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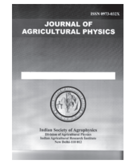

Geo-spatial Hydro-geochemical Contribution to Groundwater Resources under Intensively Cropped Farm

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ABSTRACT

Continuous loading of agrochemicals on any intensive agricultural land is likely to move with irrigation water through the soil zone, leading to groundwater contamination. The Indian Agricultural Research Institute, New Delhi Farm is one such area where groundwater is being mainly used for irrigation. Geographic Information System based investigation has helped to understand the spatial distribution of contaminants in the farm area. The results reveal that the farm groundwater is not a homogeneously mixed system, and has dominance of sodium and chloride ions. Increasing both chloride and sodium levels in groundwater indicates common source of these ions in the recharge process. The general groundwater quality has evolved due to silicate weathering as the prominent process, in association with evaporation effect. The N-fertilizer applications and use of untreated wastewater for irrigation are responsible for elevated nitrate content in the groundwater. In view of the continued intensive agricultural practice in the farm area even now, measures have been suggested to protect and prevent depletion and degradation of groundwater for irrigation.

Key words: GIS, Groundwater, Hydro-geochemical process, Nitrate

Introduction

The Indian Agricultural Research Institute (IARI; Figure-1) area significantly depends upon groundwater for irrigation, drinking and various other uses. The farm area within the IARI has been exposed to continuous loading of different kinds of agrichemicals, FYM, etc., for various research experiments conducted over six decades. Depending on local soil conditions, the chemical inputs in different doses on/in the soil may be leading to groundwater contamination, through leaching, when chemical applications exceed uptake by plants. Many studies showed that extensive use of fertilizers (Datta *et al.*, 1997; Chowdary *et al.*, 2005), and irrigation of land by sewage effluent (Keeney, 1986; Bouchard *et al.*, 1992 and McLay, 2001) is the main source of nitrate in groundwater. In the IARI farm area, fast movement of moisture front along with mobile pollutants ions like, nitrate, chloride etc., even up to 5m depth in the soil zone, has been observed due to frequent water input from irrigation and rainfall (Tyagi *et al.*, 2003). The north-eastern and western parts of the farm area showed high nitrate levels in groundwater (Tyagi *et al.*, 2003). The principal mechanisms for leaching of soluble chemicals below the root zone are physical processes, such as, advection, diffusion, dispersion, sorption and biogeochemical transformations (Hillel, 1982).

Chemistry of Groundwater evolves by interacting with aquifer minerals, inter-mixing of groundwater along-flow paths, spatially variable recharge, micro-topographic controls and weathering of minerals (Domenico, 1972; Wallick and Toth, 1976; Toth, 1984; Schuh, 1997; Bartarya, 1993). Geographic Information System

