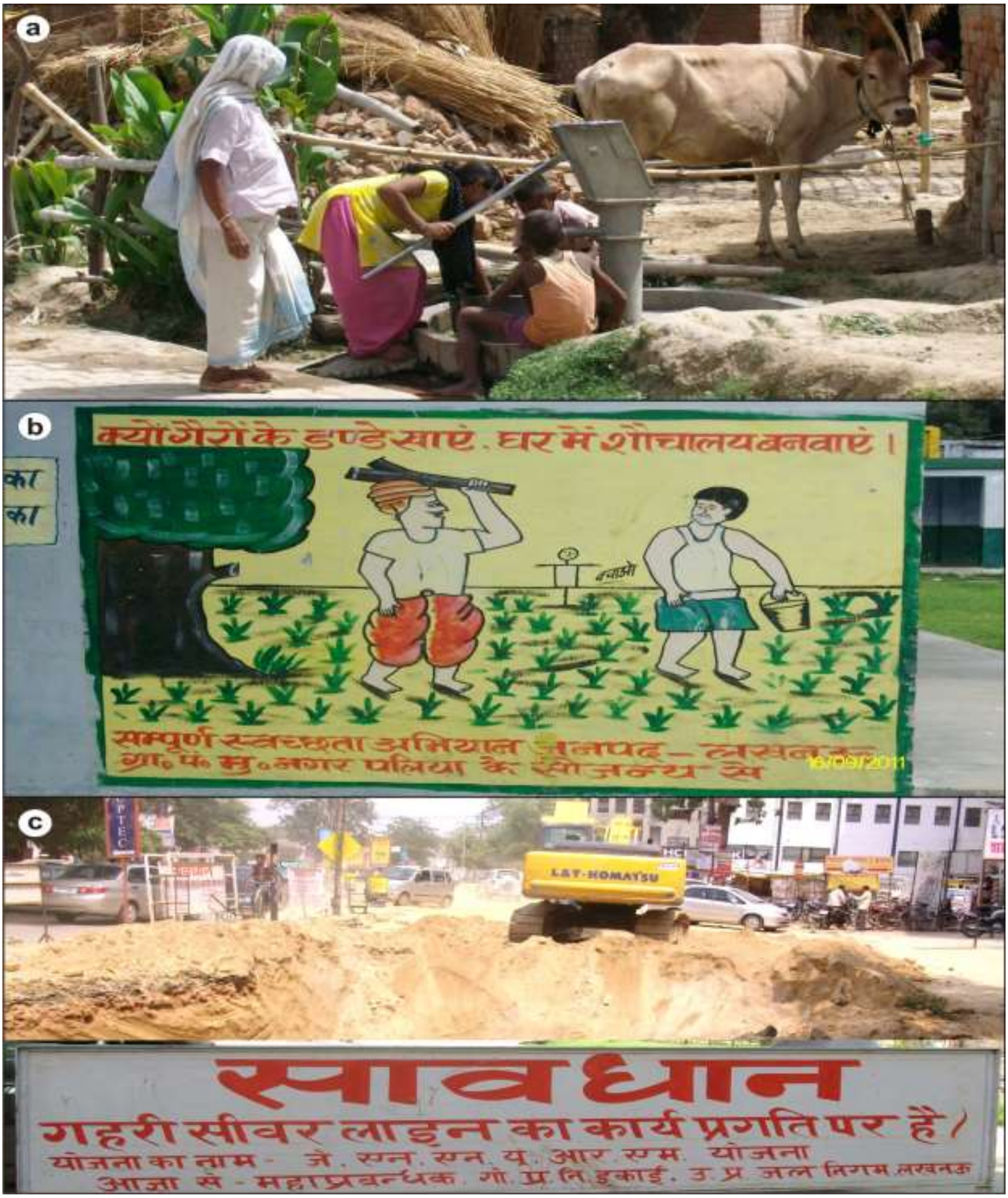

Figure 3: (a) Photographs depicting groundwater management rural sanitation and urban development programme of GoI: (National Rural Drinking Water Programme) showing proper installation of India Mark II handpump in Lucknow area (b) Central Rural Sanitation Programme (c) Jawaharlal Nehru Urban Renewal Mission focused on transformation of old sewer lines/urban drains in Lucknow.

