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Study of Groundwater Salinity in Few Districts Adjoining River Ganga in Uttar Pradesh - A Case Study

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Abstract

Central Pollution Control Board has focused on impact assessment of sewerage system and groundwater studies on River Ganga particularly in Uttar Pradesh state. Variation of total dissolved solid values in groundwater in some of the locations reveal that the water has become ‘Saline’ and ‘Brackish’ which could be due to over-extraction, besides contamination from anthropogenic sources. The chloride concentration in groundwater in the study shows that 10 locations are beyond the desirable limit as specified by BIS. There is a direct relationship between total dissolved solid and sodium, indicating of contamination. Nitrate content in groundwater in only one location, i.e., Dinapur, exceeded more than 7 times from the Indian Drinking Water Quality Criteria. The higher value of fluoride in groundwater was observed at various locations of Uttar Pradesh and appeared an inverse relationship between calcium concentrations indicating the cause as anthropogenic sources. Similarly, sulphate in 16 locations and phosphate in various locations of Saharanpur and Unnao districts exceeded the maximum permissible limit of BIS specified. Total coliform and faecal coliform counts was found in 27 locations above the permissible limits of BIS specified.

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Keywords

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Introduction

River Ganga is the longest river of India and is the second greatest river in the world in terms of water discharge. It has many tributaries and sub tributaries such as Alaknanda, Yamuna, Ramganga, Gomti, Ghaghara, Gandak, Kosi, Kali-east/Sharda, Chambal, Sindh, Betwa, Ken, Tons, Sone, Punpun, Damodar, Kangsbati Haldi and Mandakini (NGRBA, 2013).

Rapid urbanization and industrialization in adjacent districts of River Ganga has resulted discharge of treated, partially treated and untreated sewage and solid wastes into main stem and tributaries of River Ganga. Since 1986, various steps have been taken to control pollution of River Ganga to protect from different non-point and point sources including steps such as interception and diversion of sewage drains as well as setting up of Sewage Treatment Plants (STPs). Installed STPs are not operated satisfactorily and large quantity of untreated sewage is being taken through bypasses into main stem of River Ganga. Consequently, setting up of STPs and its operation and maintenance is the concern which has raised many questions over the years. The action plan for conserving Ganga has also covered River front development programs like setting up of wood based and electric crematoria, sanitation facilities for pilgrimage and construction of proper bathing facilities etc. (CPCB, 2015). Industries, factories, ashrams, hotels and apartments have traditionally disposed sewage into drains which ultimately meet River Ganga directly or through its tributaries.

Materials and methods

Study area and hydro-geologic setting

The River Ganga basin is bound in the north by the Himalayas and in the south by the Vindhyas. The River originates in the Garhwal Himalaya (30^{o} 55' N, 79^{o} 7' E) under the name of the Bhagirathi.

Fig. 1: Study area.

The ice-cave of Gaumukh at the snout of the Gangotri glacier, 4100 meters above sea level, is recognized as the traditional source of River Ganga (Photo 1). The River cuts its path through the Himalayas and flows a distance of about 205 km from Gaumukh and transverses through two districts of Uttarakhand state i.e. Uttarkashi and Tehri to reach Devprayag where another head stem, the Alaknanda, joins it to form Holy Ganga (Photo 2). The River Alaknanda is a major tributary of the River Ganga at Uttarakhand that begins at the confluence of the Satopanth and Bhagirathi Kharak glaciers in Uttarakhand and it travels approximately 190 km before meeting Bhagirathi. After flowing through the northernmost part of Uttarakhand, the River flows through Uttar Pradesh, Bihar, Jharkhand and West Bengal and finally meets Bay of Bengal. The River traverses a length of 1450 km in Uttarakhand and Uttar Pradesh while touching the boundary between Uttar Pradesh and Bihar for a stretch of 110 km. It then flows through Bihar, more or less covering a distance of 405Km length of the River measured along the Bhagirathi and Hugli Rivers during its course in West Bengal is about 520 km.

The growth of groundwater resources has increased manifold in the highly productive Gangetic plains, which hosts thick Quaternary deposits possessing multi-tier aquifer system. In complex multi-layered alluvial formations, the shallowest phreatic aquifer is often most vulnerable to anthropogenic pollution and most susceptible to saline intrusion. In a groundwater system in an alluvium-covered area, clues may not be simple due to masking of chemical alteration trends by anthropogenic influences (Umar and Absar, 2003).

Photo 1: Gangotri

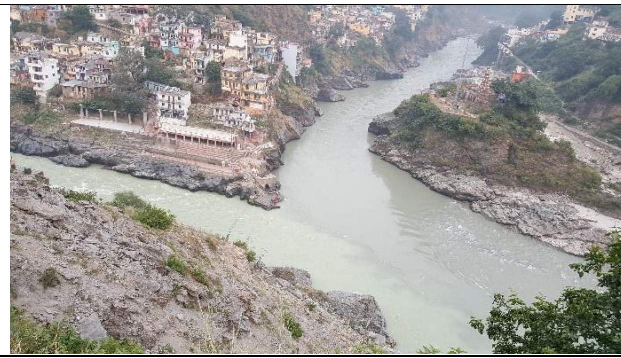

Photo 2: Devprayag

Photo 3: Forming Cesspools

Photo 4: River converted into Sewerage

Photo 5: Groundwater for Drinking

Photo 6: Solid Waste dumping in drain

The Ganga has by far the largest river basin in India, 15th in Asia and 29th in the world, draining as much as 861404 Sq.Km within the country, covering more than a quarter (26.2%) of India's geographical area. The basin has large surface water and groundwater resources and receives rainfall from both the northeast and southwest monsoons and the wettest months are July, August, September and October in that order and the annual flow in the basin is 468.7 billion m^3, which accounts for 25.2% of India's total water resources (Joshi et al., 2009).Geography, geomorphology, climate and quaternary stratigraphy of the study area have been detailed by Ahamed et al., (2006) and Acharyya and Shah (2007). Uttar Pradesh consists of 75 districts and each district is divided into several blocks and each of these blocks has several Municipal corporation/ Nagar Palika/Gram Panchayats, which are the clusters of towns/villages. The majority of the population depends on farming as its main occupation and the Saharanpur, Meerut, Rampur, Aligarh, Kanshiram Nagar, Farrukhabad, Kannauj, Kanpur, Unnao, Fatehpur, Raibareli, Pratapgarh, Kaushambi, Allahabad, Mirzapur, Varanasi, Chandauli, Ghazipur and Ballia districts are selected as study area (Fig. 1).