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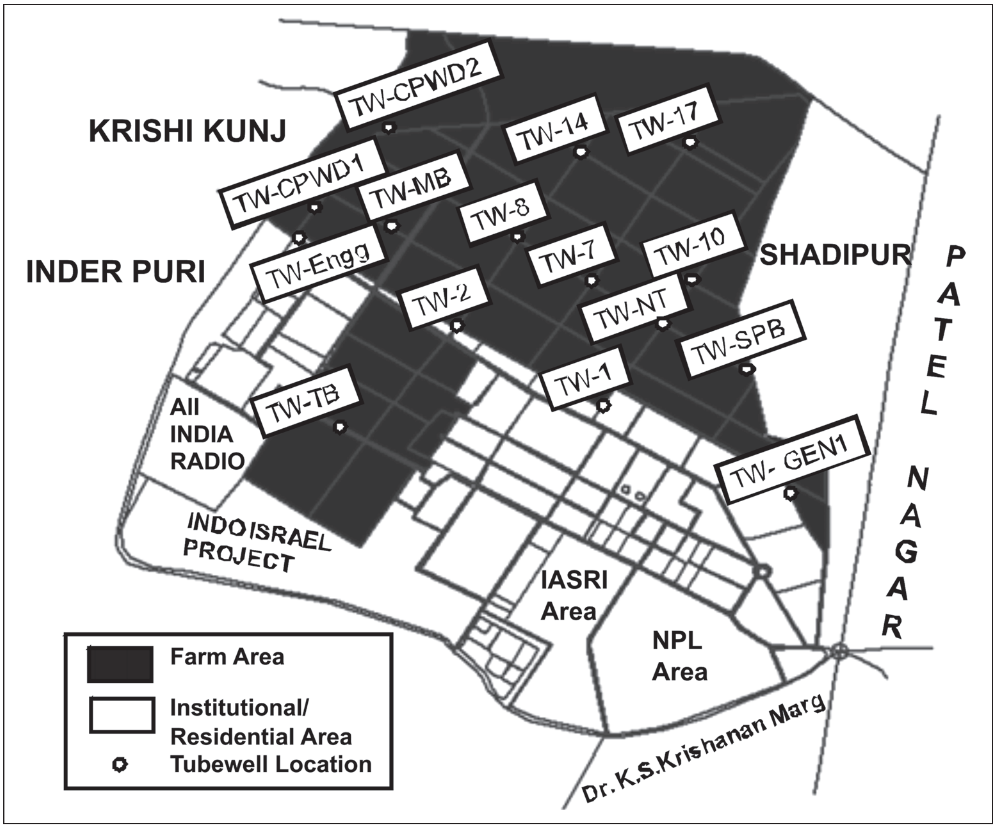

Fig. 1. Map of Indian Agricultural Research Institute (IARI), New Delhi, showing the locations of groundwater sampling points

(GIS) is a powerful tool for managing and analyzing spatial data particularly to investigate groundwater contamination (Sweeny, 1999), and locate the potential contamination zones. With this background, a detailed investigation was carried out with the objectives to evaluate the processes involved in the groundwater quality in the farm area and to suggest protective measures.

Materials and Methods

Description of the Investigated Area

Indian Agricultural Research Institute (4.8 sq km area, including 3.26 sq km farm land; 28°37'-28°39'N and 77°9'-77°11' E) is almost centrally located in the National Capital Territory of Delhi in the Indo-Gangetic alluvial plains. The geological formation is largely made of unconsolidated alluvial and colluvial materials (fine sand and clay, with nodular calcareous formations occurring locally). It has two major geomorphic units: sloping piedmont plain in the south and alluvial plain in the central and northern parts. The IARI farm is widely used for experiments on different type of crops in different seasons, and flood irrigation practice is mostly adopted, with groundwater as the main source. Groundwater occurs under both unconfined and semi-confined conditions. During the last few decades, due to increased pumping of groundwater, there has been significant decline in the water table from ~2m in 1980s to 10.0-12.0m in 2003 in the central part of the area (Tyagi *et al.*, 2003). In the soil under irrigated conditions, available-N is 200-250 kg/ha, and available K is 160-210 kg/ha. The area has semi-arid climatic conditions, with 730 mm mean annual rainfall, almost 80% of which falls between June to September and is generally erratic. The mean minimum and maximum temperatures are 18.7°C and 30.5°C respectively. During May-June, temperature exceeds 40°C. January is the coldest month and the average minimum temperature drops to 4-5°C.

Experimental Details

The IARI farm map was digitized by using Didger software. Fifteen groundwater samples were collected in the month of October 2006 in airtight polyethylene bottles from different tube wells located in the IARI farm. Locations of sampling points are indicated in Figure-1. The maps of spatial extent and variation in levels of different chemical species in groundwater were generated from the data points using kriging interpolation through Surfer-8 software. Georeferencing data of the sampling locations were obtained by Global Positioning System (GPS). Electrical Conductivity (EC) and pH were measured in the field using pre-calibrated portable conductivity and pH meters. In the laboratory, the samples were filtered by the nylon membrane filter, 0.45 μm, 47 mm diameter to separate the suspended sediments. Major anions viz, chloride, fluoride, nitrate, sulphate and cations viz, sodium, potassium, calcium and magnesium were analyzed using modular High Performance Ion Chromatograph (Metrohm, Switzerland) with analytical precision of ± 5%, and the values are given in Table 1. The geochemical evolution of groundwater has been determined by AQUACHEM software.

