Hydrogeochemical Variability and Appraisal of Water Quality of Groundwater in Mahoba District, Uttar Pradesh, India

Dev Sen Gupta (✉ devsengupta.28@gmail.com)

Banaras Hindu University <https://orcid.org/0000-0003-3576-5321>

Parthapratim Ghosh

Banaras Hindu University Faculty of Science

Shive Prakash Rai

Banaras Hindu University Faculty of Science

Shashikant Tripathi

Mahatma Gandhi Chitrakoot Gramoday Vishwavidyalaya

Research Article

Keywords: Mahoba district, hydrogeochemical processes, groundwater quality

Posted Date: May 5th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-455419/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License. [Read Full License](#)

Abstract

Mahoba district comes under the state of Uttar Pradesh (U.P.), India which is a part of mighty Bundelkhand Granitic Terrain known for its water debt condition. The region is hard rock terrain having recent alluvium cover of variable thickness relating to slope and level of erosion. Secondary porosity i.e. in the fractures and cracks present hosts the groundwater in the study area. The high water scarcity and poor drinking quality led us to carry our research work in the study area. The water facies analysed shows Ca-Mg-HCO₃ and Na-HCO₃ water types which indicated their compositional source from rock and anthropogenic inputs. Majority of the samples showed dominance of alkaline earths over alkalis and weak acids over stronger counterparts. The correlation coefficients calculated between hydrochemical parameters projects a strong positive correlation of EC and TDS with most of the major ions, including SO₄²⁻, NO₃⁻. The excessive fertilizers, unplanned municipal wastes and agricultural wastes resulted to high SO₄²⁻ and NO₃⁻. High F⁻ showed concentration in various samples may have geogenic sources due to fluorapatite in granitic terrain and Fe found in excess gives unpleasant taste on drinking. The analysed irrigation parameters (% Na, MR, TDS, RSC, SAR, TH, and KI) revealed perfect under permissible quality. Various negative human health issues like indigestion, bone problems, alimentary canal problems have been seen due to excess of SO₄²⁻, NO₃⁻ and F⁻). The study reflects the need of immediate preventive measures to improve drinking quality from health alarming ion concentrations and also would help for further management programs.

1. Introduction

It is a common fact that groundwater is a freshwater source which can be consumed readily and directly without processing. In India the daily consumption of water for various purposes of human and associated necessities is ever increasing (CGWB reports 1995, 1997, 2006, 2008, 2009, 2013, 2014a, 2014b). The indiscriminate development in consumption of groundwater reflects a worse effect of groundwater decline especially in case of hard rock terrains in respect to alluvial plains. A long term decline in groundwater has been observed in various states including Rajasthan, Gujarat, Haryana, Punjab, Tamil Nadu, Parts of U.P. and M.P. specially in Bundelkhand region (Gupta, 2014; Krishnamurthy, 1996; Krishna kumar, 2012; Shankar, 2006, Abhay K.S. et al, 2012; Paul et al, 2020). The groundwater usage among people increased many folds and unmannered huge consumption of groundwater lead to over exploitation of groundwater, aquifer depletion and increase of groundwater pollution (Raju N.J. et al., 1994; Chowdhury et al, 2009, 2010; Pradhan, 2009; Pratap, 2000; World Bank Deep Wells and Prudence, 2010; World Bank Report India Groundwater, 2012, Paul et al, 2020). The high dependence on groundwater for irrigation purpose has also resulted in high depletion in terms of quality and quantity (Mohanthy and Behera, 2010; Shahid and Nath, 1999; Shahid et al, 2000; Ibrahim-Bathis and Ahmed, 2014b).

India hosts various types of groundwater and surface water pollutions of different elements. Some pollution is geogenic and rest are anthropogenic pollution. The presence of arsenic, fluoride, iron, chromite, chloride, etc. are some few important elements which are useful as constituents of water in different use upto a limit but their excessive presence (above permissible limit) cause harmful effects combinely known as pollution. The endemic water problem of fluorosis (Choubisa, 2001; Susheela et al, 1993; Susheela, 1999; Teotia and Teotia, 1984; Subba Rao N. and John Devadas D., 2003; Sreedevi PD et al., 2006; Raju NJ et al., 2009) has been found in many parts.

The quality and quantity of groundwater in hard rock terrains are threatening and in this context authors have selected a neglected area, Mahoba district, with little previous published work but facing huge issues of groundwater which is a part of Bundelkhand region. Mahoba suffers acute shortage of groundwater and excess of SO₄²⁻, NO₃⁻ and F⁻ in quality parameters along with high water hardness making drinking water tougher to sustain.

2. Study Area

The district Mahoba, covering 2884 square kilometres, is situated in the south western part of Uttar Pradesh lying between 25°01'30" and 25°39'40" North latitude and 79°15'00" and 80°10'30" East longitude. The district is bordered by four districts of two states. In Uttar Pradesh district Hamirpur at north, district Jhansi at west, district Banda at east and only district Chhatarpur at south of Madhya Pradesh.

Agriculture is major occupation of the study area. Wheat can be seen as staple food of the district which requires intensive water irrigation for proper cultivation which is however not fulfilled throughout the year. The Kharif crops are paddy, jowar, maize, pulses (tur, moong, urad, etc.) and Rabi crops are wheat, gram, barley and mustard.

3. Geology And Hydrogeology

Mahoba is an integral part of Bundelkhand region mostly comprising of Bundelkhand Gneissic Complex (BGC) and Alluvium of Archaean Age and Recent Age respectively (Fig. 1). The alluvium thickness is highly variable ranging from 7 m to 38 m having average value of 10 m so the cover is very less to hold water as groundwater reservoir. BGC consists mostly of non-foliated granitic rocks of older age (2500-26-Ma) with intermittent presence of ultramafics, gneiss as enclaves, calc-silicates, proper banded magnetite (Basu 1986). In some regions presence of elongated quartz reefs, tuffaceous serpentines, basic dykes have been noted. The dolerite dykes of various lengths is characterised by dark greyish colour and moderate grains found intruding granite and quartz reefs. Along with felsites, porphyry dykes were also reported (Basu 1986). The region has quartz and plagioclase feldspar as leucocratic minerals and ferromagesium minerals as hornblende, chlorite, pyroxene and olivine forming the major mineral assemblages whereas muscovite, apatite, zircon, magnetite and sphene as minor minerals (Mishra and Sharma 1975).

Physiographically the total area is divided in two parts as hillocks with high relief constitute southern portion whereas northern portion is showing low altitude hillocks with low relief. The major rivers present in the district are Arjun, Birma, Dhasan and Urmil which are district's natural drainage system. Wide seasonal rainfall fluctuations result to poor infiltration and poor water content availability in the perennial and seasonal rivers. Waterborne disease and unhygienic

sanitation practices are some common problem among villagers. The improper solid and liquid waste management leads contamination of nearby surface water and shallow groundwater.

4. Methodology

The study area was divided into 60 grids for sampling purpose and some modifications made during sampling in the field based on population and water availability. One litre each sample was collected from different shallow (dug wells) and/or deep aquifer (handpumps) according to availability in 60 pre-washed thick polyethylene bottles. The pH and electrical conductivity (EC) were analysed in the field using a movable hand handling (portable) conductivity and pH meter (Consort C831).

The samples in laboratory were filtered using 0.20µm Millipore membrane syringe filters and for major cations (Ca^{2+} , K^+ , Mg^{2+} , Na^+) and anions (NO_3^- , F^- , Cl^- , Br^- , SO_4^{2-}) were analysed in Ion Chromatograph (model: Dual channel 930 Compact IC Flex ChS/PP).

The bicarbonate (HCO_3^-) was detected using acid titration method (APHA 1998).

In field 100 ml of each 60 samples were collected along with their 1 litre counterparts and were treated with ultra pure nitric acid to analyse heavy metals in laboratory. The heavy metal analysis was done by ICP-MS (model: iCAP6200 Duo).

Instruments were calibrated, prior to analysis, with diverse standard solutions and the results were crosschecked using ion balance error equation which was within $\pm 10\%$. The groundwater suitability for drinking purposes has been assessed using (Table 4) drinking water quality standards (BIS 2012, WHO 2011). The groundwater for irrigation purpose suitability has been analysed using proper indices (Table 7) and diagrams in United States Salinity Laboratory (Wilcox 1955).

5. Results And Discussion

The various physical and chemical data have been analysed for 60 groundwater samples of the Mahoba district. Major ions in milligram per litre (Table 1) were used to calculate chloroalkaline indices (CAI) (Table 3), sodium adsorption ratio (SAR), % Na, residual sodium carbonate (RSC), Kelly Index (KI), magnesium ratio (MR) and total hardness (TH) (Table 5). Minor elements or trace metals in µg/L (Table 2) element have been analysed. The ionic dominance has been shown by Scholler's plot (Fig. 2).

5.1 Groundwater chemistry

a) Physical parameter- The pH value ranges from 6.74 to 8.89 (7.69 as average) which suggest the acidic to alkaline nature of the groundwater samples. The electrical conductance (EC) is the measure of salt concentrations of water and it also gives the indications of presence of ionic concentration. The EC value of the samples ranges from 122µS/cm to 1867 µS/cm (755.6µS/cm as average) at 25°C. The total dissolved solid (TDS) in the water samples of the study area varies from 37 mg/L to 1250mg/L (539.28mg/L as average). According to Freeze and Cherry (1979) water has been classified into fresh ($\text{TDS} \leq 1000$ mg/L), brackish ($\text{TDS} \geq 1000$ mg/L), saline ($\text{TDS} \geq 10,000$ mg/L) and brine ($\text{TDS} \geq 100,000$ mg/L) based on the total dissolved solids. According to the TDS values 96.6 to 95% of samples belongs to freshwater type and 3.4 to 5% of samples belongs to brackish type. Excessive hardness causes cardio-vascular disorder, urolithiasis, parental mortality (Durvey et al, 1991; Agrawal and Jagetia, 1997)

b) Chemical parameters-

CATIONS- The cation chemistry shows Na^+ and Ca^{2+} forms the major cationic concentration of the groundwater in the study area. The general trend of cationic abundance has been found $\text{Ca}^{2+} > \text{Na}^+ > \text{Mg}^{2+} > \text{K}^+ > \text{Li}^+$. The measured Ca^{2+} concentration varies from 0.25 mg/L to 348.05 mg/L (100.36 mg/L as average) whereas Mg^{2+} concentration varies from 0.038 mg/L to 98.28 mg/L (40.15 mg/L as average) which accounts around 59% yearly of the total cationic concentration. The alkaline earth ($\text{Ca}^{2+} + \text{Mg}^{2+}$) account of 59% and it dominates over alkaline ($\text{Na}^+ + \text{K}^+$) of the groundwater.

At many places Mg^{2+} value exceed Ca^{2+} concentration owes to the fact that the supply of ions are from the weathering of ferromagnesian minerals having an association with basic and ultrabasic/ mafic rocks. Concentration of Na^+ is 0.077 mg/L to 261.56 mg/L (103.57 mg/L as average) whereas concentration of K^+ is 0.04 mg/L to 2.76 mg/L (1.24 mg/L as average) and, Na^+ and K^+ together contribute 40% of total cationic charge balance.