Sampling

One hundred and ninety-five (195) groundwater samples from the various locations of Ganga front towns of Uttar Pradesh were collected in distilled water washed polyethylene bottles after 10 min of initial pumping to prevent any contamination during the Pre-Monsoon. For sample collection, polyethylene bottles of different size with inner cap were used. For each sample, details of location, temperature, odour, color, turbidity, surrounding environmental conditions etc. were recorded and appropriately labeled, sealed and transported to the laboratory on the same day.

The sampling locations were selected within 500 meters radius from the sewerage system and Ganga main stem (core zone).The sample locations were chosen in such a way to represent the both side of the Ganga main stem. Analysis of all parameters was done at laboratory of Central Pollution Control Board.

Groundwater pollution

There is a large gap between generation, collection, treatment and disposal of sewage in study area. A large quantity of untreated sewage inventions makes its way either to nearby water body or land in the village/ town forming cesspools. These cesspools are good breeding ground for mosquitoes and also point of groundwater recharge (Photo 3). The sewage accumulated in these cesspools gets percolated in the ground and pollutes the groundwater. Also in many villages/towns conventional septic tanks and other low cost sanitation facilities exists and all drains are converted into sewerage network system (Photo 4). Due to non-existence of proper maintenance these septic tanks become major source of groundwater pollution. In many villages/ towns groundwater is the only source of drinking (Photo 5). Thus, a large population is at risk of exposing to water borne diseases of infectious or chemical nature and water borne diseases are still a great concern in Uttar Pradesh. Also, solid waste from households and industries are being dumped near the residents and factories respectively and is subjected to reaction with percolating rainwater and reached the groundwater level (Photo 6). The percolating water picks up a large amount of dissolved constituents and reaches the aquifer system and contaminates the groundwater.

A vast majority of groundwater quality problems are caused by contamination, over-exploitation, or combination of both. The solutions are usually very expensive, time consuming and not always effective. An alarming picture is beginning to emerge in many parts of our country. Diffuse sources can affect entire aquifers, which is difficult to control and treat. The only solution to diffuse sources of pollution is to integrate land use with proper water management, as well as proper solid and waste water disposal.

Results and discussion

A study by Ray et al. (1983) shows that the groundwater is partially suitable for drinking purposes and public health, because the concentrations of NO_3^-, F^-, Na^+ and TDS in the groundwater are observed to exceed the recommended limits for drinking purposes and also, reported 24.91% dental fluorosis in Ledhupur and Rustampur villages of Varanasi environs and found that maximum prevalence of dental fluorosis is in 11 to 15 years age group, and its prevalence is higher in males than females. While studying hydro-chemistry of groundwater in Aligarh city of Uttar Pradesh, Wasim et al. (2014) used to determine its suitability for drinking and irrigation purpose. Physico-chemical parameters of groundwater such as pH, EC, TDS, Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, HCO_3^-, CO_3^{2-} and SO_4^{2-}, in 2010. Ionic concentrations of the groundwater vary spatially and temporarily and the water is alkaline in nature. Twenty five percent of the locations lie under the medium salinity zone (EC: 750 to 2250 μS/cm).

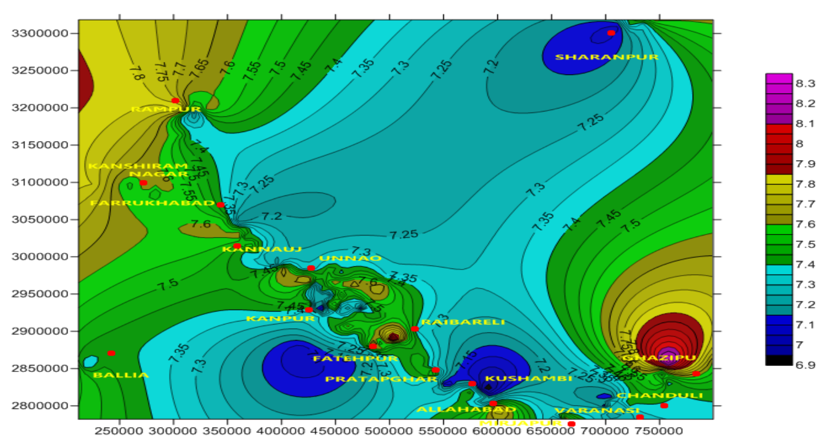

Fig. 2: Contour map of concentration of pH in groundwater.

Similarly, in this study, only one location of Tandao, Fatehpur exhibited more than desirable limit of pH value (as per 6.5-8.5pH, BIS: 10500) indicating the presence of carbonates of Ca^{2+} and Mg^{2+} (Fig. 2). Alternately, the total alkalinity ranged from 28 to 610 mg/l with an average value of 328 mg/l and it is observed that groundwater in 171 locations were beyond the desirable limit (200 mg/l, BIS: 10500:2012) (Fig. 3).

The value of Electric Conductivity (EC) ranged from 5 to 9440 µS/cm with an average value of 1099 µS/cm. The locations closed to sewerage and drain channel showed higher values indicating sewage intrusion into groundwater regime (Fig. 4). On the basis of EC, the groundwater has been classified into fresh (<1500 µS/cm), brackish (1501–3000 µS/cm) and saline (>3000 µS/cm) types (Saxena et al., 2003). According to variation of EC values in study locations like Amaritpur, Nevada, Abrahimpur, Gugrapur, Jajmau, Golaghat, Sisamau,Dabka nala-Jajmau, Tarragon, Papyri,Mazara, Khajur, Gautam-purwa, Manikpur, Shahjadpur,Allahabad, Dariabad, Bhiti, Bhagwanpur, Varanasi and Nandganj the groundwater is 'Brackish' and Asoha, Maswasi, Bhadni, Pariar and Unnao city of Unnao district of groundwater are 'Saline' which could be due to over-extraction (Handa, 1969), besides contamination from anthropogenic sources (Jiban Singh et al., 2010 and 2012) (Figs. 4 and 5).