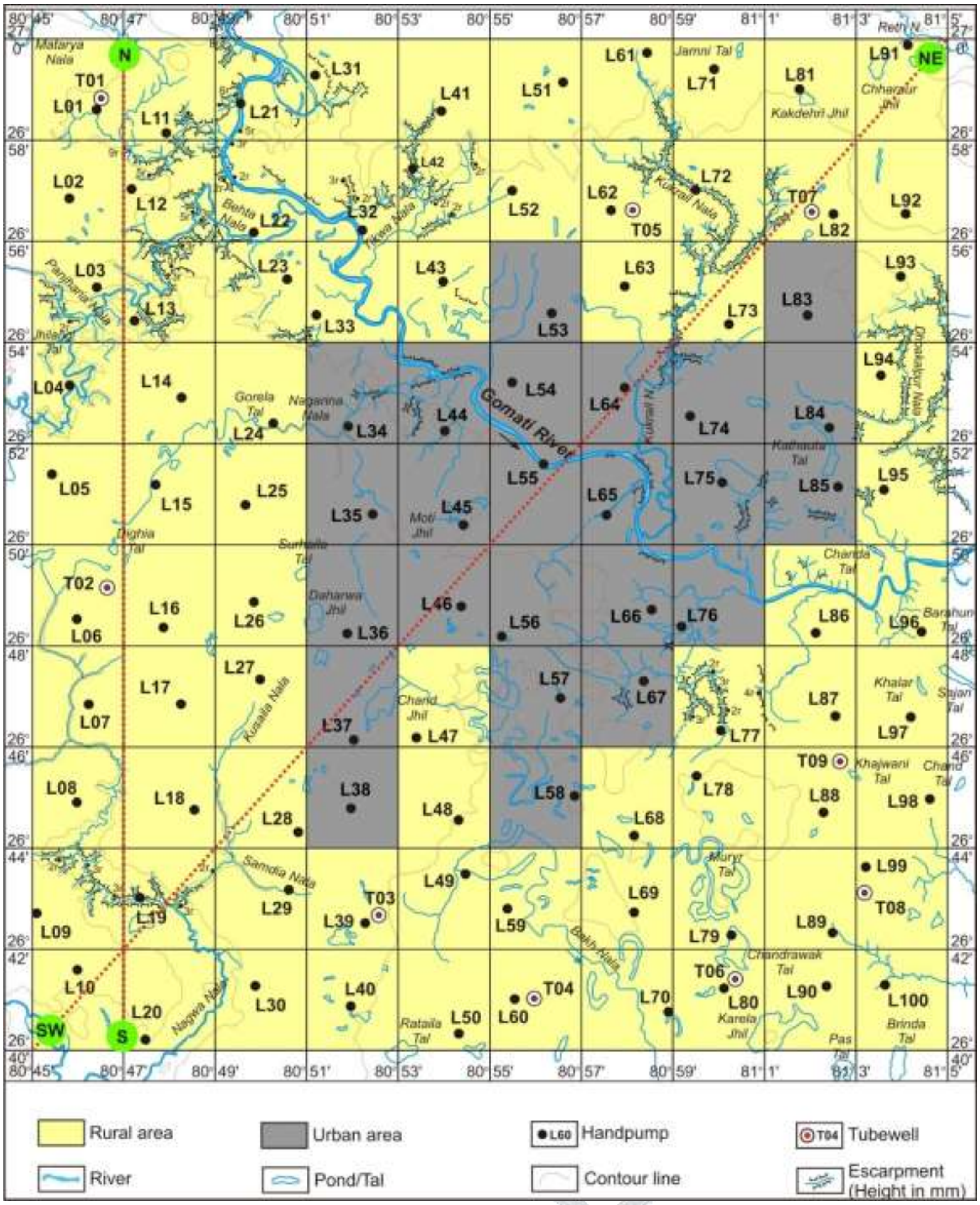

Figure 4: Sampling map with grid interval of 2minute for latitude and longitude.