Results and Discussion

In the farm area, the groundwater is neutral to moderately alkaline in nature with pH of 7.1 to 7.5. The electrical conductivity (EC) ranges from 1231 to 2930 μmhos/cm at 25°C, with TW-TB, 2 and 1 in the southern part and TW-SPB showing higher EC-values. The chloride ion concentration in groundwater varies from 194.83 mg/l to 551.42 mg/l. The isochlores of the groundwater are shown in Figure-2. Wide variation in the EC and chloride values suggests that the farm area has a non-homogeneously mixed groundwater system, as was also observed earlier by stable isotopic investigations (Tyagi *et al.*, 1995). The Figure-2 also suggests that groundwater pumping induced lateral mixing of waters of varying chemical composition contributes to deterioration of groundwater quality in the southern and south-western parts of the farm area, as observed earlier (Datta *et al.*, 1996; Tyagi *et al.*, 1997).

The nitrate levels in the groundwater show a wide range from 1.58 mg/l to 50.92 mg/l suggesting different sources of origin (Datta *et al.*, 1997; Tyagi *et al.*, 2009). The spatial distribution of nitrate in groundwater is shown in Figure-3. TW-17 and TW-CPWD2 have the nitrate content 50.92 and 48.82 mg/l respectively,

Table 1. Concentration of chemical constituents in groundwater at IARI farm

Sample ID	EC	pH	Na	K	Ca	Mg	HCO_3	F	Cl	NO_3	SO_4
TW-1	2480	7.4	286.14	7.54	173.10	89.49	252.37	0.39	498.62	7.82	44.86
TW-2	2760	7.2	365.09	12.35	155.61	140.60	348.24	0.62	509.89	13.48	78.81
TW-7	1265	7.2	126.42	2.58	100.40	68.76	372.41	0.50	202.05	25.41	26.15
TW-8	1436	7.5	186.67	1.86	89.69	63.59	432.19	0.63	227.99	24.18	48.69
TW-10	1504	7.3	107.66	6.10	122.19	92.38	326.96	0.50	270.61	41.04	56.33
TW-14	1302	7.4	118.61	2.55	114.84	56.17	278.48	0.35	208.41	28.64	51.26
TW-17	1310	7.7	192.12	4.23	53.49	68.63	324.15	0.44	254.86	50.92	71.62
TW-Gen1	1231	7.4	161.29	1.84	119.75	30.68	286.26	1.16	194.83	28.82	81.36
TW-SPB	2710	7.1	198.75	16.99	223.28	123.02	232.93	0.36	520.89	16.95	37.58
TW-NT	1671	7.2	135.89	6.77	129.88	85.90	263.81	0.32	384.17	14.12	36.16
TW-CPWD1	1756	7.4	310.87	3.86	74.38	48.82	465.75	0.41	336.81	30.41	57.31
TW-CPWD2	1737	7.5	351.64	2.64	65.94	33.13	419.38	1.36	327.13	48.82	75.29
TW-MB	1623	7.5	175.45	6.23	100.10	70.53	351.90	0.35	266.72	26.30	61.99
TW-Engg	1478	7.4	224.94	3.22	37.53	39.74	437.81	0.29	220.46	20.87	33.46
TW-TB	2930	7.1	341.79	5.91	134.86	87.99	232.93	0.53	551.42	1.58	37.44

Units of Electrical Conductivity (EC) - μmhos/cm. Concentration of All ions reported in mg/l.