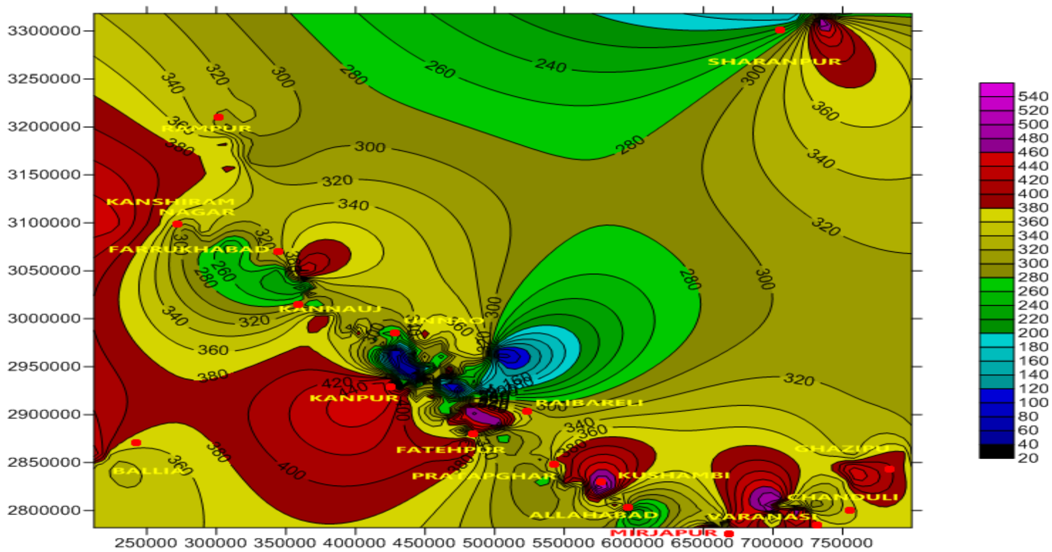

Fig. 3: Contour map of concentration of Alkalinity in groundwater.

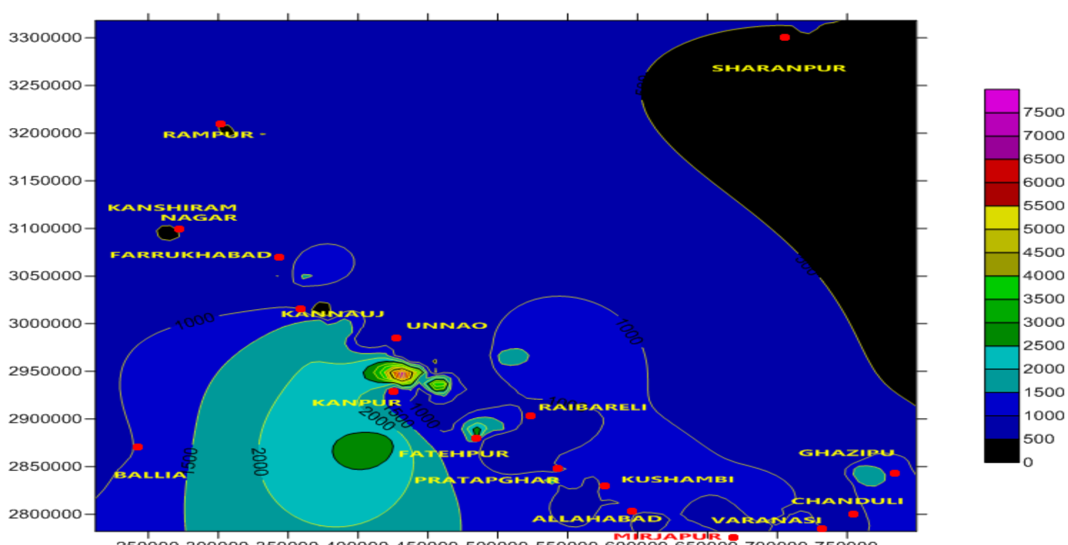

Fig. 4: Contour map of concentration of EC in groundwater.

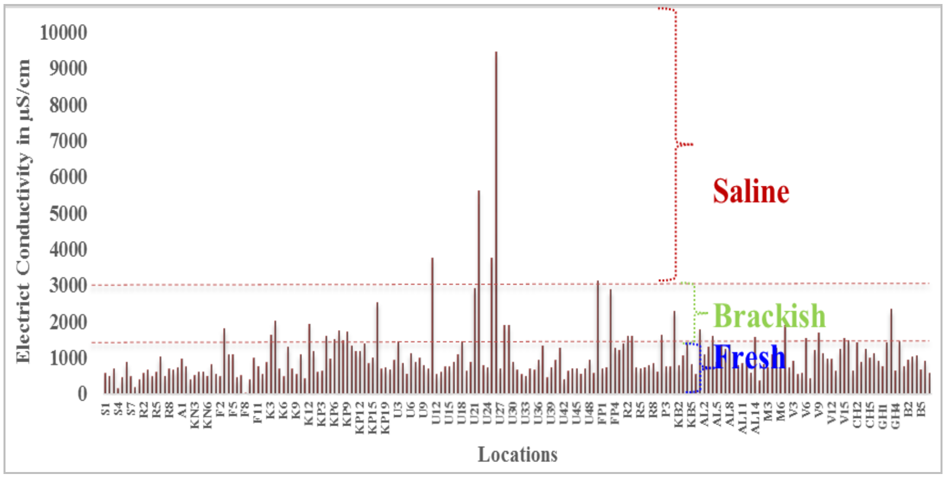

Fig. 5: Classification of groundwater on the basis of Electric Conductivity by Saxena et al. (2003).