ANIONS- In general concentration of Cl^- is less in any common rock type compared to other constituents of ions in natural water. Higher concentration of Cl^- resembles either lithological source examples from halite and evaporates weathering and atmospheric source or from sea water. The Cl^- concentration varies from 0.12 mg/L to 360.948 mg/L (65.824 mg/L as average). The study area is situated far away from coastal region thus a Na^+/Cl^- higher concentration ratio shows a non lithogenic and non- atmospheric source of chloride (Jalali, 2007; Singh et al, 2011). At some places higher concentration of Cl^- suggest local contaminations due to agricultural runoff, domestic, anthropogenic or animal waste. The measured concentration of HCO_3^- in the study area varies from 40mg/L to 289 mg/L (131.4 mg/L as average).

Nitrate being important pollutant in atmosphere are mostly contributed to groundwater from atmospheric precipitation, human faunal excreta, and biological fixation of nitrogen, nitrification process of N and NH_4 and agricultural fertilizer (Appelo and Postma, 1996). The nitrate concentration has ranging values from 0.13 mg/L to 1344.52 mg/L (74.62 mg/L as average) so the enhancement of NO_3^- in the groundwater are mostly due to anthropogenic activities, and uses of fertilizer (ex- urea $(\text{NH}_2)_2\text{CO}$, ammonium nitrate (NH_4NO_3) , superphosphate and livestock manure) proving to be the important source of contamination and its excess causes methaemoglobinaemia, cancer, etc.

The sulphate concentration varies from 2.05 mg/L to 355.34 mg/L (43.37 mg/L as average) showing higher value than normal concentration at some locations is strong indication of agricultural activities and anthropogenic factors (Berner and Berner 1987). The correlation matrix showed strong positive correlations between SO_4^{2-} , NO_3^- , Cl^- indicating anthropogenic source of contamination (Alemayehu et al, 2010; Demlie et al, 2007).

The fluoride concentration in the study area varies from 0.15 mg/L to 2.57 mg/L (1.00 mg/L as average) where in many locations concentration exceeds the desirable limits of drinking water is due to geogenic source i.e., from muscovite, biotite, fluorite, fluoro- apatite etc. The weathering of apatite, biotite, sphene contributes F^- ions in groundwater found as accessory minerals in granites and granitic gneisses of the area (Mishra and Sharma, 1975)

The general trend of anionic abundance has been found $\text{HCO}_3^- > \text{Cl}^- > \text{SO}_4^{2-} > \text{NO}_3^- > \text{F}^-$

The presence of HCO_3^- and SO_4^{2-} in the groundwater and moreover in higher value signifies two major reactions for their contribution. The two major reaction are carbonation and sulphide oxidation that are the cause of two proton producer which can be shown on the basis of $\text{HCO}_3^- / (\text{HCO}_3^- + \text{SO}_4^{2-})$ equivalent ratio called C- ratio (Brown et al 1996, Singh, 2002). The C-value 1 shows carbonic acid weathering and acid hydrolysis having atmospheric proton source whereas 0.5 value shows coupled reaction involving weathering of carbonates by proton derived from sulphide oxidation. The formation of HCO_3^- and SO_4^{2-} also suggests a continuous process having fluctuation E^{H} - pH conditions and resulting to relative concentration.

Trace elements

Trace metals are very important to understand specially the quality aspect of drinking water of any area. Mahoba groundwater has been analysed and are discussed below (Table 2)

Iron- Aquifer naturally contains iron but the levels of iron increased in groundwater because of dissolution of ferrous component of borehole. The iron contain groundwater generally looks orange or light red and has an unpleasant smell. Iron occurs in two forms ferrous and ferric in water. According to WHO, iron is recommended ≤ 0.3 mg/L for drinking purpose or $300\mu\text{g/L}$ as desirable whereas $1000\mu\text{g/L}$ as permissible limit. The Fe concentrations ranged from 86 to $1082\mu\text{g/L}$ (average $400.39\mu\text{g/L}$) showing 58.33% of the total samples exceeding desirable limit. The region is dominated by agricultural practice, stone mining and stone crushing having no such industrial practice so the higher Fe content in the groundwater resembles geogenic origin i.e. rock-water interaction.

Copper- Copper play very important role in animal and plant metabolism. In earth crust occur as free native metal, Cu^0 or, as Cu^+ or Cu^{2+} in minerals. In solution it occur as either Cu^+ or Cu^{2+} oxidation states and Cu^+ ions has tendency to break into more oxidize form ($\text{Cu}^+ = \text{Cu}^0 + \text{Cu}^{2+}$). Modern industrialization uses copper extensively, which result in its dispersal in the environment. Sometime, to suppress the growth of algae small amount of copper salt is added to water supply reservoirs. In agriculture, many organic and inorganic form of copper is used as pesticide sprays. It has been found that copper deficiency is linked with anaemia, diarrhoea, demineralization of bone etc.

Lead- The free ion Pb^{2+} , hydroxide complexes and probably the sulphate and carbonate ions pairs are dissolved inorganic forms of lead. Due to large amount of used in automobiles, it is widely dispersed in the environment. In the study it ranges from 0.04 to $9.86\mu\text{g/L}$. It's increased in quantity is poisonous and may cause nervous, heart, skin, gastrointestinal and respiratory disorder.

Aluminium-Aluminium occurs as Al^{3+} under acidic conditions and as $\text{Al}(\text{OH})_4^-$ under neutral to alkali conditions. Other forms of aluminium include AlOH_2^+ and $\text{Al}(\text{OH})_3$. The dissolved form of aluminium Al^{3+} affect the roots and decrease their phosphate intake, it is also toxic to plants. Aluminium has negative effect to terrestrial and aquatic life in different life. The solubility of aluminium from the soil is increases in acidic condition. So, the aluminium concentration in river and lakes rises during minimal rainy season because of acid rain.

The other measured toxic metals like As, Se, Cd, Cr, Cu were found well within the specified limit of Indian drinking standards (BIS 2012).

5.2. Hydro-geochemistry and hydro-geochemical facies

The proper relationship between the dissolved ions helping to understand the geochemical evolution of groundwater can be done by Piper (1944) trilinear diagram plots. There are three diamond shaped fields where the central one indicates the combination of anions and cations concentrations together whereas the other two diamond shaped fields at right and left indicates concentration of cations and anions separately showing their intra-dominance. The central diamond field plot has been categorised into different numbers based on their classification. The plot values reveal the dominance of area number 1, 3, 5 and 8 (Fig. 4) i.e. most of the plot falls in these numbered areas. The plots indicates dominance of alkaline earth (Ca^{2+} and Mg^{2+}) over alkalis (Na^+ and K^+) and weak acids (HCO_3^-) over strong acids (SO_4^{2-} , Cl^-). Although the central plot classification shows majority of points in 5 number area indicates secondary alkalinity and carbonate hardness. Lesser samples falls under 8 area showing primary alkalinity and carbonate alkali water.

The trilinear diagram mostly suggests the groundwater of the area consists of alkaline earths and weak acidic chemistry having Ca-Mg-HCO_3 and Na-HCO_3 as dominant facies in hydrochemical analysis. The major dominance of Ca-Mg-HCO_3 and Ca-Na-HCO_3 type water mainly indicates the water-rock relationship

where dissolution of plagioclase-feldspar, ferromagnesian minerals and carbonates takes place of country rock by the recharging water (that may bear other reactive ions) to groundwater from different sources i.e. from irrigation, rainfall, or other surface inputs. This reaction process of cation exchange may have given the Ca-Na-HCO₃ water type.

5.3. Water rock interaction and solute acquisition process

The groundwater chemistry depends on various factors that may be having different sources of types- geogenic, anthropogenic, natural borne etc.

Rainwater, geological setting, country rock's mineral composition and other anthropogenic sources are responsible for water chemical composition (Datta and Tyagi 1996, Andre et al. 2005, Singh et al. 2007).

The important and higher contribution of (Ca²⁺ + Mg²⁺) to the total cations, relatively high (Na⁺ + K⁺) / T⁺ ratio (0.35) and low equivalent ratio of (Ca²⁺ + Mg²⁺) / (Na⁺ + K⁺) i.e. 2.29 suggest that the chemical composition of the water controlled mostly by silicate weathering along with limited carbonate weathering.

The level of atmospheric inputs to the dissolved salts present in the water can be understood by assessment of local rainwater chemical composition or by the ions/ element's ratio to Cl⁻ (Sarin et al 1989, Singh et al. 2005, Zhang et al. 1995). The average ratios of Na⁺/Cl⁻ and K⁺/Cl⁻ for subsurface water in the study area (Na⁺/Cl⁻ = 6.34 and K⁺/Cl⁻ = 0.04) was found to be more than marine aerosol (Na⁺/Cl⁻ = 0.85 and K⁺/Cl⁻ = 0.0176) suggesting limited contribution of these ions from atmosphere and mostly from hosting rock i.e. weathering of the hosting minerals forming rock.