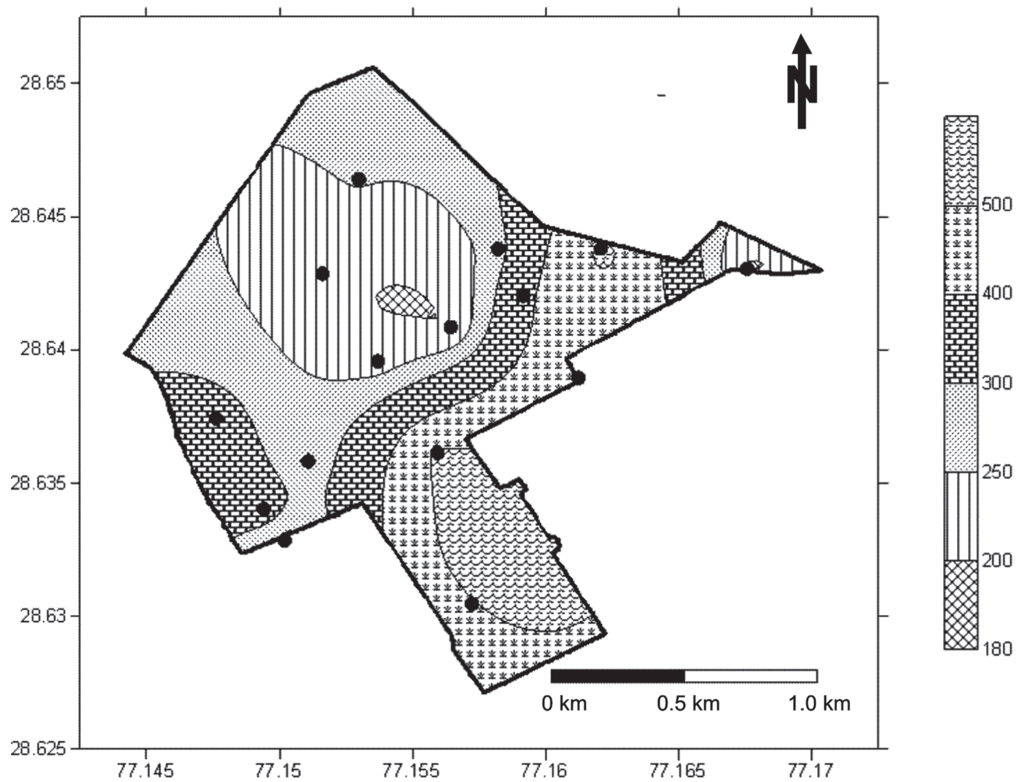

Fig. 2. The isochlores (mg/l) of the groundwater in the IARI farm area

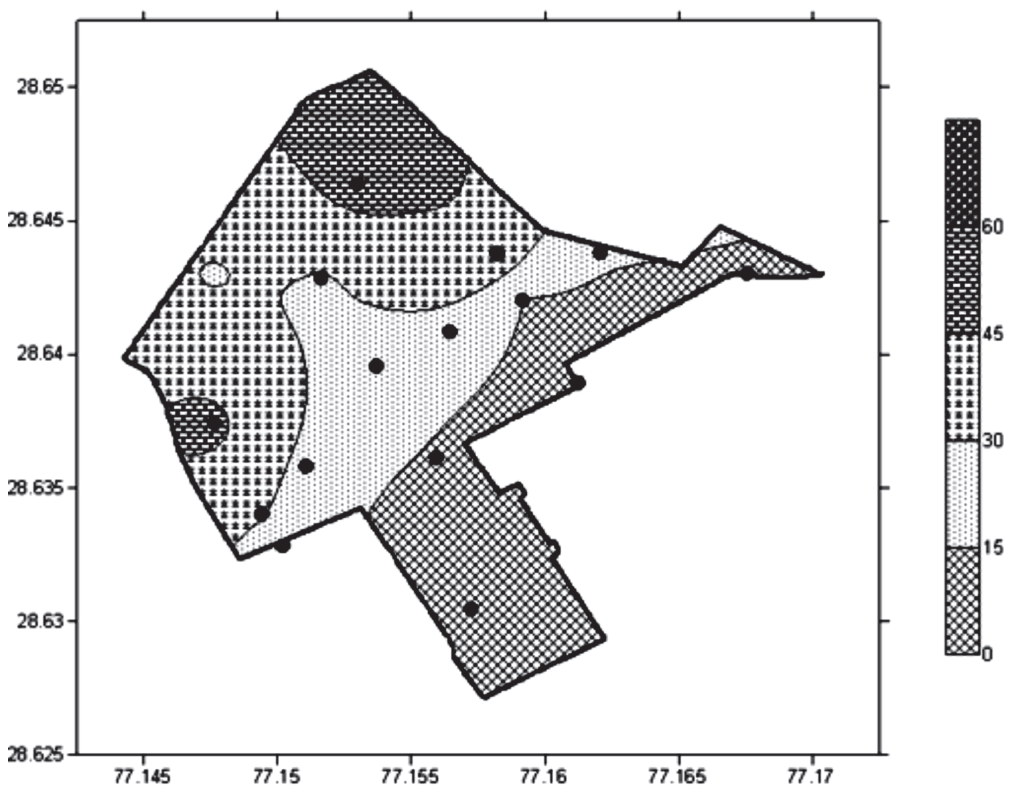

Fig. 3. The spatial distribution of nitrate (mg/l) in the groundwater of the IARI farm area

which are above the maximum permissible limits prescribed by WHO for drinking purpose. TW-17 being located near the domestic sewage drain possibly has continuous contribution from the drain. The northern, western and some of the central parts of the farm area show elevated levels of nitrate in groundwater. The central part with moderate nitrate levels (14 to 41 mg/l) may be possibly caused by frequent application of nitrogenous fertilizers, and the irrigation water and rain water as carrier inputs help in migration of nitrogenous pollutants even in unsaturated zone (Datta *et al.*, 1997; Tyagi *et al.*, 2009). The western parts of the farm area TWs-CPWD2 and CPWD1 show elevated nitrate levels in groundwater, as this part of the area is irrigated substantially by sewage water along with the application of nitrogenous fertilizers. The wastewater containing significant levels of ammonium compounds may be getting converted to nitrate via nitrification, and subsequently leach out.

Hydrochemical Facies

The geochemical evolution of the groundwater is presented in Figure-4. Although, the main hydro-chemical type in the Delhi region is Ca-Mg-HCO_3 type (Datta and Tyagi, 1996), but, the farm area has different water qualities of various combinations of ions resulting from interaction within the vicinity of the tube wells. For example, the TWs-CPWD1, CPWD2 and Engg in the western part of the farm area shows Na-Cl-HCO_3 type, while in the southern part TWs-1, 2 and TB represent the Na-Mg-Ca-Cl water type. While the central part of the farm (TWs-10, 7, 8,