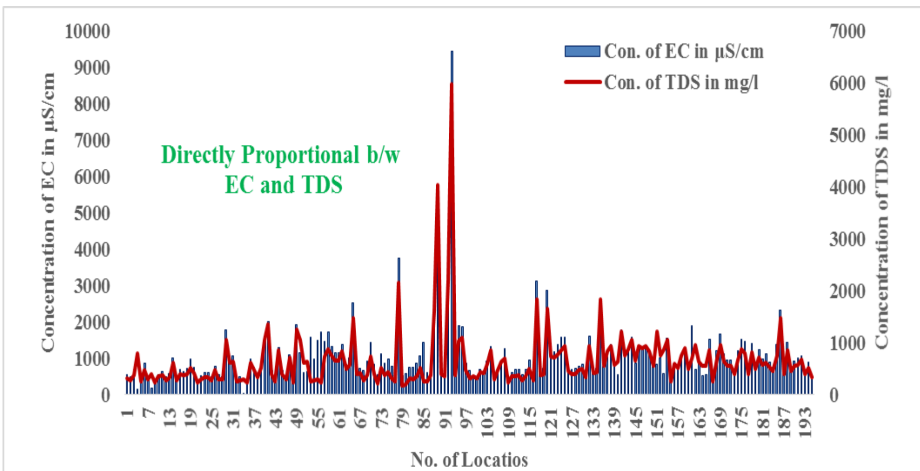

Fig. 6: Concentration of EC and TDS is directly proportional in study area.

Further, concentration of EC and TDS in groundwater is directly proportional (Fig. 6) and it can be classified on the basis of TDS, up to 500 mg/l as desirable for drinking; 500 to 1000 mg/l as permissible for drinking; up to 3000 mg/l as useful for agricultural purposes and above 3000 mg/l as unfit for drinking and irrigation (Davis and De Wiest, 1966) (Fig. 7). In this study, TDS values were found ranging from 182 to 5974 mg/l with an average value of 665 mg/l. It is observed that out of 195 groundwater locations, 100 locations are beyond the desirable limit (500 mg/l, IS: 10500:2012) (Fig. 8). But, as per Fetter (1990) classification of waters based on the TDS, 174 locations come under fresh water (TDS <1000 mg/l) and remaining 21 locations like Amaritpur, Navada, Abrahimpur, Gugrapur, Wajitpur, Jajmau, Asoha, Taargaon, Maswasi, Bhadni, Pariar, Ambedkar Gram, Fatehpur Chaurasi, Unnao city center, Mazara, Shahjadpur, Allahabad, Karelibag, Dariabad and Nandganj were under brackish water (TDS >1000 mg/l) categories (Fig. 8). However, a general increase in TDS and salinity in study area is accounted by the presence of HCO_3^-, SO_4^{2-}, Cl^-, CaH, MgH, and Na^{2+} and they elevate the density of water (Nawlakhe et al., 1995) and attributed to evaporation from water table, irrigation return flows, and anthropogenic activities such as effluents from fertilizers, sugar, paper, distillery, tannery slaughterhouse industries etc. (Umar et al., 2009).

Earlier on 2009, Tyagi and co-workers have specified, a positive correlation between Na^{2+} and Cl^- suggests that the salinity of groundwater is due to intermixing of two or more groundwater bodies with different hydro-chemical compositions. Chemical fertilizers, sugar factories and anthropogenic activities are contributing factors to the SO_4^{2-} and Cl^- concentrations in the groundwater of the Muzaffarnagar, Uttar Pradesh. Overexploitation of aquifers induced multi componential mixing of groundwater with agricultural return flow waters is responsible for generating groundwater of various compositions in its lateral extent. Consequently, the Cl^- concentration in this study ranged from 0 to 1993 mg/l and it is observed that 10 locations like Jajmau, Asoha, Morawa Tiraha, Langarpur, Ghoor Khet, Maswasi, Bhadni, Pariar, Rahman Daulatpur and Nandganj are beyond the desirable limit (250 mg/l, BIS: 10500:2012). It suggests definitely attribution to the industrial activities in the vicinity (Fig. 9). Also, Cl^- value showed a direct relationship with TDS and Na^{2+}, which suggests that they can be used as effective indicators of contamination (Figs. 10 and 11).

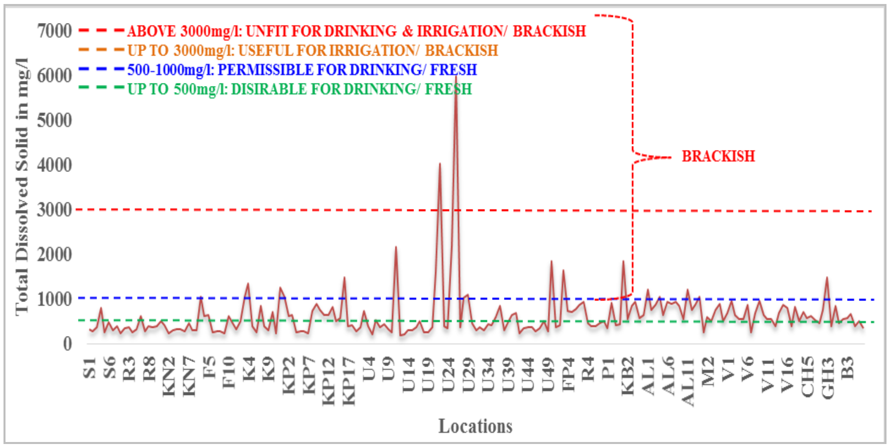

Fig. 7: Classification of groundwater on the basis of TDS by Davis and De Wiest (1966) and Fetter (1990).