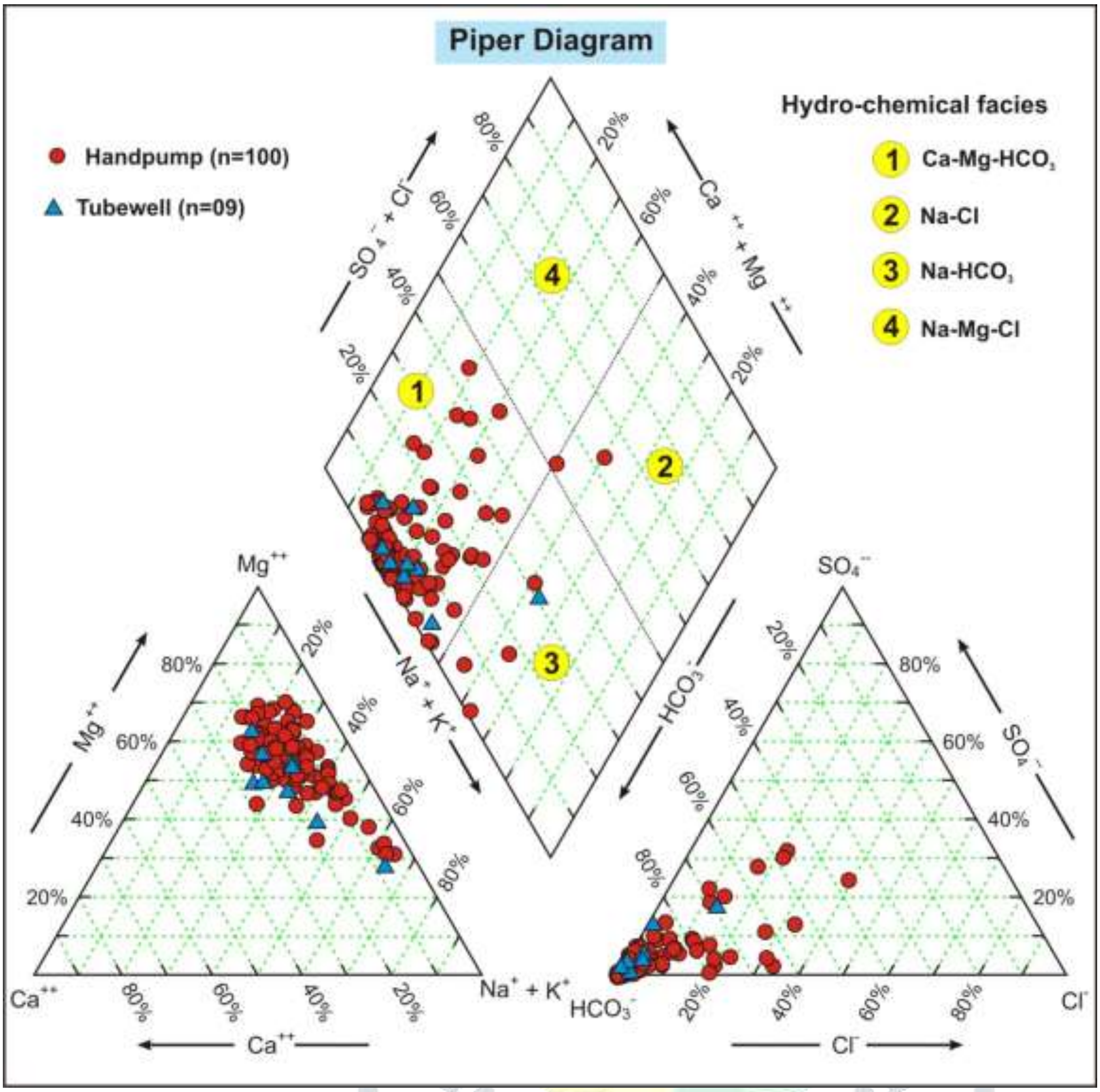

Figure 5: Piper Diagram

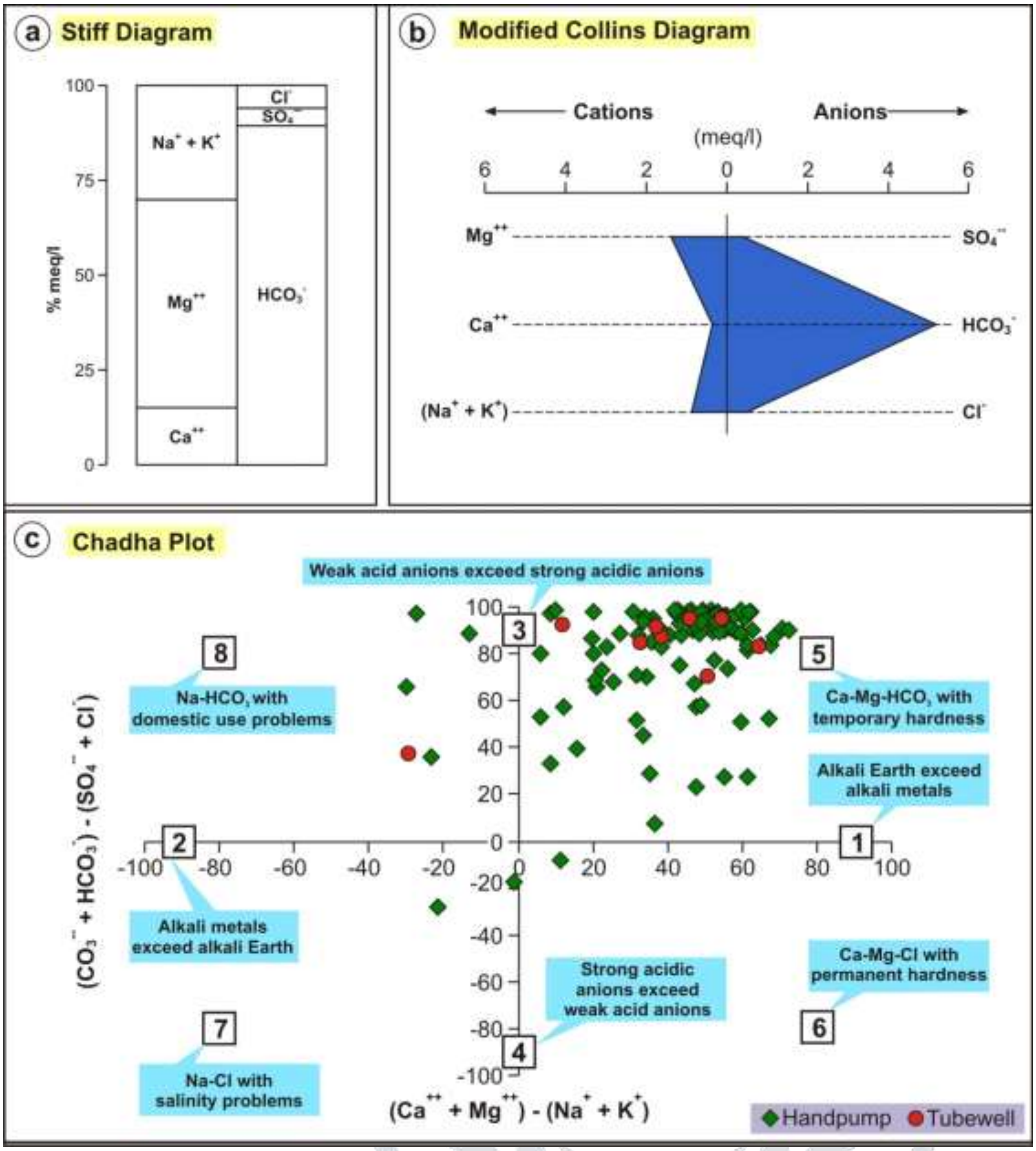

Figure 6: (a) Stiff diagram (b) Modified collins diagram (c) Chadha plot

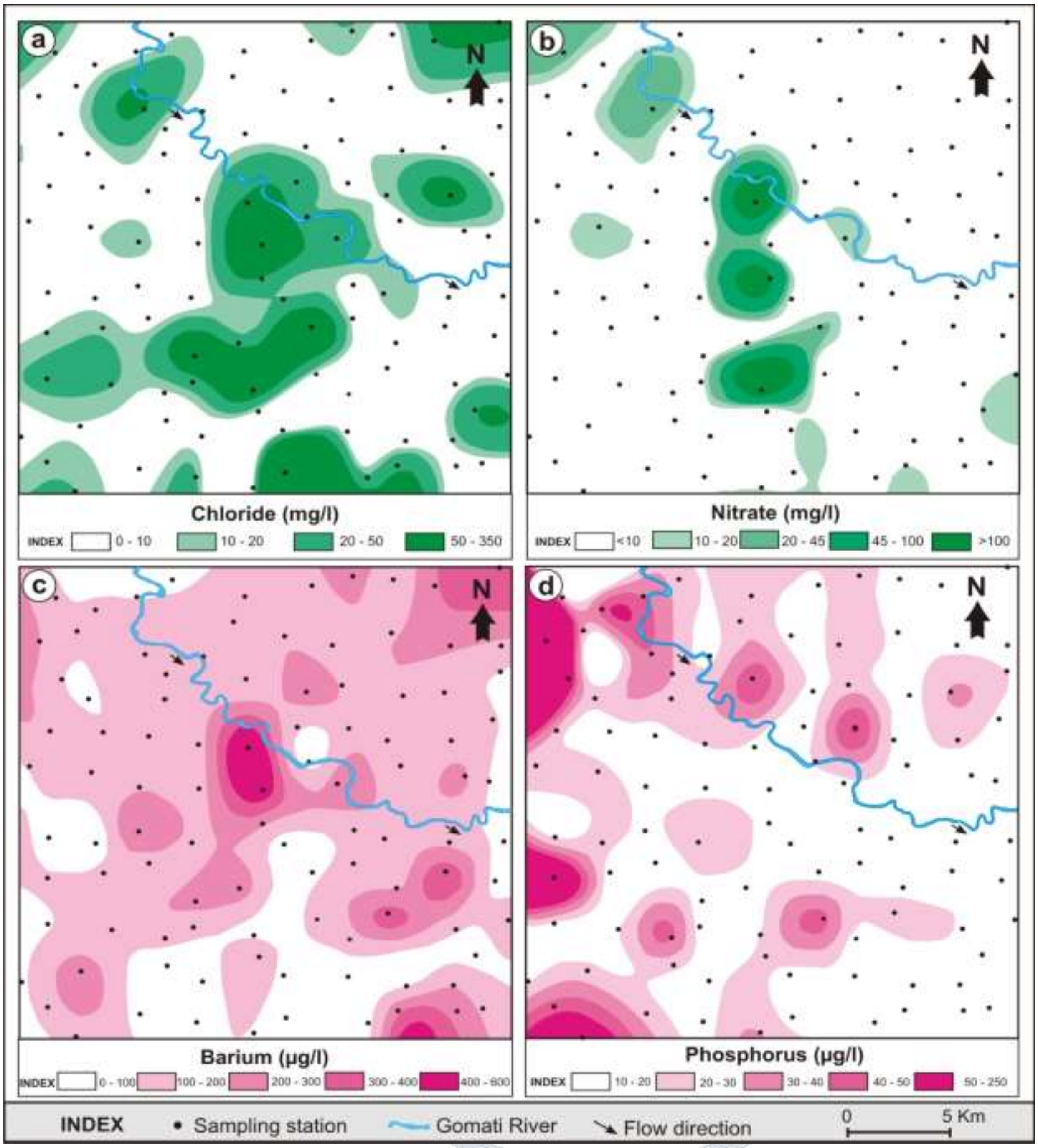

Figure 7: Graph shows natural background level of major/trace element in all samples (a) Chloride concentration contours (b) Nitrate concentration contours (c) Barium concentration range/contours (d) Three high phosphorous concentration contours.