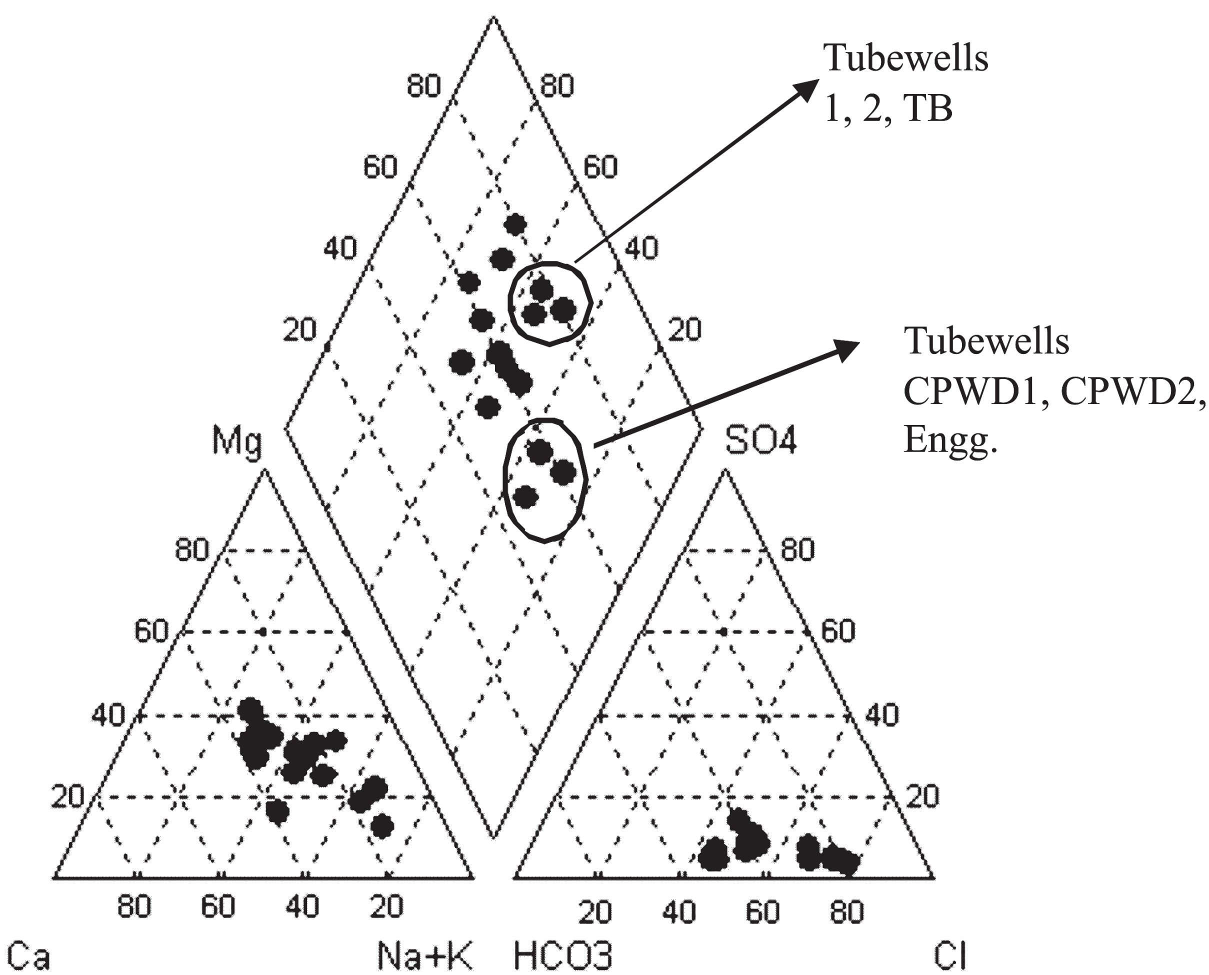

Fig. 4. Piper's diagram showing groundwater composition in the IARI farm area

NT and MB) shows Mg-Ca-Na-Cl-HCO_3 type of water, the TWs-Gen1 and 17 shows Na-Ca-Cl-HCO_3 type, and the TWs-SPB, 14 have Ca-Mg-Na-Cl type. Majority of the groundwater samples exhibit that Na is the dominant cation while Cl is the more prevalent anion.

Hydrogeochemical Processes

The hydrochemical and geochemical processes in the aquifer system along with evaporation process generally cause changes in concentrations of all ionic species in water. If the evaporation process is dominant, assuming that no mineral species are precipitated, the Na/Cl ratio remains unchanged (Jankowski and Acworth, 1997). If halite dissolution is responsible for sodium, the Na/Cl molar ratio should approximately be equal to 1, whereas a ratio greater than 1 is typically interpreted as Na released from a silicate weathering (Meybeck, 1987). The molar ratio of Na/Cl ranges from 0.59 to 1.66. the Na/Cl ratio values more than 1 indicates prevalent silicate weathering also in addition to the evaporation effect, as also reported earlier using isotopes (Tyagi and Datta, 1995). The Sodium vs Chloride (Figure-5) plot indicates that most of the samples lie around the equiline. The excess of Na in some of the points is attributed from weathering of silicate (Datta, and Tyagi, 1996; Stallard and Edmond, 1986).