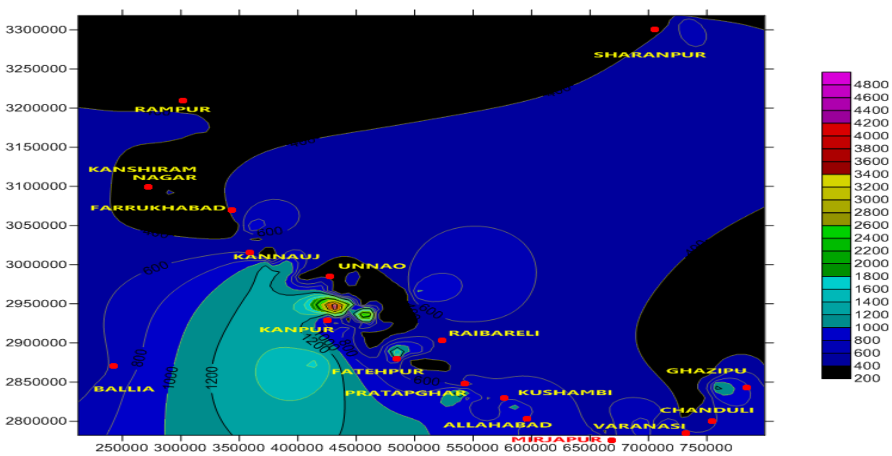

Fig. 8: Contour map of concentration of TDS in groundwater.

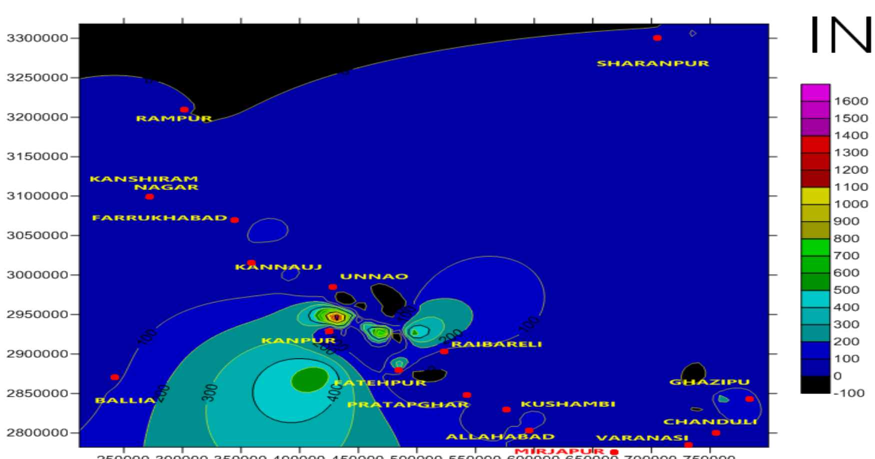

Fig. 9: Contour map of concentration of Cl^- in groundwater.

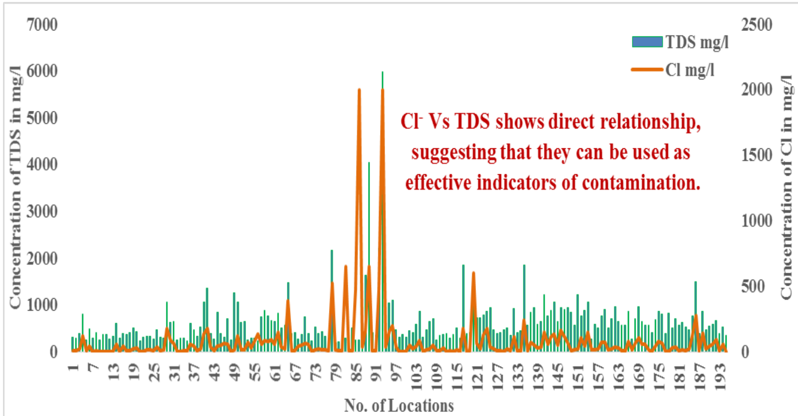

Fig. 10: Direct relationship between Cl and TDS in Uttar Pradesh.

Consumption of water with higher NO_3^- causes blue baby or methemoglobinemia in infants and gastric carcinomas, abnormal pain, central nervous system birth defects and diabetes among others. Nitrogen compounds are present in groundwater in the form of nitrate (NO_3^-) and nitrite (NO_2^-) ions. Nitrates are extremely soluble in water and can move easily through soil into the groundwater. The fertilizers and domestic wastes are the main sources of nitrogen-containing compounds and its concentration may be further affected by complex hydrochemical processes such as nitrification or denitrification (Arnade, 1999; Graniel et al., 1999; Rosen et al., 1999). Higher levels of NO_3^- and other chemical pollution in the groundwater and surface waters in Varanasi environs have been reported by different researchers and found NO_3^- concentration ranging from 66-199 mg/l (Bilas, 1980; Pandey, 1993; Sinha, 2003).

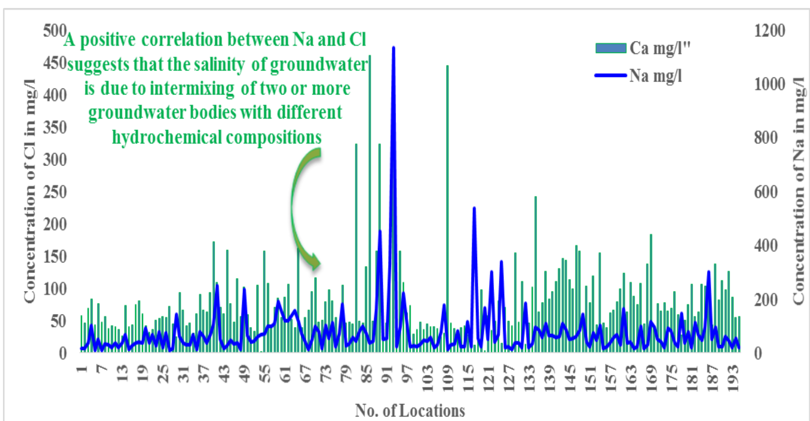

Fig. 11: Positive high correlation between Na and Cl in Uttar Pradesh.