In the Gibbs diagram (Gibbs, 1970) plot (Fig. 3a&b) showing ratio between (Na⁺ + K⁺) / (Na⁺ + K⁺ + Ca²⁺) and (Cl⁻ + NO₃⁻) / (Cl⁻ + NO₃⁻ + HCO₃⁻) as a function of TDS describes the plots under rock dominance region indicative of the ionic source from weathering of rock rather than atmospheric and anthropogenic sources (Hounslow 1995, Rose 2002). The major lithogenic sources of ions in groundwater are weathering of carbonate, silicate and sulphide minerals, and also dissolution of evaporates. The plot between (Ca²⁺ + Mg²⁺) versus (HCO₃⁻ + SO₄²⁻) (Fig. 5a) has most of its samples falling at and nearest to 1:1 line showing dissolution of calcite, dolomite and gypsum acting crucial reactants (Cerling et al 1989, Fisher and Mullican 1997). The part of the samples of the study area falls below the equiline plotted between (Ca²⁺ + Mg²⁺) and (HCO₃⁻ + SO₄²⁻) suggests significant contribution from various non-carbonate sources and the excess HCO₃⁻ / SO₄²⁻ would be balanced by alkalies (Na⁺ + K⁺). Similarly the samples falling above equiline shows more cations that would be balanced out by Cl⁻ or other anions in the system. According to stoichiometric balance of carbonate derived from (Ca²⁺ + Mg²⁺) must be more or less equal to (HCO₃⁻) derived carbonates. The chemical plot between (Ca²⁺ + Mg²⁺) and HCO₃⁻ (Fig. 5e) shows most plots have more HCO₃⁻ value than (Ca²⁺ + Mg²⁺), so this cation deficiency should be balanced by alkalies (Na⁺ + K⁺) in order to balance excess negative charge of HCO₃⁻ and this alkali ions (Na⁺ + K⁺) are mostly derived from silicate weathering. Samples having excess (Ca²⁺ + Mg²⁺) in comparison to HCO₃⁻ should be balanced by SO₄²⁻ and Cl⁻ in the media. The poor correlation coefficient between Ca²⁺-HCO₃⁻ and Ca²⁺-SO₄²⁻ (Fig. 5g and 5h) indicates gypsum and calcite were not major contributors of ions in the solution, hence other sources including anthropogenic causes may lead to act as sources of Ca²⁺. The plots between (Ca²⁺ + Mg²⁺) and total cations (Fig. 5c) major contribution of Ca²⁺ and Mg²⁺ in the total cation count which further cleared by (Ca²⁺ + Mg²⁺) versus (Na⁺ + K⁺) (Fig. 5d) plot. Na⁺ and K⁺ together constitute 36% of total cations which shows a significant amount shown by plot between (Na⁺ + K⁺) and total cations (Fig. 5b) having their sources from atmosphere or weathering of alkaline silicates richer in K⁺ and Na⁺. The plot between (Na⁺ + K⁺) versus Cl⁻ shows average samples are dominating in Na⁺ and K⁺ with respect to Cl⁻ (Fig. 5f) suggesting origin of alkalies from various sources other than precipitation process and sources may be from weathering of silicates enriched with Na⁺ and K⁺ which can be understood by reaction mentioned below. The chemical composition of the solution (water) mostly controlled by weathering of silicates and few by carbonate weathering. According to Gaillardet et al (1999) lithology having carbonate dominance shows higher ratios of Ca²⁺ / Na⁺ (around 50), Mg²⁺ / Na⁺ (around 10), HCO₃⁻ / Na⁺ (around 120) and same values abruptly decreases in case of silicates end member as Ca²⁺ / Na⁺ = 1.26 ± 0.95, Mg²⁺ / Na⁺ = 0.81 ± 0.52 and HCO₃⁻ / Na⁺ = 0.6 ± 0.5 in the study area. The ratio of Ca²⁺ / Na⁺ in molar terms is around 1.26 showing more solubility of Na⁺ with respect to Ca²⁺ results to lower (Ca²⁺ / Na⁺) molar ratio in the dissolved ions of water drained silicate terrain compared to carbonate terrain (Taylor and Mac Lennan 1985). Thus, the expected chemical reaction responsible for silicate weathering for source of various solutes under presence of carbonic acid:

Albite Kaolinite

Anorthite Kaolinite

Biotite Kaolinite

Olivine

Formation of HCO_3^- shows the interaction of CO_2 gases from atmosphere with the weathering of carbonate and aluminosilicate rocks, hence the soil zone in its subsurface region has elevated CO_2 pressure with in turn combines with water dripping down from different source specially rainwater and leads to formation of HCO_3^- in groundwater. The presence of HCO_3^- concentration relative to other anions in groundwater shows weathering of primary silicate mineral i.e. dominated by alkaline earth (Rose 2002). The correlation between major ions and physical parameters in (Table 6) showed the EC and TDS have a good and mostly positive correlation including NO_3^- , SO_4^{2-} and K^+ which suggests the chemical composition of water have their origin from geogenic as well as anthropogenic causes. The correlations (> 0.5) suggest that the concentration of respective parameter increased in groundwater with more and more rock-water interaction. Nitrate is showing a strong correlation with Cl^- and SO_4^{2-} suggesting the nitrate sources from urban, animal wastes and return flow from irrigation. Fluoride has moderate correlation with Na^+ and HCO_3^- suggesting increase of fluoride in groundwater shows more alkaline conditions and other studies (Li et al., 2015; Ali et al., 2018; Adimalla et al., 2019) showed alkaline water helps in release of fluoride from F- bearing minerals.

Chloro-Alkaline Indices

It describes the exchange of ions under suitable environment between groundwater and the host rock/ soil while residue or movement of water in host medium. It is understood by Base Exchange reaction (Schoeller, 1967, 1977). The water rich in salt experiences positive CAI whereas low salt water suffers negative CAI value. During the exchange reaction host plays primary source for the dissolved salts in water.

$$\text{CAI-I} = \text{Cl}^- - (\text{Na}^+ + \text{K}^+) / \text{Cl}^-$$

$$\text{CAI-II} = \text{Cl}^- (\text{Na}^+ + \text{K}^+) / \text{SO}_4^{2-} + \text{HCO}_3^- + \text{NO}_3^-$$

If CAI (I and II) values are positive then exchange of Na^+ & K^+ (from water) and Ca^{2+} & Mg^{2+} (from soil or rock), and if negative then exchange of Ca^{2+} & Mg^{2+} (from water) and Na^+ & K^+ (from soil or rock) takes place. The positive is termed as Base Exchange reaction and the negative is termed as disequilibrium.

Base Exchange types- If $\text{HCO}_3^- < (\text{Ca}^{2+} + \text{Mg}^{2+})$ then Na^+ ion are exchanged for alkaline earths, and is referred as Base Exchange Hardened water. If $\text{HCO}_3^- > (\text{Ca}^{2+} + \text{Mg}^{2+})$ then alkaline earths were exchanged for Na^+ ion, and is referred as Base Exchange Softened water. Alkali metals/ions as Na^+ & K^+ , and alkaline earth metal/ ion as Mg^{2+} & Ca^{2+} are involved.

5.4. Water quality assessment

The data acquired from different laboratory analysis were calculated for their efficiency in drinking and irrigation purposes.

5.4.1. For drinking purpose

The quality assessment was done by various previous leading authors (Szabolcs and Darab 1964; Davis and DeWiest 1966; Back, 1966; Sawyer and Mc. Carty, 1967; Schoeller 1977; Todd, 1980, 2013; Dhang et al. 1984; Ayers and Westcot 1985; Stuyfzand, 1989; Gogai et al. 1991; Eawari and Ramanibai 2000; Raju 2006) which were considered as reference purpose for the present study and the present study parameters were strictly classified under standards prescribed by World Health Organisation (WHO 2011) and Bureau of Indian Standards (BIS 2012). The pH condition of the samples examined is well under drinking range (around 6 to 8.5). Among all the ions, variable concentrations mentioned in concentration distribution maps (Fig. 6a to j), some have been found exceeding their permissible and desirable limits (Ca^{2+} , Mg^{2+} , Na^+ , NO_3^- , Cl^- , F^-) in various samples (Table 4). NO_3^- and F^- have been detected exceeding permissible limits in significant spatial distribution and have been reported first time in the study area by the authors.

High NO_3^- concentration in drinking water has lots of drawbacks in form of harmful diseases as goiter, gastro-intestinal complications, methaemoglobinaemia in infants, hypertension, etc (Majumdar and Gupta 2000). Fluoride being a crucial element has various drawbacks when found in excess and results to ortho/ bones related diseases like bending of backbones. Teeth along with bones are also highly affected as mottling of teeth on excess intake of fluoride.

Excess of Na^+ causes nervous imbalance, heart diseases, kidney disorders whereas Ca^{2+} and Mg^{2+} excessive intake causes stone problems in alimentary canal and kidney (Maragella et al. 1996).

Most of the metal concentrations found to be within desirable limits as specified by World Health Organisation (WHO 2011) and Indian drinking standards (BIS 2012). There are some exceptions which crossed the desirable and permissible limits. The Fe concentrations ranged from 86 to 1082 $\mu\text{g/L}$ (average 400.39 $\mu\text{g/L}$) showing exceeding desirable limit.

5.4.2. For irrigation purpose

Water quality in combination to associated soil types is very much linked with different cropping practices which can be understood as different parameters governing the suitability of water for irrigation.

Percent sodium (%Na)- It is a parameter used to understand the water quality suitability for irrigation purpose.

$$\% \text{Na} = [(\text{Na}^+ + \text{K}^+) / (\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Na}^+ + \text{K}^+)] * 100$$

If Na^+ ion is more/ excess in water then exchange of Na^+ takes place between water and soil, and Ca^{2+} & Mg^{2+} in soil is replaced by Na^+ i.e. exchange of Na^+ ion is exchanged for Ca^{2+} & Mg^{2+} in rock/soil. This decreases the permeability of soil (Na^+ affinity is more than Ca^{2+} & Mg^{2+} for replacement) leading to decrease in internal flow/ drainage of water in soil (Collins & Jenkins 1996). The recommended standard for irrigation of Na% is 60% according to Indian Standard (BIS 2012). The Wilcox diagram shows status of sample based on percent sodium with respect to total concentration (meq/l) either suitable or permissible or doubtful or unsuitable (Fig. 7).

Kelley Index is a ratio showing suitability of water for irrigation purpose (Kelley, 1946). If the ratio is more than one (> 1) then the water quality is unsuitable for irrigation which is due to the fact that excess Na content leads to reduction of soil fertility.

Higher total hardness and salt concentration in water leads to increase in salinity in soil whereas high Na concentration makes a soil more alkaline. The increase in sodium or amount of sodium/ or alkali in terms of hazard can be expressed as SAR (Sodium Adsorption Ratio), magnesium hazard expressed as magnesium ratio (Szabolcs and Darab 1964; Schoeller 1977) and total hardness calculated based on concentration of Ca and Mg which are calculated as:

$$\text{SAR} = \text{Na}^+ / [\sqrt{(\text{Ca}^{2+} + \text{Mg}^{2+})/2}] \text{ in mg/L or meq/L}$$

$$\text{Magnesium Ratio (MR)} = \text{Mg}^{2+} \times 100 / (\text{Ca}^{2+} + \text{Mg}^{2+})$$

$$\text{TH (mgCaCO}_3\text{/l)} = (2.5 \times \text{Ca}) + (4.1 \times \text{Mg})$$

The total hardness shows majority of the water samples are very hard in nature. Along with Kelly index and %Na total hardness of some region proves water samples to be difficult for irrigation purpose.

6. Conclusion

The hard rock area, Mahoba, has higher concentration of various parameters (Ca^{2+} , Mg^{2+} , Na^+ , NO_3^- , Cl^- , F^-) analysed along with TDS at various locations. Total hardness and TDS exceeded as 81.66% and 53.33% above desirable limits prescribed by WHO and BIS makes water hard to very hard in nature. The water samples exhibited Ca-Mg- HCO_3 and Na- HCO_3 water types owing to their source from rock and anthropogenic inputs. The calculated correlation coefficients among hydrochemical parameters indicate a strong positive correlation of EC and TDS with most of the major ions, including SO_4^{2-} , NO_3^- . NO_3^- and F^- detected exceeding desirable limits of about 31.67% and 33.33% respectively in significant spatial distribution have been reported first time in the study area by the authors. The potential sources of hardness and nitrate found in higher amount have their contamination from fertilizers and, other inputs from urban and animal wastes. High F^- showed concentration in various samples may have geogenic sources due to fluorapatite in granitic terrain and Fe found in excess gives unpleasant taste on drinking. The various evaluations of drinking and irrigation parameters reflected their contribution from anthropogenic and geogenic processes at different locations based on their respective exposures. At some parts the Kelly's index value is greater than one which means that the groundwater at that part is not much suitable for agricultural purpose. The excess of various components at different sites due to local effects strongly require treatment before groundwater utilization. The general water purification processes like demineralization, ion exchange and water softening can be used to minimize the concentration of impurities. It is high time to carry out immediate and legitimate measures to control long term human health issues and agricultural production in the hard rock terrains in and around Mahoba district.