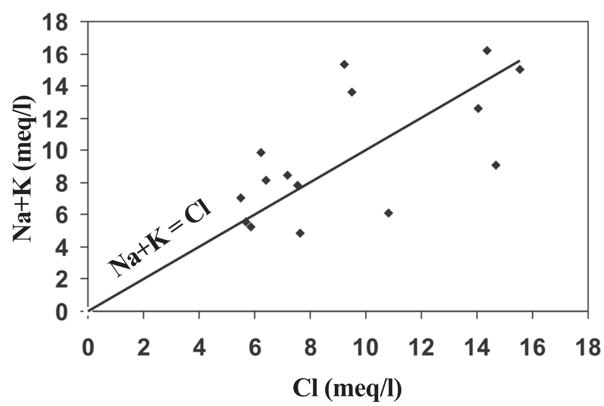

Fig. 5. Na versus Cl plot, indicating excess sodium points attributed to silicate weathering in the IARI farm area

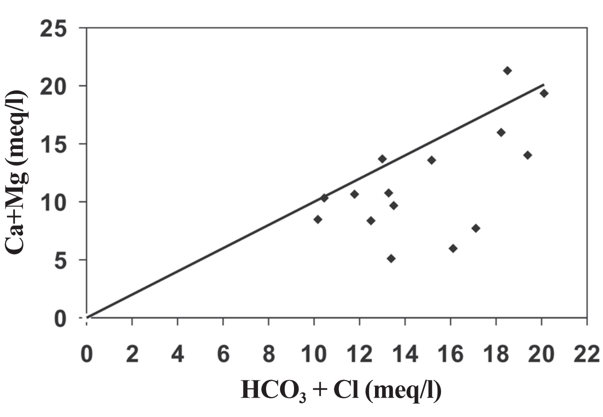

Fig. 6. The plot between (Ca+Mg) and (HCO_3+Cl), indicating excess of (Ca+Mg) in groundwater is balanced by chloride in the IARI farm area

The scatter diagram of (Ca+Mg) and (HCO_3+SO_4) shows that majority of the points fall above the equiline, indicating excess of (Ca+Mg) over (HCO_3+SO_4), suggesting balancing of (Ca+Mg) requires another anion, but the dominance of (Ca+Mg) ions point towards carbonate weathering (Datta and Tyagi, 1996), due to the presence of kankar in the geological formation which could also favour dissolution of carbonates thereby increasing calcium concentration to a certain extent (Datta and Tyagi, 1996). The plot between (Ca+Mg) and (HCO_3+Cl) (Figure-6) suggests that (HCO_3+Cl) ions are balancing the (Ca+Mg) in the groundwater but also posses the excess of (HCO_3+Cl) indicating dominance of the Chloride ion in the groundwater, helping the emergence of chloride dominated water type.

Conclusions

Geographic Information System (GIS) has been found to be useful tool to understand the spatial distribution of contaminants in the IARI Farm. The investigation suggests that the farm does not have a homogeneously mixed groundwater system, and Silicate weathering associated with evaporation effect prominently determines the hydro-geochemical evolution of groundwater. N-fertilizer applications together with the use of untreated wastewater for irrigation are responsible for elevated nitrate content in groundwater. Since, the agricultural practices could not have changed much even now in an intensive agricultural area like the IARI farm, any excess input is likely to carry soluble chemicals along with water below the root zone. To protect the groundwater in the farm from pollution and depletion, the following measures are suggested: (i) enhance irrigation water use efficiency by sprinkler irrigation wherever possible, (ii) apply nitrogenous fertilizers judiciously only after taking into consideration the nitrate content in locally pumped groundwater, and economic use high nitrate water for irrigation, (iii) use untreated waste water for irrigation judiciously, and (iv) harvest rain water to recharge groundwater.

References

Bartarya, S.K. 1993. Hydrochemistry and rock weathering in a sub-tropical lesser Himalayan river basin in Kumaun, *Indian J. Hydrol.* **146**, 149-174.

Bouchard, D.C., Williams, M.K. and Surampalli, R.Y. 1992. Nitrate combination of groundwater sources and potential health effects. *J. Am. Med. Addoc.* **7**: 85-90.