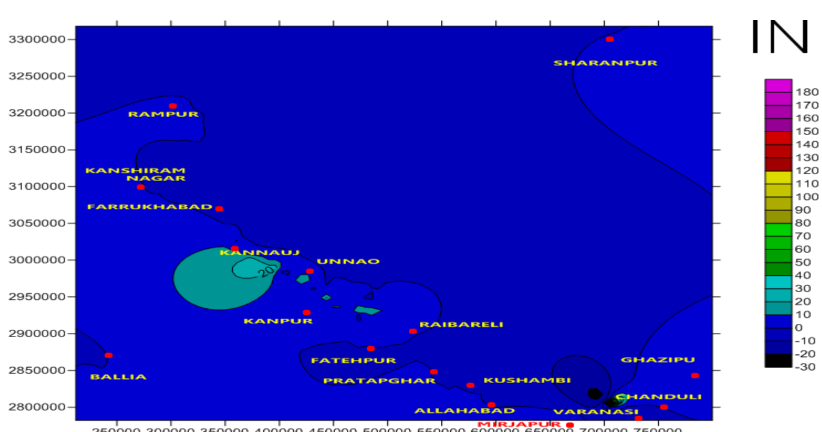

Fig. 12: Contour map of concentration of NO3- in groundwater.

In the study area, NO_3^- content in groundwater at only one location i. e. Dinapur (Varanasi) was found exceeded more than 7 times (320 mg/l) from the Indian Standard norms (45 mg/l as NO_3^-) (Fig. 12). The most likely cause is drainage of water through soil containing domestic and industrial wastes, and vegetable and animal matters (Girard and Hillarie Marcel, 1997). Septic tanks and garbage dump disposals are also responsible for the higher NO_3^- (Gumtang et al., 1999; Basappa Reddy, 2003; Owens, 2003). The pockets of higher NO_3^- in the groundwater regime of the Varanasi appear to be related to sewage and agricultural land. A significant correlation between NO_3^- and Ca^{2+} and Mg^{2+} in groundwater strongly indicates that hardness is closely associated with NO_3^- concentration in Dinapur village.

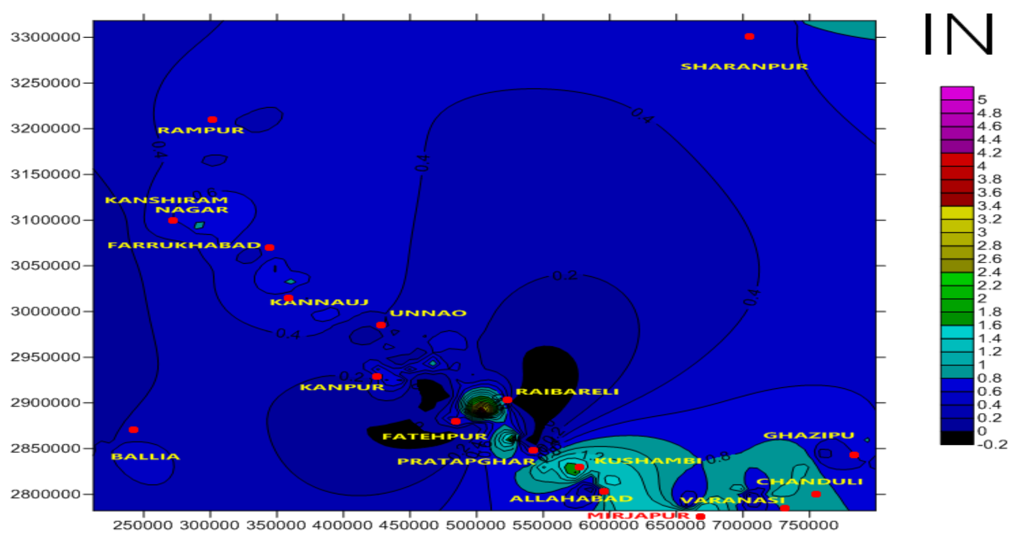

Fig. 13: Contour map of concentration of F^- in groundwater.

The main source of Fluoridesin water is fluoride bearing rocks. The maximum permissible limit for F^- in drinking water is 1 mg/l (BIS: 10500: 2012). The concentrations of F^- in groundwater may vary considerably over short distance. In the study area, the F^- concentration ranged from 0.02 to 5.78 mg/l. The higher F^- was observed at Jajmau, Dalwar,Ashni, Kaushambi, Kasia, Palhana, Ujaini, Chupperpur, Jhansi, Kuresar ghat, Shrinagwarepur, Mirzapur, Bhiti, Bhagwanpur, Varanasi, Chauraha, Rautpur, Tadiyapar and Lallanpur (Fig. 13). On the other hand, once the solubility limit of fluorite (CaF_2) is reached, an inverse relationship appears between F^- and Ca^{2+} concentrations, and many studies have been found a strong association between high F^- and soft, Alkaline (i.e., $NaHCO_3$) groundwater with depleted Calcium (Bardsen et al., 1996; Conrad et al., 1999; Gupta et al., 1999; Earle and Krogh, 2004; Chae et al., 2006a; Dhiman and Keshari, 2006; Chae et al., 2007). It appears although that the solubility of fluorite (CaF_2) might have reached maximum in Uttar Pradesh aquifers. Also an inverse relationship between F^- and $Ca^{2+}$is evident (Fig. 14). The source of F^- contamination in groundwater could be even anthropogenic activities, because even when environmental conditions are held constant in laboratory experiments, the percentage of total leachable F^-varies widely from one rock type to another (Lirong et al., 2006).

Apart from the natural processes which cannot be controlled, huge amount of F^- are contributed from anthropogenic resources, such as the use of F^- salts in large number of industries such as steel, aluminum, brick and tiles industries in the present case which often use F^-. Pesticides and fertilizers used in agricultural activities are also contributing significant amounts of F^- to the groundwater regime in Uttar Pradesh aquifers.