Declarations

Acknowledgment

The authors would like to thank Central Instrument Facility, Indian Institute of Technology, BHU, Varanasi Uttar Pradesh for the generation of water quality data. Authors are also thankful to the Head, Department of Geology, BHU, Varanasi for encouraging to conduct this study.

References

- Abhay K.S., B. Raj, A.K. Tiwari, M.K. Mahato, (2012). Evaluation of hydrogeochemical processes and groundwater quality in the Jhansi district of Bundelkhand region, India, Environ Earth Sci., 1-23, <http://doi.org/10.1007/s12665-012-2209-7>.
- Adimalla, N., Venkatayogi, S., Das, S.V.G., (2019). Assessment of fluoride contamination and distribution: a case study from a rural part of Andhra Pradesh, India. Appl. Water Sci. 9, 94.
- Agarwal V. And Jagetia M., (1997). Hydrogeochemical assessment of groundwater quality in Udaipur City, Rajasthan, India, Proceedings of National Conference on dimension of environmental stress in India, Department of Geology, MS University, Baroda, India, p. 151-154.
- Ali, S., Shekhar, S., Bhattacharya, P., Verma, G., Chandrasekhar, T., Chandrashekhar, A.K., 2018. Elevated fluoride in groundwater of Siwani Block, Western Haryana, India: A potential concern for sustainable water supplies for drinking and irrigation. Groundw. Sustain. Dev. 7, p 410–420.
- Alemayehu T, Dietzel M, Leis A, (2010). Geochemical evolution of groundwater quality in shallow and deep wells of volcanic aquifer in Axum, Ethiopia, In: Proceedings of XXXVIII IAH Congress, Krakow-Poland.
- Andre L, Franceschi M, Pouchan P, Atteia O, (2005). Using geochemical data and modeling to enhance the understanding of groundwater flow in a regional deep aquifer, Aquitaine Basin, south-west of France, J Hydrol, 305, 40-62, sd

APHA, (1998). Standard methods for the examination of water and waste water, 20thedn., American Public Health Association, Washington, DC.

Appelo C. A. J. And Postma D., (1999). Geochemistry, Groundwater and Pollution, AA Balkema, Rotterdam, p.535.

Ayers RS and Westcot DW, (1985). Water quality for irrigation. FAO Irrigation and Drainage Paper No. 20, Rev I, FAO Rome.

Back W., (1966). Hydrochemical facies and ground water flow patterns in northern part of Atlantic coastal plain, USGS Prof. Paper, 498-A, p.42.

Basu AK, (1986). Geology of parts of the Bundelkhand Granite Massif, Central India, Rec Geol Sur India 117:61-120.

Berner E. K. And Berner R.A., (1987). The global water cycle, Prentice-Hall Inc., Englewood Cliffs. NJ, p.397.

BIS, (2012). Bureau of Indian Standards- Indian Standard specification for drinking water IS:10500.

Brown G. H., Sharp M. J. And Tranter M., (1996). Subglacial chemical erosion: seasonal variations in solute provenance, Haunt Glaciard Arolla, Valais, Switzerland, Ann. Glaciol., 22, p.25-31.

Cerling T. E., Pederson B. L. And Damn K.L.V., (1989). Sodium-calcium ion exchange in the weathering of shales implication for global weathering budgets, Geology, 17, p.552-554

C.G.W.B. (1995). Perspectives plans of ground water in India. Ministry of Water Resources , Govt. of India, Central Ground Water Board, Ministry of Water Resources, Govt. of India, Faridabad, New Delhi, India.

C.G.W.B. (1997). Report of the Ground Water Resource Estimation Committee-Ground water resource estimation methodology 1997. Central Ground Water Board, Ministry of Water Resources, Govt. of India, New Delhi 107p.

Central Ground Water Board, (2006). Dynamic Ground Water Resources of India . New Delhi.

C.G.W.B. (2008). Report on Hydrogeomorphological Mapping and Delineation of Ground Water Potential Zones using Remote Sensing and GIS in Khallikote Block, Ganjam District, Orissa. Central Ground Water Board, Ministry of Water Resources, Govt. of India.195p.

C.G.W.B. (2009). Ground Water Resource Estimation Methodology, Report of the Ground Water Resource Estimation Committee, Central Ground Water Board, Ministry of Water Resources, Govt. of India, Faridabad, 87p.

C.G.W.B. (2013). Annual Report 2010-11 Central Ground Water Board (Ministry of Water Resources Govt. of India) Faridabad.188p.

C.G.W.B. (2014a). Dynamic Ground Water Resources of India (As on 31st March 2011) Central Ground Water Board Ministry of Water Resources, River Development & Ganga Rejuvenation. Government of India, Faridabad 282 p.

C.G.W.B. (2014b). Ground Water Yearbook (2013-14): Central Ground Water Board, 76, July 2014.
<http://www.cgwb.gov.in/documents/Ground%20Water%20Year%20Book%202013-14.pdf>.

Choubisa SL, Endemic flourosis in southern Rajasthan, India. Fluoride, 34, 61-70, 2001.

Chow V., (1964). Handbook of applied hydrology, Mc. Graw-Hill, New York, p.1453.

Chowdhury, A., Jha, M.K. and Chowdary, V.M., (2010). Delineation of Groundwater Recharge Zones and Identification of Artificial Recharge Sites in West Medinipur district, West Bengal, using RS, GIS and MCDM Techniques. Environmental Earth Science, vol. 59, 1209-1222.

Chowdhury, A., Jha, M.K., Chowdhary, V.M. and Mal, B.C. (2009). Integrated Remote Sensing and GIS-based approach for accessing Groundwater Ootential in West Medinipur district, West Bengal, India. International. Jour. Remote Sensing, vol. 30, no. 1, 231–250.

Collins R. And Jenkins A., (1996). The impact of agricultural land use on stream chemistry in the middle hills of the Himalayas, Nepal, Jou. Hydrol., 185, p. 71-86.

Datta PS, Tyagi SK, (1996). Major ion chemistry of groundwater of Delhi area: chemical weathering processes and groundwater flow regime, J Geol Soc Ind, 47, 179-188.

Davis S.N. and De Wiest R. J. M., (1966). Hydrogeology, Wiley, New York, 463.

Demlie M, Wornlich S, Wisotzky F, Gizaw B, (2007). Groundwater recharge, flow and hydrogeochemical evolution in a complex volcanic acquifer system, Central Ethiopia, J Hydrogeol, 15, 1169-1181.

Dhang H. K., Wadhwane C. N., Jaiswal D. D. And Somasundaram S., (1984). Drinking water- An important source of trace element intake, Indian Jour. Environ. Health.

Durvey V. S., Sharma L. L., Saini V. P. And Sharma B. K., (1991). Handbook on the methodology of water quality assessment, Rajasthan Agricultural University, India.

- Eawari Y. N. K. And Ramanibai R., (2000). Trace Metal Distribution in the Estuarine Waters of Chennai, South East Coast of India, Proceedings of Analytical Techniques in Monitoring the Environment, p. 333-328.
- Fisher R. S. And Mulican W. F., (1997). Hydrogeochemical evolution of sodium-chloride groundwater beneath the Northern Cniahvahvan desert. Trans-Pecos, Texas U.S.A. Hydrogeol. Jour., 10(4), p. 455-474.
- Freeze R. A. And Cherry J. A., (1979). Groundwater, Prentice Hall, Englewood Cliffs., p. 604.
- Gaillardet J, Dupre B, Louvat P, Allegre CJ, (1999). Global silicate weathering and CO₂ consumption rates deduced from the chemistry of large rivers, ChemGeol, 159, 3-30.
- Gibbs RJ, (1970). Mechanisms controlling world water chemistry, Science, 17, 1088-1090.
- Gogai A. K., Mahanta J., Das H. And Hazarika A. C., (1991). Estimation of iron content in the drinking waters of Duliajan area, Indian Jour. Of Environ. Protection, 11(12), p. 115-117.
- Gupta, A. K., Nair, S.S., Ghosh, O., Singh, A. and Dey, S. (2014). Bundelkhand Drought: Retrospective Analysis and Way Ahead. National Institute of Disaster Management, New Delhi, 148p.
- Hounslow AW, (1995). Water quality data: analysis and interpretation, CRC Lewis Publishers, New York.
- Ibrahim-Bathis, K. and Ahmed, S.A. (2014b). Identification of suitable sites for water harvesting in the water scare rural watershed by the integrated use of Remote Sensing and GIS. In: International Symposium on Integrated Water Resources Management (IWRM-2014), February 19–21, 2014, CWRDM, Kozhikode, Kerala, India, vol. 1.
- Jalali M., (2007). Salinization of groundwater in arid and semiarid zones: an example from Tajarak, western Iran, Env. Geol., 22, p. 1133-1149.
- Kelly WP, (1946). Permissible composition and concentration of irrigation waters. In: Proceeding American Society of Civil Engineering.
- Krishna Kumar, S., Chandrasekar, N., Seralathan, P., Godson, Prince S. and Magesh, N.S. (2012). Hydrogeochemical study of shallow carbonate aquifers, Rameswaram Island, India. Environ Monit Assess vol. 184, 4127-4138.
- Li, C., Gao, X., Wang, Y., (2015). Hydrogeochemistry of high-fluoride groundwater at Yuncheng Basin, northern China. Sci Total Env. 508, 155–65.
- Krishnamurthy, J.N., Venkatesa, K., Jayaraman, V. and Manivel, M. (1996). An approach to demarcate groundwater potential zones through remote sensing and geographical information system. Internatioanal. Jour. Remote Sensing. Vol. 17, 1867–1884.
- Majumdar D, Gupta N, (2000). Nitrate pollution of groundwater and associated human health disorders, Indian J Environ Hlth, 2, 28-39.
- Maragella M, Vitale C, Petrarulo M, Rovera L, Dutto F, (1996). Effects of mineral composition of drinking water on risk for stone formation and bone metabolism in idiopathic calcium nephrolithiasis, Clin Sci, 91, 313-318.
- Mishra RC, Sharma RP, (1975). Petrochemistry of Bundelkhand complex of central India. Indian Mineral, 15, 43-50.
- Mohanthy, C. and Behera, S. C. (2010). Integrated remote sensing and GIS study for hydrogeomorphological mapping and delineation of groundwater potential zones in Khallikote block, Ganjam district, Orissa., [Jour. of the Indian Society of Remote Sensing](#), June 2010, vol. 38, no. 2, 345–354.
- Piper A. M., (2007). A graphical procedure in the geochemical interpretation of water analysis, Am. GEophys. Union. Trans., 25, p. 119-129.
- Pradhan, B. (2009). Groundwater Potential Zonation for basaltic watersheds using Satellite Remote Sensing Data and GIS techniques. Cent. Eur. Jour. Geosci, vol. 1, no.1, 120–129.
- Rajesh Solomon Paul, Umakant Rawat, Dev SenGupta, Arkoprovo Biswas, Shashikant Tripathi and Parthapratim Ghosh., (2020). Assessment of groundwater potential zones using multi-criteria evaluation technique of Paisuni River Basin from the combined state of Uttar Pradesh and Madhya Pradesh, India, vol.79, Issue13, 340-364.
- Raju N. J., (2006). Seasonal evaluation of hydro-geochemical parameters using correlation and regression analysis, Curr. Sci., 91(6), p. 820-826.
- Raju N. J., Reddy T. V. K., Nayudu P. T. And Kotaiah B., (1994). Estimation of Aquifer Parameters and Groundwater Balance of the Upper Gunjanaeru River Basin, Cuddapah District, Andhra Pradesh, BHU-JAL News, p. 11-15.
- Rose, (2002). Comparative major ion geochemistry of piedmont streams in the Atlanta, Georgia region: possible effects of urbanization, Environ Geol, 42, 102-113.
- Sarin M. M., Krishnaswami S., Dilli, Somayajulu B. L. K. And Moore W. S., (1989). Major ion chemistry the Ganga-Brahmaputra river system: weathering processes and fluxes of the Bengal, Geochem. Et CosmochimActa., 53, p. 997-1009.