Chowdary, V.M., Rao, N.H. and Sarma, P.B. 2005. Decision support framework for assessment of non-point-source pollution of groundwater in large irrigation projects. *Agr. Water Management,* **75**: 194-225.

Datta, P.S., Deb, D.L. and Tyagi, S.K. 1996. Stable isotope (^{18}O) investigations of the processes controlling fluoride contamination of groundwater. *J. Contaminant Hydrol.,* **24**(1): 85-96.

Datta, P.S., Deb, D.L. and Tyagi, S.K. 1997. Assessment of groundwater contamination from fertilizers in Delhi area based on ^{18}O, NO3- and K+ composition. *J. Contaminant Hydrol.*, **27**(3-4): 249-262.

Datta, P.S. and Tyagi, S.K. 1996. Major ion chemistry of groundwater in Delhi area: Chemical weathering processes and groundwater flow regime. *J. Geol. Soc. India.* **47**: 179-188.

Domenico, P.A. 1972. *Concepts and Models in Groundwater Hydrology*. McGraw-Hill, New York.

Hillel, D. 1982. *Introduction to Soil Physics*. Academic Press, New York.

Jankowski, J. and Acworth, R. I. 1997. Impact of debris-flow deposits on hydrogeochemical processes and the development of dryland salinity in the Yass River catchment, New South Wales, Australia. *Hydrogeol. J.* **5**(4): 71-88.

Keeney, D. 1986. Sources of nitrate to groundwater. *CRC Crit. Rev. Environ. Control.*, **16**: 257-304.

McLay, C.D.A., Dragten, R., Sparling, G. and Selvarajah, N. 2001. Predicting groundwater nitrate concentrations in a region of mixed agricultural land use: a comparison of three approaches. *Environ. Pollution.,* **115**: 191-204.

Meybeck, M. 1987. Global chemical weathering of surficial rocks estimated from river dissolved loads. *Am. J. Sci.,* **287**: 401-428.

Stallard, R.F. and Edmond, J.M. 1983. Geochemistry of Amazon, the influence of geology and weathering environment on the dissolved load. *J Geophys. Res.,* **88**: 9671-9688.

Schuh, W.M., Klinekebiel, D.L., Gardner, J.C. and Meyar, R.F. 1997. Tracer and nitrate movements to groundwater in the Norruem Great Plains. *J Environ Qual.,* **26**: 1335-1347.

Sweeny, M.W. 1999. Geographic information systems. *Water Environ. Res.,* **71**: 551-556.

Tyagi, S.K. and Datta, P.S. 1995. Stable isotopic and hydrochemical study on groundwater contamination at IARI farm. *J. Nuclear Agric. Biol.,* **24**(4): 248-252.

Tyagi, S.K., Datta, P.S. and Mookerjee, P. 1997. Groundwater quality fluctuation in the IARI farm, New Delhi, *J of Indian Water Resources Society.* **17**(3): 41-43.

Tyagi, S.K., Datta, P.S., Sharma, P.K. and Kulshresth, Shilpi. 2009. Nitrate and fluoride contamination in groundwater under intensive agricultural landuse. *Asian J. of water, Environ. and Pollution.* **6**(2): 81-86.

Tyagi, S.K., Kulkarni, U.P., Datta, P.S., Sud, Y.K., Navada, S.V. and Aggarwal, P. 2003. Isotopic approach to assess the pollutants transport in the unsaturated zone under agricultural activities. *Proc. Int. Conference on Water and Environment, India.* pp: 347-353.

Toth, J. 1984. The role of regional gravity flow in the chemical and thermal evolution of groundwater. *In: Proceedings of the 1st Canadian/American conference on hydrogeology,* Banff, Alberta, June 1984.

Wallick, E.I. and Toth, J. 1976. Methods of regional groundwater flow analysis with suggestions for the use of environmental isotope and hydrochemical data in groundwater hydrology. IAEA, Vienna, 1976, pp 37-64.