Similarly, the concentration of SO_4^{2-} in the groundwater varied from 2 to 1843 mg/l. During the study period, SO_4^{2-} in 16 locations exceeded the maximum permissible limit (200 mg/l, BIS: 10500:2012), particularly at Aligarh, Abrahimpur, Morawa Tiraha, Langarpur, Ghoor Khet, Taargaon, Maswasi, Bhadni, Pariar, Papr,Chaurasi and Unnao (Fig. 15). Also, the concentration of PO_4^{3-}in groundwater during the study period varied from 0.0 to 1.22 and beyond the maximum permissible limit (0.3 mg/l, IS: 10500:2012) in various locations of Saharanpur and Unnao. The range of Total

Coliform (TC) and Faecal Coliform (FC) detected from the groundwater varied from <1.8 to 6000and <1.8 to 1700MPN/100 ml respectively and 27 locations in study area, like Bhagwat ghat, Golaghat, Wajitpur, Unnao, Koluhagaarha, Bighapur, Sagwar Block, Uuchgaon, Sumerpur, Gopalpur, Gautam purwa, Muraibag Chauraha, Amiliya purwa, Shahjadpur, Kasia, Palhana, Allahabad, Mirzapur, Varanasi, Rautpur, Sakaldeaha, Mugalsarai and Ram Nagar showed TC and FC counts above the threshold limits (<1.8MPN/100 ml).

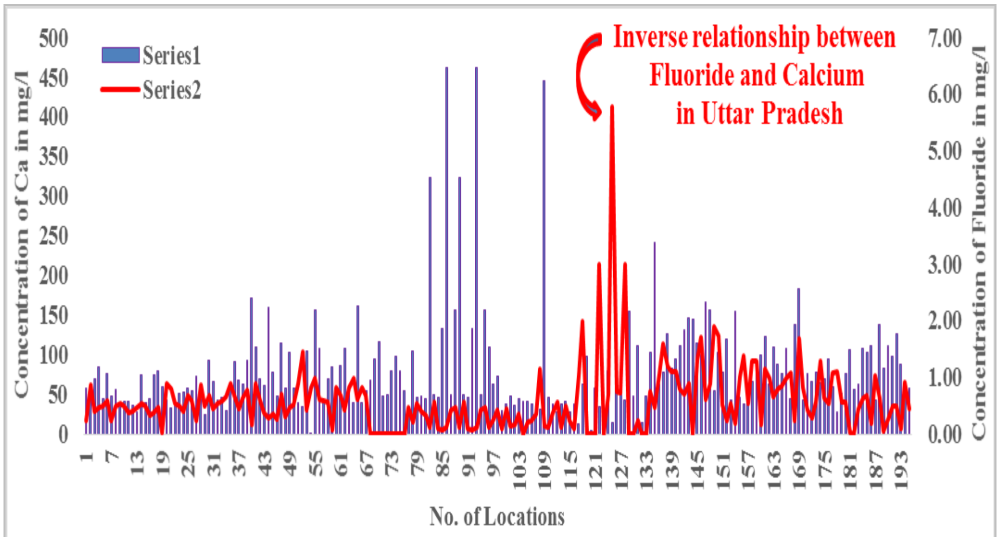

Fig. 14: Inverse relationship between F- and Ca^{2+}in Uttar Pradesh.

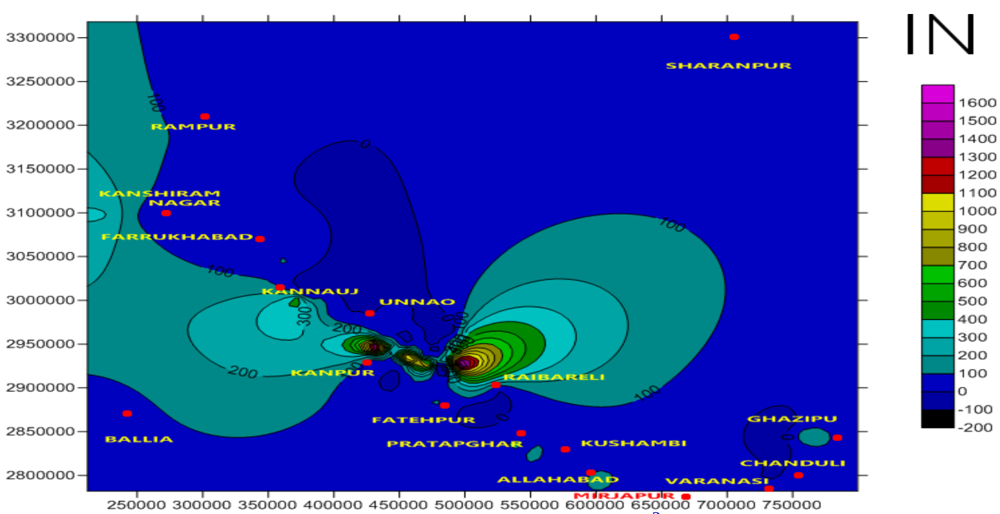

Fig. 15: Contour map of concentration of SO_4^{2-} in groundwater.

As per WHO and IS: 10500:2012guidelines TC and FC count should be zero in water used for drinking purpose. As such, the analysis indicate gross pollution of groundwater (Polo *et al.*, 1998) via percolation under natural hydraulic pressure. Faecal coliform are a subset of the TC bacterial group found in human and animal intestinal wastes. The FC bacteria group includes the genera *Escherichia* and to a lesser extent, *Klebsiella* and *Enterobacter*. They are more precise indicators of the presence of sewage contamination than TC. Highest proportion of indicator organisms were found in various locations of Jajmau, Unnao, Fatehpur, Raibareli, Kaushambi, Allahabad, Mirzapur, Varanasi and Chandauli district (Figs. 16 and 17).

As per field observation, it was noticed that sewage disposal practices like soak pits, pit latrines and septic tanks were in use. Cracks or holes in the well casing might have allowed microbial contamination of ground water through the permeable soil layer.