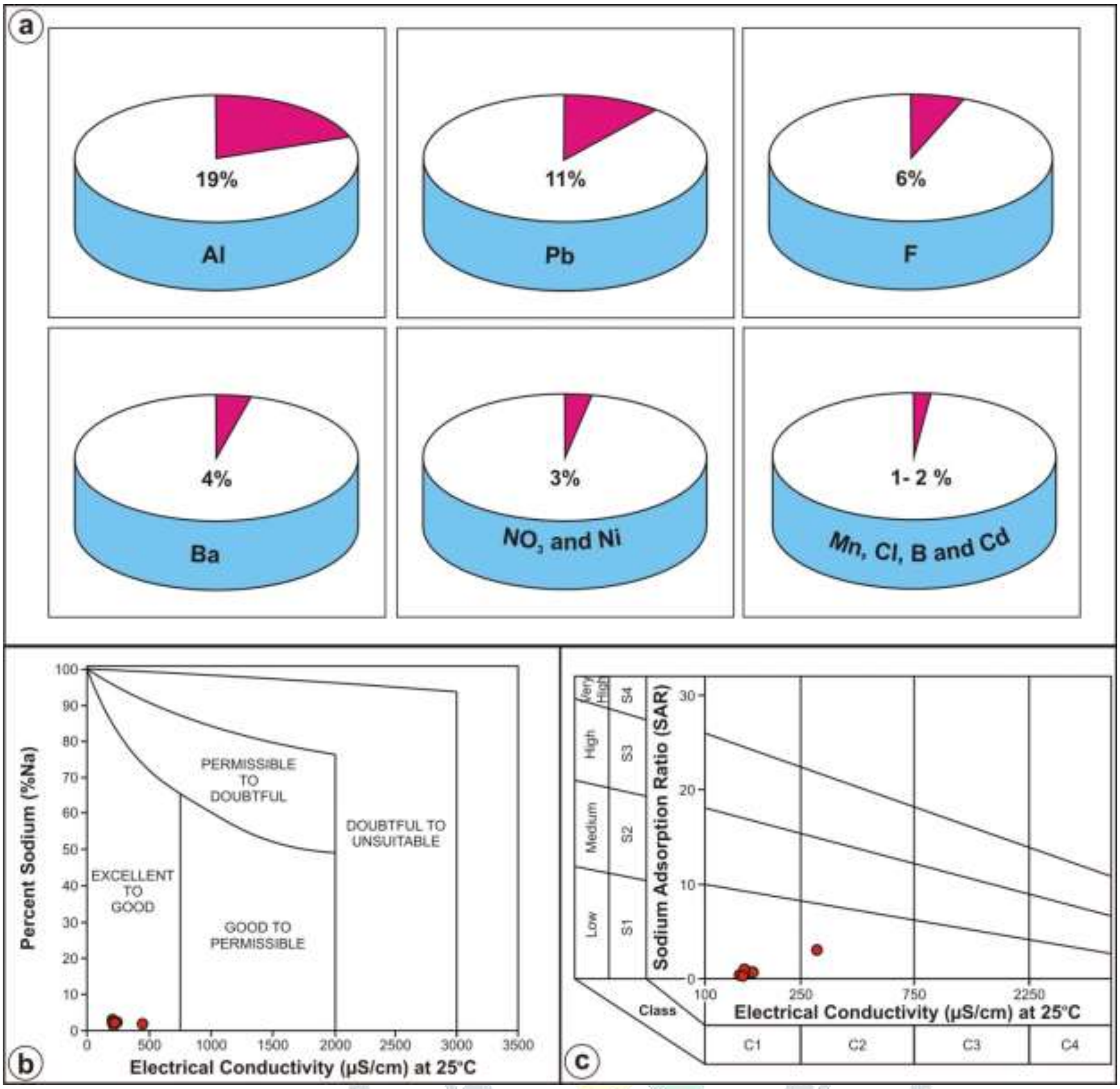

Figure 8: displays pie diagram showing the percent groundwater samples crossing WHO limits(b)showing plot of electrical conductivity and sodium percent data on wilcox diagram (c) diagram showing classification of irrigation water with respect to salinity and sodium hazard in USSLs classification (1954).