- Sawyer C. N. and Mc. Carty P. L., (1967). Chemistry for sanitary engineers, 2nd Ed. Mc. Graw-Hill, New York, 1967. Schoeller H., Methods and techniques of groundwater investigation and development, Water Resources Series no. 33, UNESCO.
- Scholler H., (1967). Methods and techniques of groundwater investigation and development, Water Resources Series no. 33, UNESCO.
- Scholler H., (1977). Geochemistry of groundwater, In: Groundwater studies- An international guide for research and practice. UNESCO, Paris, Ch. 15, p. 1-8.
- Shahid, S. and Nath, S.K. (1999). GIS Integration of Remote Sensing and Electrical Sounding Data for Hydrogeological Exploration. Jour. Spatial Hydrology. Vol. 2, no. 1, 1–12.
- Shahid, S., Nath, S.K. and Roy, J. (2000). Ground Water Potential Modeling in Soft Rock Area using GIS. Jour.Remote Sensing, vol. 21, 1919–1924.
- Shankar, M.N.R. and Mohan, G. (2006). Assessment of the Groundwater Potential and Quality in Bhatsa and Kalu River Basins of Thane District, Western Deccan Volcanic Province of India. Environmental Geology, vol. 49, 990-998.
- Singh A. K., (2002). Quality assessment of surface and subsurface water of Damodar River basin, Indian Jour. Environ. Health, 44, p. 41-49.
- Singh A. K., Mondal G. C., Singh S., Singh P. K., Singh T. B., Tiwary B.K. and Sinha, A., (2007). Aquatic Geochemistry of Dhanbad, Jharkhand: Source Evaluation and Quality Assessment, Jour. Geol. Soc. Of Ind., 69, p. 1088-1102.
- Singh AK, Mondal GC, Singh PK, Singh S, Singh TB, Tewary BK, (2005). Hydrochemistry of reservoirs of Damodar River basin, India: weathering processes and water quality assessment, Environ Geol, 48, 1014-1028.
- Singh AK, Tewary BK, Sinha A, (2011). Hydrochemistry and quality assessment of groundwater in part of NOIDA metropolitan city, Uttar Pradesh, J Geol Soc Ind, 78, 523-540.
- Sreedevi P. D., Ahmed S., Made B., Ledoux E. And Ganddolfi J. M., (2006). Association of hydrogeological factors in temporal variations of fluoride concentration in a crystalline aquifer in India, Environ. Geol., 44, p. 587-591.
- Stuyfzand P. J., (1989). Nonpoint sources of trace elements in potable groundwaters in the Netherlands, Proc. 18th TWSA Water Workings, Testing and Research Institute KIWA.
- SubbaRao N. and John Devadas D., (2003). Fluoride incidence in groundwater in an area of Peninsular India, Environ. Geol., 45, p. 243-251.
- Susheela AK, (1999). Fluorosis management programme in India, Curr. Sci., 77, 1256-1259.
- Susheela AK, Kumar A, Bhatnagar M, Bahadur M, (1993). Prevalence of endemic fluorosis with gastrointestinal manifestations in people living in some north-Indian villages. Fluoride 26, 97-104.
- Szabolcs I. And Darab C., (1964). The influence of irrigation water of high sodium carbonate content of soils, In: Proc. Of 8th International Congress Of Isss, Trans, II, p. 803-812.
- Taylor SR, MacLennan, (1985). The continental crust: its composition and evolution. Blackwell, Oxford.
- Teotia SPS, Teotia M, (1984). Endemic fluorosis in India: challenging national health problem, J Assoc Phys India, 32, 347-352.
- Todd D. K., (1980). Groundwater Hydrology, John Wiley and Sons, New York, p. 535.
- Todd, D.K. and Mays, L.W. (2013). Groundwater Hydrology, John Wiley & Sons.
- USSL, (1954). Diagnosis and improvement of Saline and Alkali soils, USDA Handbook, 60, p. 147.
- World Bank Deep Wells and Prudence: Towards Pragmatic Action for Addressing Ground water Overexploitation in India, (2010) p.97.
- World Bank Report India Groundwater: A Valuable But Diminishing Resource, Feature Story, (2012). March- 6.
- WHO, (1971). International standards for drinking water, 3rd edn., Geneva, p. 70.
- WHO, (2004). Guideline for drinking water quality. Recommendations, 3rd edn., WHO, Geneva.
- World Health Organization, (2017). Guidelines for drinking water quality: fourth edition incorporating the first addendum. World Health Organization, Geneva, ed. (2017).
- Wilcox L. V., (1948). Classification and use of irrigation waters, US. Department Of Agriculture, Circular 962, Washington DC.
- Yufeng S, Fengxiang J (2009) Landslide stability analysis based on generalized information entropy. IntConf Environ SciInfAppl Technol 2:83–85
- Yufeng S, Fengxiang J (2009) Landslide stability analysis based on generalized information entropy. IntConf Environ SciInfAppl Technol 2:83–85

Yufeng S, Fengxiang J (2009) Landslide stability analysis based on generalized information entropy. *IntConf Environ SciInfAppl Technol* 2:83–85

Zhang J, Huang WW, Letolle R, Jusserand C, (1995). Major element chemistry of the Huanghe (Yellow river), China-weathering processes and chemical fluxes, *J Hydrol*, 168, 173-203.

Tables

Table 1: Chemical and physical parameters of the samples

S. No.	Latitude	Longitude	Elevation	CO ₃ ²⁻	HCO ₃ ⁻	F ⁻	Cl ⁻	SO ₄ ²⁻	NO ₃ ⁻	Na ⁺	K ⁺	Mg ²⁺	Ca
				Milligram/litre									
1	25°15'27.4"	79°51'12.4"	211m	10	155	1.665	7.441	5.121	0.799	98.767	2.626	23.894	50
2	25°14'04.1"	79°49'54.2"	228m	12	117	1.658	23.587	13.416	22.192	79.581	1.539	29.726	95
3	25°10'55.6"	79°47'10.1"	225m	10	132	0.969	32.731	18.067	25.221	33.136	0.908	24.672	10
4	25°8'47.1"	79°44'17.3"	223m	10	95	0.599	17.954	5.356	0.134	21.515	1.514	10.263	85
5	25°8'53.8"	79°40'23.5"	233m	20	171	0.771	12.767	7.556	23.8	60.268	1.889	19.605	15
6	25°8'47.2"	79°39'59.6"	232m	14	173	0.154	38.091	81.356	37.143	34.699	2.768	20.625	34
7	25°10'06.1"	79°37'41.4"	225m	8	70	1.003	9.61	6.26	8.585	37.77	0.616	18.814	76
8	25°15'13.1"	79°33'46.7"	192m	10	107	0.49	120.768	65.798	169.731	111.825	0.694	40.4	31
9	25°14'26.1"	79°33'5.2"	205m	14	76	0.525	5.612	2.664	10.567	48.071	0.644	24.528	12
10	25°9'08.3"	79°28'35.8"	218m	20	121	0.732	47.249		109.136	36.161	0.609	23.084	18
11	25°12'17.4"	79°29'23.8"	206m	30	165	2.039	13.442	4.607	3.803	134.987	1.636	42.357	62
12	25°16'49.4"	79°27'54.9"	189m	10	106	0.725	13.667	3.337	14.742	77.933	1.162	29.844	10
13	25°18'32"	79°26'33.3"	186m	12	84	0.653	64.334	50.034	73.917	105.971	1.347	13.438	15
14	25°26'17.9"	79°28'38.9"	170m	20	186	0.449	125.461	83.564	166.534	127.646	2.165	33.787	24
15	25°21'47.2"	79°25'59.5"	190m	48	273	0.809	11.012	7.876	7.855	221.579	1.196	27.344	86
16	25°19'43.2"	79°22'34.7"	179m	10	110	0.908	36.153	12.109	11.503	94.278	1.329	35.987	99
17	25°23'10.7"	79°26'52.7"	173m	12	121	0.736	44.662	33.272	50.531	86.058	1.558	75.61	95
18	25°26'56"	79°29'01.9"	160m	24	194	0.482	17.657	9.895	12.295	60.51	1.802	46.974	98
19	25°28'31.8"	79°30'0.01"	158m	18	164	0.586	11.602	7.351	15.637	49.172	1.594	45.861	95
20	25°18'45.8"	79°50'57.1"	208m	12	109	0.928	172.42	68.585	13.429	95.161	1.05	5.293	85
21	25°17'30.7"	79°51'42.9"	207m	10	81	0.939	54.92	47.922	54.539	38.192	0.692	34.666	15
22	25°20'40.1"	79°47'51.7"	175m	24	131	2.573	19.712	7.801	34.439	132.161	0.478	31.146	85
23	25°21'50.1"	79°46'52.7"	187m	22	90	1.589	8.304	8.377	17.969	91.786	0.822	26.864	98
24	25°23'57.1"	79°44'34.1"	193m	23	79	1.678	37.787	6.788	35.676	92.576	0.978	27.898	95
25	25°26'11.3"	79°42'11.1"	176m	23	89	1.677	30.787	7.898	36.787	97.676	0.968	29.789	96
26	25°27'51.3"	79°46'43.2"	154m	16	113	0.972	41.3	28.632	48.788	102.545	1.188	47.334	24
27	25°29'14.6"	79°47'20"	134m	34	152	1.106	126.445	107.741	40.534	261.556	2.073	52.231	95
28	25°27'21.3"	79°53'6.9"	154m	12	124	1.002	4.26	2.058	7.3	102.696	1.002	21.83	85
29	25°26'45.6"	79°56'15"	141m	48	140	0.937	7.313	5.079	3.893	106.874	1.362	56.187	65
30	25°30'49.4"	79°56'58.3"	129m	34	145	0.898	6.788	36.787	8.787	158.298	1.626	72.896	76
31	25°22'52.4"	79°59'47.9"	147m	70	226	0.954	39.552	10.002	1.134	233.671	1.234	22.621	59
32	25°18'0.94"	79°54'56.1"	206m	6	59	0.287	58.649			51.208	2.013	21.079	80
33	25°18'07.9"	79°46'20.3"	197m	32	0		0.121			0.077	---	0.038	0.
34	25°18'50.9"	79°42'43.6"	193m	16	183	2.124	60.024	21.09	31.87	107.476	1.52	61.925	98
35	25°19'09.5"	79°38'40.9"	200m	8	93	1.378	360.948	129.294	124.067	203.665	2.034	50.21	20
36	25°16'35.6"	79°35'05.4"	215m	10	117	0.548	335.024	155.343	344.529	102.242	1.433	68.312	10
37	25°16'30.3"	79°31'35.6"	197m	12	88	0.663	14.435	7.454	1.153	95.009	1.718	48.64	10
38	25°22'46.7"	79°31'41.3"	171m	26	136	0.803	6.995	4.855	19.094	70.018	1.311	31.369	78
39	25°21'33.9"	79°34'14.2"	192m	18	91	1.314	30.093	37.866	29.798	124.838	0.726	53.792	72
40	25°23'18.2"	79°53'35.3"	166m	24	203	0.983	48.949	18.626	9.912	106.775	1.42	22.392	10
41	25°24'39.2"	79°53'13.1"	153m	22	213	1.881	14.658	7.895	37.285	104.343	1.215	29.219	84
42	25°21'51.7"	79°51'10.9"	167m	12	126	1.695	45.069	16.095	35.095	105.095	0.896	26.862	62