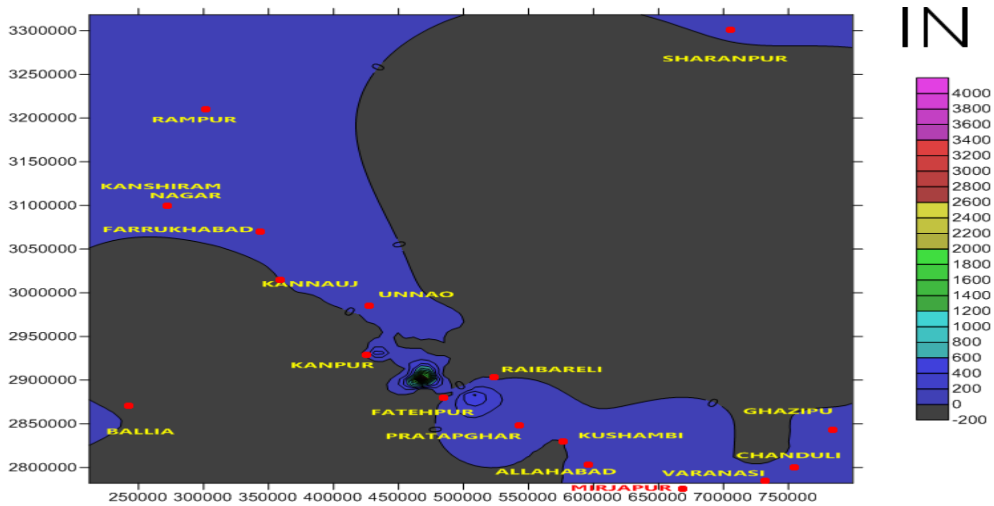

Fig. 16: Contour map of concentration of TC in groundwater.

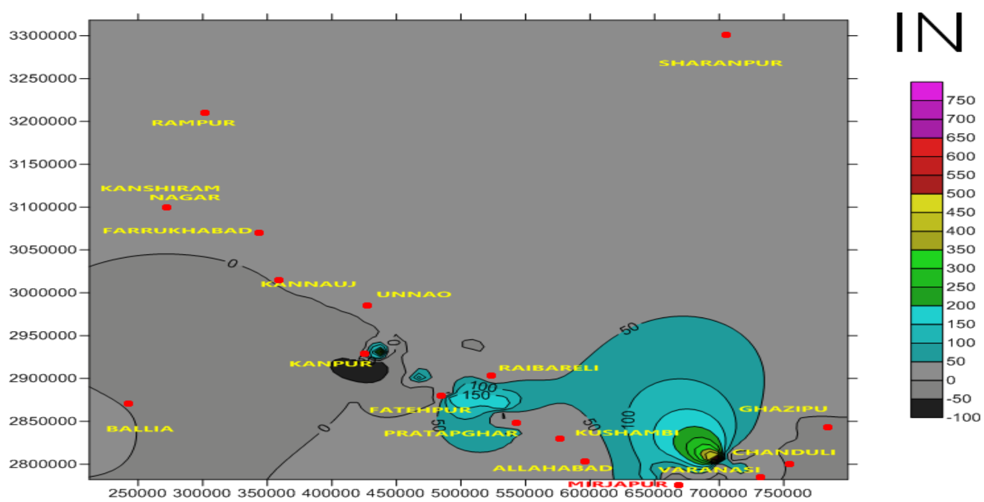

Fig. 17: Contour map of concentration of FC in groundwater.

Conclusion

Alkalinity in 171 locations was beyond the BIS desirable limit. According to variation of EC values in study area, groundwater in some of the locations are 'Brackish' and 'Saline' which could be an outcome of over-extraction, besides contamination from anthropogenic sources. Further, concentrations of EC and TDS in groundwater are directly proportional and it is observed that out of 195 groundwater locations, 100 are beyond the desirable limit of TDS. However, a general increase in TDS and salinity in study area is accounted by the presence of HCO_3^-, SO_4^{2-}, Cl^-, CaH, MgH, and Na^{2+} and they elevate the density of water and attributed to evaporation from water table, irrigation return flows, and anthropogenic activities such as fertilizers, effluents from sugar factories, paper mills and slaughterhouse. Consequently, the Cl^- concentration in this study observes that 10 locations are beyond the desirable limit, suggesting definitely the attribution to the industrial activities in the vicinity. Also, Cl^- shows a direct relationship with TDS and Na^{2+}, suggesting that they can be used as effective indicators of contamination. Groundwater NO_3^- content of only one location Dinapur exceeded more than 7 times (320 mg/l) from the Indian Drinking Water Quality Criteria (45 mg/l as NO_3^-). Organic origin is probably the cause for most of such occurrences, which can be assigned fairly to drainage of water through soil containing domestic and industrial wastes, vegetable and animal matter. Septic tanks and garbage dump disposals are also responsible for the higher NO_3^-. A significant correlation between NO_3^- and Ca^{2+} and Mg^{2+} in groundwater strongly indicates that hardness is closely associated with NO_3^- concentration in Dinapur village. The higher F^- was observed at various locations of Uttar Pradesh and appeared an inverse relationship between Ca^{2+} concentrations in groundwater, indicating contribution from anthropogenic resources, such as the use of F^- salts in large number of industries such as steel, aluminum, brick and tiles industries as well as pesticides and fertilizers used in agricultural activities are also contributing significant amounts of F^- to the groundwater regime in Uttar Pradesh aquifers. Similarly, SO_4^{2-} in 16 locations exceeded the maximum permissible limit. But, the concentration of PO_4^{3-}in groundwater during the study period exceeded the maximum permissible limit in various locations of Saharanpur and Unnao districts.

Total coliform and faecal coliform count should be zero in water used for drinking purpose. But, in the observation of all 27 locations in study area, counts above the permissible limits, it was noticed that sewage disposal practices like soak pits, pit latrines and septic tanks were in use. Cracks or holes in the well casing must have allowed microbial contamination of ground water through the permeable soil layer.

Conflict of interest statement

Authors declare that they have no conflict of interest.

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