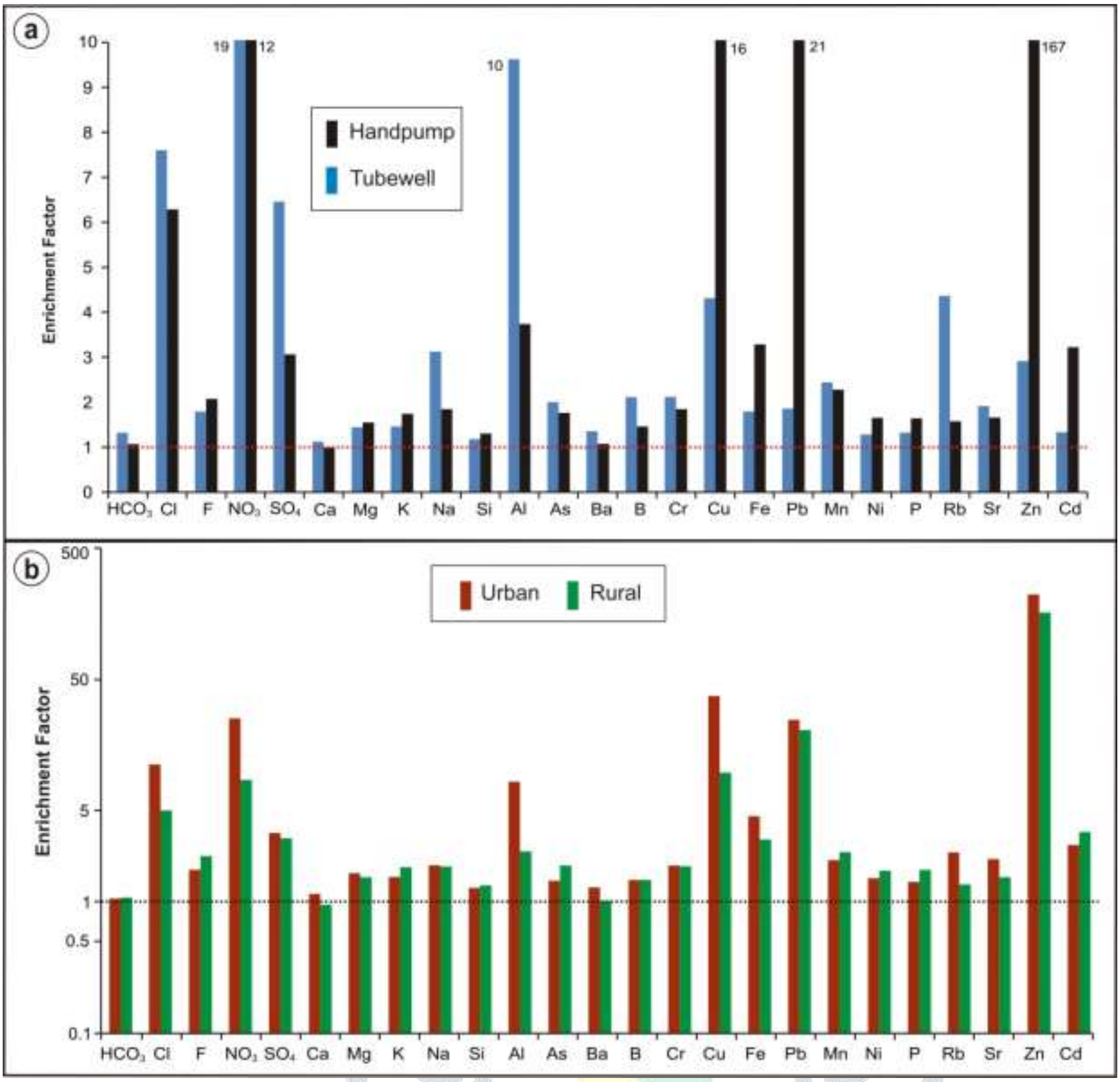

Figure 9: (a) Bar diagram showing enrichment factor of tubewell and handpump groundwater data calculated by established natural background level results as a reference. (b) Bar diagram showing comparative data of elements of urban vs rural groundwater.