43	25°21'49.76"	79°39'42.25"	178m	10	85	1.628	105.095	48.95	35.065	32.062	0.326	9.926	24
44	25°21'48.57"	79°38'29.24"	184m	6	40	1.329	105.065	98.85	85.098	104.862	0.925	42.264	84
45	25°23'27.79"	79°38'36.51"	180m	9	125	1.028	95.005	45.653	35.065	106.295	0.126	45.284	90
46	25°27'09.54"	79°40'20.60"	161m	10	146	0.926	89.095	28.065	98.094	96.326	1.294	68.096	72
47	25°27'04.98"	79°37'18.68"	174m	26	285	0.856	85.065	48.098	85.094	89.342	1.005	32.324	84
48	25°27'15.53"	79°31'07.31"	174m	14	126	1.285	84.028	35.298	26.085	149.096	1.326	24.263	10
49	25°12'25.09"	79°39'48.47"	229m	20	105	1.009	98.785	98.269	35.095	136.024	1.428	28.243	68
50	25°11'59.52"	79°41'09.41"	235m	19	185	0.985	85.985	85.625	46.085	186.126	1.946	96.328	85
51	25°11'18.93"	79°44'03.34"	247m	26	126	0.856	65.925	46.098	42.098	126.264	1.238	24.262	92
52	25°11'56.51"	79°48'46.19"	227m	9	146	0.786	78.256	31.094	85.098	133.086	1.054	82.348	84
53	25°18'18.27"	79°45'21.94"	196m	16	85	0.859	85.098	38.094	16.295	124.024	1.062	48.326	90
54	25°13'34.50"	79°45'08.25"	247m	14	145	0.629	98.945	36.985	85.025	185.096	1.292	36.394	85
55	25°14'48.17"	79°45'24.71"	228m	10	185	0.542	102.855	26.094	28.048	146.286	1.845	42.286	94
56	25°14'55.97"	79°43'15.92"	228m	17	104	0.428	94.085	6.298	78.295	96.268	1.009	84.296	85
57	25°32'25.27"	79°45'17.13"	157m	18	289	0.898	68.035	28.928	25.025	85.264	0.896	64.284	10
58	25°32'23.712"	79°53'13.848"	141m	12	109	0.625	78.258	56.027	51.026	106.284	0.496	78.296	80
59	25°32'23.712"	79°56'15"	134m	14	85	0.549	85.234	29.082	85.098	105.296	0.042	98.284	85
60	25°32'23.712"	79°57'54.252"	132m	15	105	0.629	68.925	29.925	86.098	102.298	0.326	74.285	88

Table 2: Trace element concentration

Latitude	Longitude	Ba	Bi	Cd	Co	Cu	Cr	Fe	Al	As	Pb	Se
		Metal concentration in µg/L										
25°15'27.4"	79°51'12.4"	4.6	0.06	0.03	0.01	3.62	0.62	128	10.6	3.2	3.62	0.26
25°14'04.1"	79°49'54.2"	10.9	0.09	0.04	0.04	2.81	0.71	162	34.8	3.6	4.32	0.31
25°10'55.6"	79°47'10.1"	21.6	0.04	0.08	0.62	1.62	0.03	152	8.0	2.8	6.06	0.49
25°8'47.1"	79°44'17.3"	17.9	0.08	0.02	0.31	0.98	0.61	228	15.6	2.9	7.89	0.02
25°8'53.8"	79°40'23.5"	8.6	0.09	0.06	0.49	2.62	0.80	205	9.8	3.4	3.62	0.09
25°8'47.2"	79°39'59.6"	15.6	0.06	1.20	0.62	4.62	0.83	118	20.1	3.9	8.41	0.71
25°10'06.1"	79°37'41.4"	20.5	0.01	1.80	0.92	2.61	0.46	86	16.7	10.6	6.32	0.62
25°15'13.1"	79°33'46.7"	12.9	0.01	0.01	0.06	3.62	0.36	782	12.8	11.2	2.62	0.78
25°14'26.1"	79°33'5.2"	16.8	0.01	0.01	0.07	6.92	0.91	402	28.8	12.4	3.41	0.67
25°9'08.3"	79°28'35.8"	17.9	0.01	0.06	0.06	2.81	0.89	562	11.2	9.6	3.42	0.72
25°12'17.4"	79°29'23.8"	28.6	0.01	0.04	0.05	3.62	0.68	129	3.06	4.8	6.05	0.15
25°16'49.4"	79°27'54.9"	13.4	0.01	0.07	0.01	4.61	1.80	230	2.98	2.1	3.61	0.62
25°18'32"	79°26'33.3"	18.6	0.06	0.03	0.01	3.62	1.69	285	6.2	3.4	6.27	0.18
25°26'17.9"	79°28'38.9"	10.9	0.08	0.01	0.06	4.32	1.32	1082	11.8	1.6	3.63	0.79
25°21'47.2"	79°25'59.5"	11.2	0.09	0.01	0.02	4.31	1.34	462	2.1	2.9	2.62	0.24
25°19'43.2"	79°22'34.7"	130.6	0.01	0.05	0.36	3.62	0.03	246	3.6	3.8	3.06	0.23
25°23'10.7"	79°26'52.7"	104.8	0.01	0.06	0.28	2.69	0.04	568	4.8	1.6	4.61	0.62
25°26'56"	79°29'01.9"	16.7	0.01	0.07	0.16	3.32	0.31	118	4.1	1.7	5.62	0.72
25°28'31.8"	79°30'0.01"	18.9	BDL	0.08	0.23	2.61	0.81	107	5.6	2.6	5.05	0.09
25°18'45.8"	79°50'57.1"	7.8	BDL	0.30	0.39	2.81	0.69	128	12.9	2.9	6.09	0.06
25°17'30.7"	79°51'42.9"	9.8	0.02	0.39	0.46	2.62	0.81	286	16.8	1.8	2.63	0.39
25°20'40.1"	79°47'51.7"	2.6	0.01	0.01	0.05	2.7	0.69	374	6.7	2.6	0.61	0.41
25°21'50.1"	79°46'52.7"	9.2	0.01	0.60	0.06	1.6	0.31	289	16.4	11.8	0.62	0.39
25°23'57.1"	79°44'34.1"	6.7	0.01	0.43	0.07	1.8	0.36	629	7.8	10.2	3.63	0.46
25°26'11.3"	79°42'11.1"	8.1	0.01	0.45	0.08	1.7	0.61	465	16.7	9.8	2.61	0.07
25°27'51.3"	79°46'43.2"	9.6	0.01	0.46	0.09	1.2	BDL	285	38.9	3.4	1.08	0.69
25°29'14.6"	79°47'20"	10.2	0.01	0.36	0.39	1.9	BDL	849	30.1	2.8	2.68	0.76
25°27'21.3"	79°53'6.9"	11.6	0.01	0.03	0.31	1.6	BDL	365	56.1	6.4	2.89	0.89
25°26'45.6"	79°56'15"	30.4	0.01	0.05	0.43	2.7	BDL	385	59.1	9.8	3.62	0.23
25°30'49.4"	79°56'58.3"	16.9	0.01	0.07	0.26	2.6	BDL	562	16.7	7.2	2.61	0.81
25°22'52.4"	79°59'47.9"	12.6	0.01	0.06	0.07	6.3	BDL	495	19.6	0.6	2.62	0.06
25°18'0.94"	79°54'56.1"	17.8	BDL	0.01	0.01	3.2	BDL	298	25.6	0.8	2.36	0.07
25°18'07.9"	79°46'20.3"	0.1	BDL	0.01	0.01	0.7	BDL	308	28.9	0.3	0.04	0.01
25°18'50.9"	79°42'43.6"	0.6	BDL	0.01	0.06	3.6	BDL	534	16.7	2.9	0.39	0.71
25°19'09.5"	79°38'40.9"	16.7	BDL	0.01	0.07	2.9	BDL	302	7.8	3.2	0.36	0.82
25°16'35.6"	79°35'05.4"	8.9	0.01	0.02	0.62	1.8	BDL	365	8.1	3.4	8.96	0.05
25°16'30.3"	79°31'35.6"	19.9	0.01	0.31	0.72	1.3	0.06	507	7.2	9.6	3.32	0.62
25°22'46.7"	79°31'41.3"	20.8	0.07	0.46	0.78	9.8	0.78	408	10.7	3.5	1.82	0.72
25°21'33.9"	79°34'14.2"	16.7	0.09	0.31	0.61	2.6	0.09	965	18.1	2.8	6.45	0.81
25°23'18.2"	79°53'35.3"	17.8	0.10	0.63	0.01	2.2	0.62	492	2.6	1.2	3.96	0.72
25°24'39.2"	79°53'13.1"	18.9	0.01	0.39	0.01	2.1	0.96	489	19.2	1.6	2.82	0.06
25°21'51.7"	79°51'10.9"	16.2	0.01	0.03	0.61	3.6	BDL	364	16.7	1.8	3.61	0.72
25°21'49.76"	79°39'42.25"	17.8	0.01	0.31	0.32	3.62	BDL	284	17.8	2.9	4.68	0.18
25°21'48.57"	79°38'29.24"	18.2	0.06	0.01	0.43	3.41	BDL	679	19.9	3.6	3.81	0.16
25°23'27.79"	79°38'36.51"	17.2	0.01	0.01	0.06	3.04	BDL	385	20.6	2.9	2.98	0.34
25°27'09.54"	79°40'20.60"	18.1	0.01	0.02	0.07	2.01	BDL	369	18.6	3.9	2.63	0.18
25°27'04.98"	79°37'18.68"	10.6	0.01	0.01	0.03	1.06	0.71	596	17.8	3.9	6.21	0.32
25°27'15.53"	79°31'07.31"	11.2	0.01	0.06	0.49	6.21	0.06	289	17.2	4.6	4.32	0.64
25°12'25.09"	79°39'48.47"	12.3	0.01	0.03	0.32	11.02	0.32	375	36.2	7.8	4.96	0.91
25°11'59.52"	79°41'09.41"	20.9	0.01	0.04	0.36	3.41	0.71	285	14.6	6.8	2.81	0.62
25°11'18.93"	79°44'03.34"	31.2	BDL	0.61	0.28	3.62	0.62	128	17.8	7.6	3.89	0.46
25°11'56.51"	79°48'46.19"	16.8	BDL	0.62	0.16	2.61	0.73	126	20.9	9.2	2.63	0.32
25°18'18.27"	79°45'21.94"	30.6	BDL	0.01	0.17	3.42	0.43	178	6.7	6.2	1.79	0.72
25°13'34.50"	79°45'08.25"	28.9	BDL	0.31	0.14	9.82	0.89	198	7.8	3.8	4.63	0.81
25°14'48.17"	79°45'24.71"	16.2	BDL	0.01	0.01	2.62	0.69	562	9.6	4.2	3.92	0.36
25°14'55.97"	79°43'15.92"	7.8	0.07	0.01	0.03	3.41	0.78	782	12.9	7.8	9.86	0.72
25°32'25.27"	79°45'17.13"	9.6	0.08	0.32	0.04	3.62	0.61	372	14.6	7.6	3.82	0.82
25°32'23.712"	79°53'13.848"	12.8	0.01	0.31	0.01	3.41	0.39	485	26.9	6.8	7.82	0.31
25°32'23.712"	79°56'15"	13.6	0.01	0.01	0.03	3.06	0.46	685	28.9	6.9	6.32	0.46
25°32'23.712"	79°57'54.252"	15.9	0.01	0.31	0.03	3.48	0.30	682	30.9	9.7	6.82	0.58
Lowest value		0.1	0.01	0.01	0.01	0.7	0.03	86	2.1	0.3	0.04	0.01
Highest value		130.6	0.1	1.8	0.92	11.02	1.8	1082	59.1	12.4	9.86	0.91
Average value		19.86	0.03	0.225	0.23	3.43	0.65	400.39	17.3	4.96	4.029	0.46