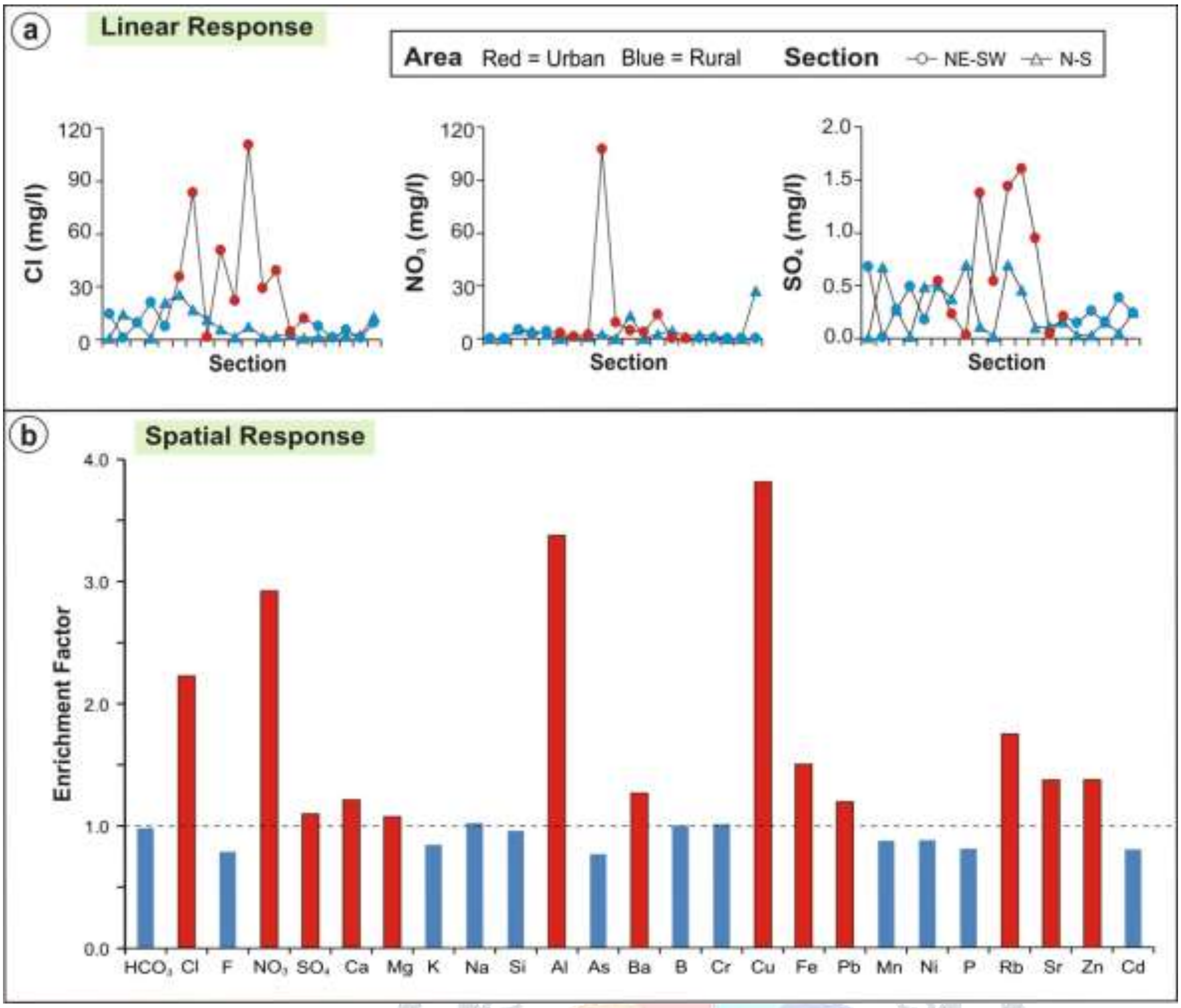

Figure 10: (a) Displays the isolated and multiple peaks of high concentration of Cl, NO3,SO4 showing enrichment of elements in the elemental profile across the N-S and NE-SW section. (b) Showing enrichment of chemical constituents in groundwater of urban vs rural areas. Bar diagram displays significant enrichment in the urban groundwater.

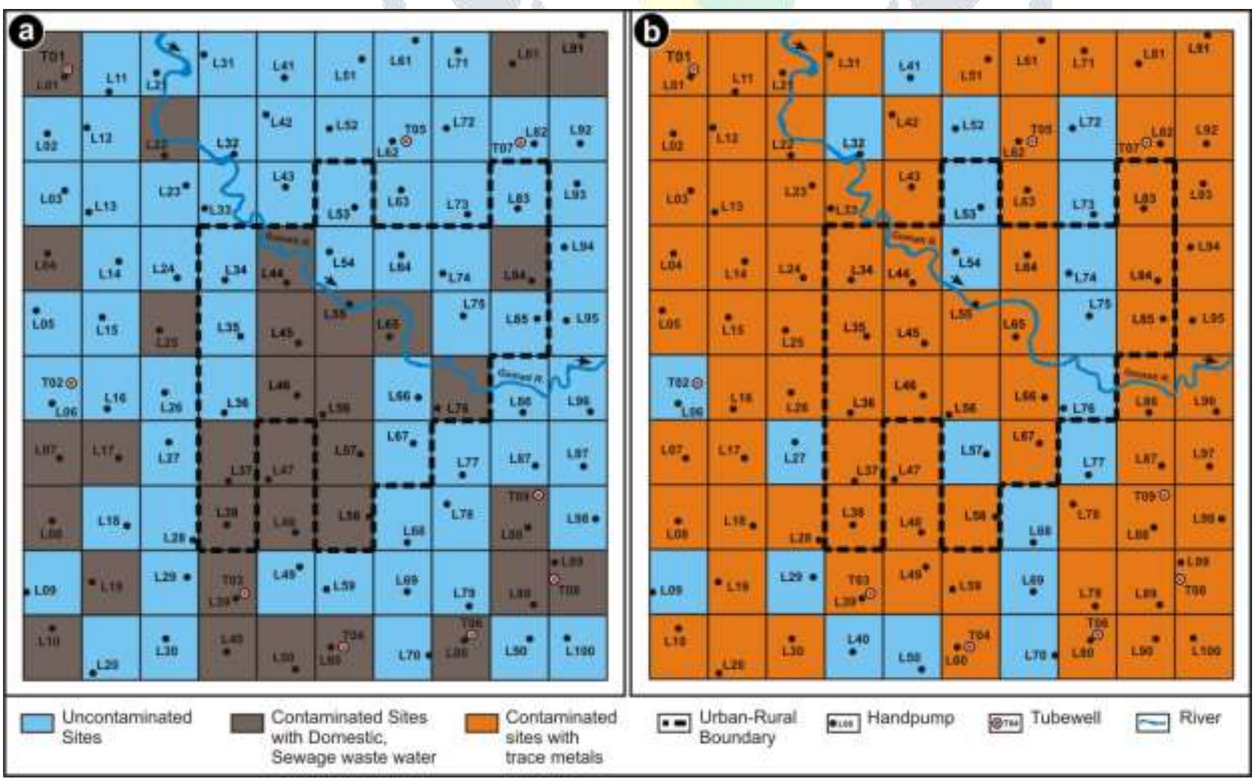

Figure 11: (a) Grid classification of contaminated sites with domestic cum sewage effluents in LMA. (b) Displays spatial distribution of sites contaminated with trace elements in both rural and urban parts of LMA.