Table 3: Computed values of chloroalkaline indices (CAI)

o.	Latitude	Longitude	CAI-I = $[\text{Cl}^- - (\text{Na}^+ + \text{K}^+)] / \text{Cl}^-$	CAI-II = $[\text{Cl}^- (\text{Na}^+ + \text{K}^+)] / \text{SO}_4^{2-} + \text{HCO}_3^- + \text{NO}_3^-$
	25°15'27.4"	79°51'12.4"	-19.428	0.337
	25°14'04.1"	79°49'54.2"	-4.287	0.889
	25°10'55.6"	79°47'10.1"	-0.597	0.452
	25°8'47.1"	79°44'17.3"	-0.901	0.294
	25°8'53.8"	79°40'23.5"	-6.388	0.285
	25°8'47.2"	79°39'59.6"	-0.457	0.313
	25°10'06.1"	79°37'41.4"	-5.185	0.313
	25°15'13.1"	79°33'46.7"	-0.438	2.761
	25°14'26.1"	79°33'5.2"	-12.25	0.229
	25°9'08.3"	79°28'35.8"	-0.203	0.568
	25°12'17.4"	79°29'23.8"	-14.578	0.783
	25°16'49.4"	79°27'54.9"	-8	0.630
	25°18'32"	79°26'33.3"	-1.558	2.246
	25°26'17.9"	79°28'38.9"	-0.575	2.555
	25°21'47.2"	79°25'59.5"	-30.064	0.623
	25°19'43.2"	79°22'34.7"	-3.019	1.842
	25°23'10.7"	79°26'52.7"	-1.992	1.330
	25°26'56"	79°29'01.9"	-4.32	0.368
	25°28'31.8"	79°30'0.01"	-5.575	0.230
	25°18'45.8"	79°50'57.1"	0.139	5.627
	25°17'30.7"	79°51'42.9"	-0.103	0.798
	25°20'40.1"	79°47'51.7"	-9.321	1.12
	25°21'50.1"	79°46'52.7"	-16.478	0.471
	25°23'57.1"	79°44'34.1"	-2.830	2.109
	25°26'11.3"	79°42'11.1"	-3.919	1.669
	25°27'51.3"	79°46'43.2"	-2.887	1.580
	25°29'14.6"	79°47'20"	-2.202	7.183
	25°27'21.3"	79°53'6.9"	-36.416	0.244
	25°26'45.6"	79°56'15"	-21.190	0.394
	25°30'49.4"	79°56'58.3"	-35.210	0.386
	25°22'52.4"	79°59'47.9"	-8.153	2.855
	25°18'0.94"	79°54'56.1"	-0.369	3.844
	25°18'07.9"	79°46'20.3"	0	0
	25°18'50.9"	79°42'43.6"	-1.781	1.985
	25°19'09.5"	79°38'40.9"	0.124	13.861
	25°16'35.6"	79°35'05.4"	0.523	3.830
	25°16'30.3"	79°31'35.6"	-9.146	1.046
	25°22'46.7"	79°31'41.3"	-14.35	0.231
	25°21'33.9"	79°34'14.2"	-5.423	1.628
	25°23'18.2"	79°53'35.3"	-2.384	1.644
	25°24'39.2"	79°53'13.1"	-10.195	0.440
	25°21'51.7"	79°51'10.9"	-2.622	1.940
	25°21'49.76"	79°39'42.25"	0.523	1.346
	25°21'48.57"	79°38'29.24"	-0.543	3.124
	25°23'27.79"	79°38'36.51"	-0.723	3.364
	25°27'09.54"	79°40'20.60"	-0.669	2.276
	25°27'04.98"	79°37'18.68"	-0.629	1.310
	25°27'15.53"	79°31'07.31"	-1.746	4.661
	25°12'25.09"	79°39'48.47"	-1.136	3.605
	25°11'59.52"	79°41'09.41"	-2.359	3.415
	25°11'18.93"	79°44'03.34"	-1.978	2.697
	25°11'56.51"	79°48'46.19"	-1.645	2.858
	25°18'18.27"	79°45'21.94"	-1.258	5.121
	25°13'34.50"	79°45'08.25"	-1.896	4.890
	25°14'48.17"	79°45'24.71"	-1.203	4.530
	25°14'55.97"	79°43'15.92"	-0.6	3.612
	25°32'25.27"	79°45'17.13"	-0.947	1.235
	25°32'23.70"	79°53'13.84"	-1.109	2.610
	25°35'14.76"	79°57'51.8"	-0.912	3.202
	25°35'14.76"	79°57'54.25"	-1.293	2.265
	Lowest value		-36.416	0.229
	Highest value		0.523	13.861
	Average value		-5.49375	2.170407

Table 4: Percentage of samples exceeding desirable and permissible limits in comparing with international and national standards

Parameters	Sample range	WHO (2011)	BIS (2012)	Percentage of samples exceeding desirable limit	Percentage of samples exceeding permissible limit
		Desirable- Permissible			
Ca ²⁺	0.254-348.052 (mg/L)	75-200	75-200	83.33	6.67
Mg ²⁺	0.038-98.248 (mg/L)	30-150	30-100	53.33	No
Na ⁺	0.077- 261.556 (mg/L)	50-200	-	96.67	6.67
K ⁺	0.042-2.768 (mg/L)	10-12	-	No	No
HCO ₃ ⁻	0-289 (mg/L)	300-600	300-600	No	No
SO ₄ ²⁻	2.058-155.343 (mg/L)	200-600	200-400	No	No
NO ₃ ⁻	0.134- 344.529 (mg/L)	≤ 45	≤ 45	31.67	31.67
Cl ⁻	0.121-360.948 (mg/L)	250-600	250- 1000	3.33	No
F ⁻	0.154-2.573 (mg/L)	0.9-1.5	1.0-1.5	33.33	21.67
TDS	37-1250 (mg/L)	500-1500	500- 2000	53.33	No
pH	6.74-8.89	7.0-9.2	6.5-9.2	No	No
EC	334-1858 (μS)		-	-	-

Table 5: Computed values of Sodium adsorption ratio (SAR), % Na, Residual sodium carbonate (RSC), Kelly index