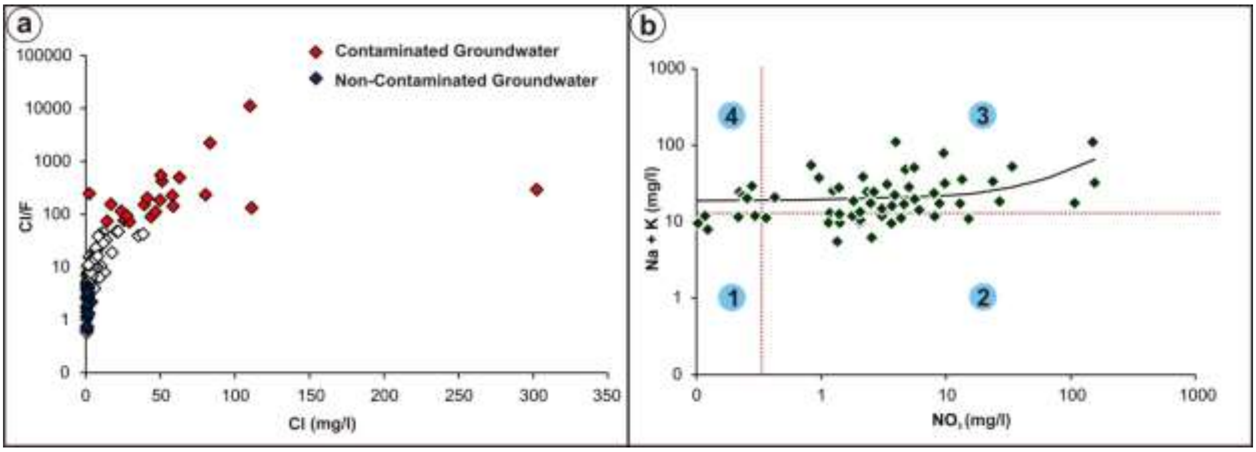

Figure 12: (a) Displays scatter diagram showing Cl vs Cl/F ratio of shallow drinking groundwater. (b) Displays scatter diagram showing NO3vs Na +K of shallow drinking groundwater.

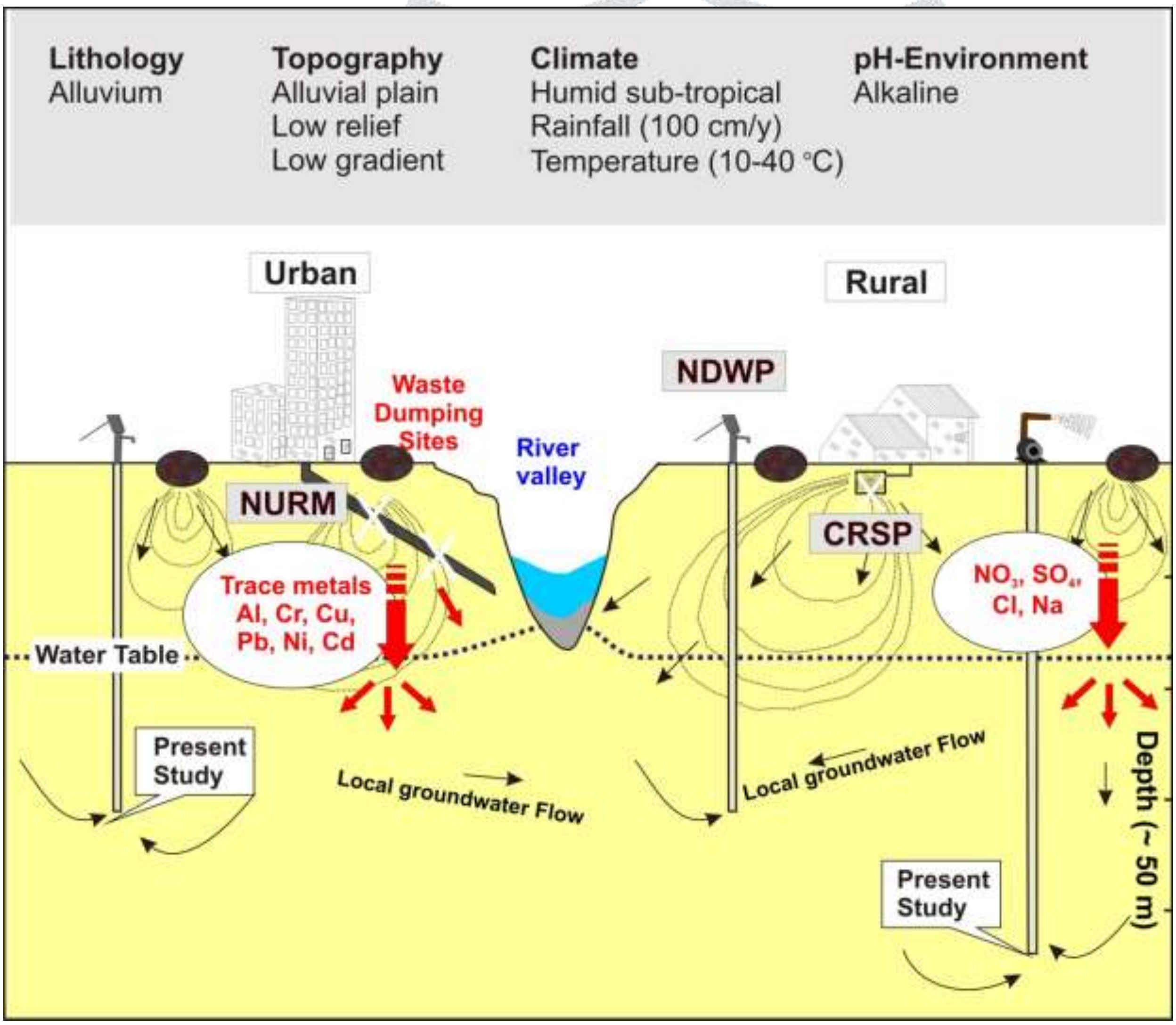

Figure 13: Displays a proposed model exhibiting migration dynamics for groundwater contaminants in the shallow aquifer of GAP under the hydrogeological and climatic conditions of the present study.