Latitude	Longitude	%Na= [(Na ⁺ +K ⁺)/ (Ca ²⁺ +Mg ²⁺ +Na ⁺ +K ⁺)] * 100	SAR= Na ⁺ / [√{(Ca ²⁺ +Mg ²⁺)/2}]	RSC= (CO ₃ ²⁻ + HCO ₃ ⁻) - (Ca ²⁺ + Mg ²⁺)	KI= Na ⁺ / (Ca ²⁺ + Mg ²⁺)	Mg ratio(MR) = Mg ²⁺ * 100/ (Ca ²⁺ + Mg ²⁺)	TH (mgCaCO ₃ /l) = (2.5 × Ca) + (4.1 × Mg)
25°15'27.4"	79°51'12.4"	48.040	2.816523	-1.77	0.924	30.83853	231.9329
25°14'04.1"	79°49'54.2"	32.314	1.809808	-4.99	0.473	23.38531	365.3466
25°10'55.6"	79°47'10.1"	16.351	0.742623	-5.03	0.191	18.32823	376.0052
25°8'47.1"	79°44'17.3"	16.166	0.592733	-3.14	0.186	10.90092	251.7908
25°8'53.8"	79°40'23.5"	26.078	1.349369	-4.07	0.347	14.18637	376.858
25°8'47.2"	79°39'59.6"	7.554	0.488752	-15.78	0.079	5.594328	954.6925
25°10'06.1"	79°37'41.4"	23.823	1.003664	-3.92	0.307	19.83135	267.2774
25°15'13.1"	79°33'46.7"	20.223	1.564895	-17.21	0.251	11.22375	964.5175
25°14'26.1"	79°33'5.2"	20.804	1.040458	-6.35	0.258	16.83702	403.4423
25°9'08.3"	79°28'35.8"	12.779	0.671898	-8.27	0.143	11.33191	546.2044
25°12'17.4"	79°29'23.8"	47.36	3.236236	-2.88	0.892	40.54698	328.9312
25°16'49.4"	79°27'54.9"	30.132	1.702465	-5.86	0.427	21.40383	396.3329
25°18'32"	79°26'33.3"	37.04	2.32396	-6.09	0.585	9.027759	393.6308
25°26'17.9"	79°28'38.9"	27.188	2.034045	-11.17	0.372	12.23444	744.4667
25°21'47.2"	79°25'59.5"	59.517	5.321335	-0.47	1.470	24.06894	327.7679
25°19'43.2"	79°22'34.7"	34.053	2.057731	-5.81	0.516	26.50917	396.9617
25°23'10.7"	79°26'52.7"	25.542	1.595467	-8.61	0.340	44.12426	549.3685
25°26'56"	79°29'01.9"	23.272	1.255946	-4.79	0.299	32.32764	438.4234
25°28'31.8"	79°30'0.01"	20.452	1.041736	-5.15	0.253	32.89508	421.9176
25°18'45.8"	79°50'57.1"	48.267	2.766154	-2.29	0.924	6.132901	224.2313
25°17'30.7"	79°51'42.9"	16.998	0.812419	-6.69	0.198	23.92871	417.6456
25°20'40.1"	79°47'51.7"	46.50	3.153349	-3.7	0.864	27.54114	332.5561
25°21'50.1"	79°46'52.7"	36.053	2.113212	-4.92	0.559	21.41274	356.6274
25°23'57.1"	79°44'34.1"	36.153	2.128435	-5.1	0.562	22.21444	358.5993
25°26'11.3"	79°42'11.1"	37.024	2.227605	-5.05	0.583	23.53411	364.1074
25°27'51.3"	79°46'43.2"	46.979	2.795703	-2.71	0.876	66.25422	254.3419
25°29'14.6"	79°47'20"	56.296	5.405101	-5.23	1.284	36.37206	442.5746
25°27'21.3"	79°53'6.9"	42.559	2.567948	-3.63	0.737	20.35583	303.033
25°26'45.6"	79°56'15"	37.131	2.341151	-3.99	0.589	46.11275	394.5167
25°30'49.4"	79°56'58.3"	41.172	3.103321	-6.32	0.699	48.64403	491.2736
25°22'52.4"	79°59'47.9"	67.733	6.531095	1.19	2.099	27.43569	242.3211
25°18'0.94"	79°54'56.1"	28.285	1.317476	-4.56	0.389	20.84347	286.5514
25°18'07.9"	79°46'20.3"	75	0	1.06	0	13.0137	0.7908
25°18'50.9"	79°42'43.6"	31.994	2.089533	-6.46	0.467	38.68257	499.2925
25°19'09.5"	79°38'40.9"	38.494	3.32276	-12.43	0.623	19.90762	710.8735
25°16'35.6"	79°35'05.4"	29.220	1.906171	-8.65	0.408	39.20929	544.8592
25°16'30.3"	79°31'35.6"	31.091	1.923533	-7.38	0.447	31.74355	460.894
25°22'46.7"	79°31'41.3"	32.079	1.686289	-3.4	0.467	28.53621	325.0079
25°21'33.9"	79°34'14.2"	40.474	2.709924	-5.94	0.676	42.65246	401.3597
25°23'18.2"	79°53'35.3"	40.189	2.48909	-2.82	0.667	17.95828	347.5497
25°24'39.2"	79°53'13.1"	40.945	2.49541	-2.4	0.685	25.69765	331.0079
25°21'51.7"	79°51'10.9"	46.324	2.799417	-2.86	0.857	30.0181	266.6942
25°21'49.76"	79°39'42.25"	41.107	1.383102	-0.3	0.688	29.04547	101.3166
25°21'48.57"	79°38'29.24"	37.306	2.327015	-6.82	0.593	33.38626	384.0999
25°23'27.79"	79°38'36.51"	35.897	2.274731	-5.9	0.56	33.29461	412.4794
25°27'09.54"	79°40'20.60"	31.245	1.951478	-6.5	0.454	48.31491	461.3086
25°27'04.98"	79°37'18.68"	36.270	2.093478	-1.33	0.564	27.71001	343.3459
25°27'15.53"	79°31'07.31"	47.173	3.394113	-4.75	0.888	18.63189	364.3783
25°12'25.09"	79°39'48.47"	50.899	3.491605	-3.34	1.031	29.30897	286.0963
25°11'59.52"	79°41'09.41"	40.069	3.280928	-8.5	0.665	53.08732	607.7548
25°11'18.93"	79°44'03.34"	45.822	3.033659	-3.61	0.838	21.0157	327.4367
25°11'56.51"	79°48'46.19"	34.684	2.473365	-8.27	0.528	49.46598	547.9418
25°18'18.27"	79°45'21.94"	38.195	2.573973	-6.85	0.614	33.44128	438.5966
25°13'34.50"	79°45'08.25"	52.741	4.230986	-4.39	1.111	29.93174	362.2054
25°14'48.17"	79°45'24.71"	43.767	3.139067	-4.85	0.774	30.83598	410.4876
25°14'55.97"	79°43'15.92"	27.092	1.754229	-9.14	0.367	48.36759	570.5786
25°32'25.27"	79°45'17.13"	25.846	1.601729	-5.39	0.345	37.04446	536.6844
25°32'23.712"	79°53'13.848"	30.188	1.994606	-8.54	0.430	47.58363	536.6336
25°32'23.712"	79°56'15"	26.968	1.837151	-10.57	0.368	52.94561	621.3344
25°32'23.712"	79°57'54.252"	29.745	1.941215	-8.29	0.423	45.63774	525.7835
west value		7.554	0	-17.21	0	5.594328	0.7908
highest value		75	6.531095	1.19	2.099	66.25422	964.5175
average value		35.84437	2.300682	-5.54967	0.596847	29.21411	415.5173

Table 6: Correlation coefficient matrix of physicochemical parameters of groundwater (all the parameters are in mg/L except EC, pH)

	HCO ₃ ⁻	F ⁻	Cl ⁻	Br ⁻	SO ₄ ²⁻	NO ₃ ⁻	Li ⁺	Na ⁺	K ⁺	Mg ²⁺	Ca ²⁺	<i>P</i>
HCO ₃ ⁻	1											
F ⁻	0.073095	1										
Cl ⁻	-0.06455	-0.08569	1									
Br ⁻	0.036468	0.052686	0.711201	1								
SO ₄ ²⁻	-0.03224	-0.1081	0.825456	0.690455	1							
NO ₃ ⁻	-0.03559	-0.185	0.736134	0.603945	0.655818	1						
Li ⁺	0.066595	0.300173	-0.00525	0.169747	-0.02707	-0.11625	1					
Na ⁺	0.364074	0.217859	0.332222	0.274158	0.364132	0.10914	0.252587	1				
K ⁺	0.349337	-0.06019	0.100491	0.167882	0.211632	-0.03338	0.168841	0.249331	1			
Mg ²⁺	0.129223	-0.09457	0.249554	0.07101	0.248099	0.330555	0.019982	0.319402	-0.01843	1		
Ca ²⁺	0.105126	-0.2687	0.259086	0.257265	0.342752	0.38704	-0.01181	-0.02953	0.307189	-0.03753	1	
pH	0.001847	0.07078	-0.39704	-0.35211	-0.39754	-0.39116	-0.14004	0.070726	-0.11142	0.081983	-0.44115	
TDS	0.384002	-0.10523	0.787291	0.641092	0.764516	0.756781	0.070633	0.553096	0.279567	0.408168	0.523005	-0.38
EC(μS)	0.168415	-0.03041	0.285976	0.467053	0.397605	0.178105	0.204631	0.339255	0.207	-0.15173	0.418431	-0.16

Table 7: Sample numbers falling under various classified categories of different irrigation parameters

%Na classification (Wilcox 1948)				RSC (Richards 1954)			
		Samples	% sample			Samples	% sample
Excellent	0-20	3, 4, 6, 10, 21	8.3	Good	<1.25	All	100
Good	20-40	2, 5, 7-9, 12-14, 16-19, 23-25, 29, 32, 34-38, 44-47, 52, 53, 56-60	55.03	Medium	1.25-2.5	----	
				Bad	>2.5	----	
				USSL (1954)			
						Samples	% sample
Permissible	40-60	1, 11, 15, 20, 22, 26-28, 30, 39-43, 48-51	30	Excellent	<250 μS cm ⁻¹	----	
				Good	250-750 μS cm ⁻¹	1-5, 7, 9, 11, 12, 16, 18, 19, 21, 23, 25, 26, 28, 29, 32, 33, 36, 37, 39, 42, 45, 47, 48, 52-57, 59, 60	58.33
Doubtful	60-80	31, 33, 54, 55	6.67				
Unsuitable	>80	----		Permissible	750-2000 μS cm ⁻¹	6, 8, 10, 13-15, 17, 20, 22, 24, 27, 30, 31, 34, 35, 38, 40, 41, 43, 44, 46, 49-51, 58	41.67
				Doubtful	2000-3000 μS cm ⁻¹	----	
SAR (Richards 1954)				Unsuitable	>3000 μS cm ⁻¹	----	
		Samples	% sample				
Excellent	<6	All except 31	1.67	Kelly Index (1946)			
Good	6-12	31	98.33			Samples	% sample
Fair	12-18	----		Safe	<1	1-14,16-26,28-30,32-48,50-53,55-60	91.67
Poor	>18	----		Unsafe	>1	15,27,31,49,54	8.33
Total Dissolved Solid (TDS) (mg/L)(Back, 1966)				Magnesium Ratio (MR) (Szabolcs and Darab 1964)			
		Samples	% sample			Samples	% sample
Nonsaline	<1000	1-13,15-34,37-60	95	Suitable	>50%	1-25, 27-49, 51-58, 60	95
Slightly saline	1000-3000	14,35,36	5	Unsuitable	<50%	26, 50, 59	5
Moderately saline	3000-10,000						
Very saline	>10,000						
		Total Hardness (Sawyer and McCarty 1978)					
				Hardness (mg/l of CaCO3)	Samples	% sample	
		Soft		< 75	33	1.67	
		Moderately hard		75-150	43	1.67	
		Hard		150-300	1,4,7,20,26,31,32,42,49,	15	
		Very hard		> 300	2,3,5,6,8-19,21-25,27-30,33-41,43-48,50-60	81.66

Figure 1

Location, drainage and lithology map

Figure 2

Scholler's plot for ionic dominance

Figure 3

The Gibbs diagram plot showing ratio between $(\text{Na} + \text{K}) / (\text{Na} + \text{K} + \text{Ca})$ and $(\text{Cl}^- + \text{NO}_3^-) / (\text{Cl}^- + \text{NO}_3^- + \text{HCO}_3^-)$ as a function of TDS

Figure 4

Piper's Trilinear diagram

Figure 5

The scatter plot between: a) $(\text{Ca}^{2+} + \text{Mg}^{2+})$ versus $(\text{HCO}_3^- + \text{SO}_4^{2-})$ b) $(\text{Na}^+ + \text{K}^+)$ versus total cations c) $(\text{Ca}^{2+} + \text{Mg}^{2+})$ versus total cations d) $(\text{Na}^+ + \text{K}^+)$ versus $(\text{Ca}^{2+} + \text{Mg}^{2+})$ e) $(\text{Ca}^{2+} + \text{Mg}^{2+})$ versus HCO_3^- f) Cl^- versus $(\text{Na}^+ + \text{K}^+)$ g) The correlation coefficient between Ca^{2+} and HCO_3^- h) The correlation coefficient between Ca^{2+} and SO_4^{2-}

Figure 6

(a to j): Spatial variability map of different physical parameters and major ions

Figure 7

Wilcox diagrams for the classification of irrigation water