Nature Environment and Pollution Technology
An International Quarterly Scientific Journal

Nature Environment and Pollution Technology An International Quarterly Scientific Journal	p-ISSN: 0972-6268 e-ISSN: 2395-3454	Vol. 17	No. 2	pp. 375-382	2018

Original Research Paper | Open Access

Hydrogeochemical Behaviour and Assessment of Groundwater Quality from WGAMG'0 Watershed, Chimur Taluka, Chandrapur District, Maharashtra

Y. A. Murkute, S. S. Deshpande and S. N. Raut
P. G. Department of Geology, R.T.M. Nagpur University, Law College Square, Nagpur 440001, Maharashtra, India

Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 15-06-2017
Accepted: 22-08-2017

Key Words:
Hydrogeochemisrty
Groundwater
Water quality
WGAMG'0 watershed

ABSTRACT

The study area of WGAMG'0 watershed is bounded by longitudes 79°14'00" and 79°21'00" and Latitudes 20°31'00" and 20°36'00" N and covers 11 villages of Chimur Tehsil, Chandrapur District, Maharashtra. Fourteen dugwells were identified and fixed as observation wells to gather the information on pre-monsoon water level fluctuation, depth to hard rock, water bearing zone, average depth of wells, average diameter of wells and other related hydrogeological data. The collected groundwater samples having pH values 7.3 to 8.1 are dominantly alkaline. While the electrical conductivity values of the collected samples vary from 845-1132 µS/cm. The TDS values from deeper aquifers range from 596-724 mg/L and the total hardness ranges from 281-616 mg/L respectively. The anion chemistry of groundwater samples from the study area is dominated by HCO_3, Cl, SO_4 and NO_3. The concentration values ranges from 325-566 mg/L, 12.3-34.1 mg/L, 6.3-56.1 mg/L and 75.4-258.3 mg/L respectively. The primary source of HCO_3^- is considered to be the dissolution of minerals like calcite and dolomite, where in addition to that the CO_2 gas is also dissolved through the process of anoxic biodegradation of the organic matter in deeper aquifers. In the present area of investigation, 100% samples fall in the range of 500-1000 mg/L indicating that water samples are of freshwater in nature and permissible for drinking. The suitability of the groundwater for irrigation purpose has also been checked by estimating the following values: Sodium Adsorption Ratio (SAR), U.S. Salinity Laboratory diagram, Percent Sodium (% Na), Residual Sodium Carbonate (RSC), Soluble Sodium Percentage (SSP), Mg Ratio (MR), Corrosively Ratio (CR), Kelley's Ratio (KR) and Permeability Index (PI). These parameters have brought the marginal utility for irrigation purpose.

INTRODUCTION

It is now a well known fact that the freshwater resources are extremely limited. The ascending graph of utilization of water is resulting in the descending levels of ground water; hence the depletion of the groundwater has created a big mess in human life as we living beings are directly affected by the quantity as well as quality of water. The high concentrations of elements like fluorine, arsenic, nitrate and other toxic entities pollute the groundwater making it unsafe for drinking and domestic utilities. Many times water is not sufficiently safe for irrigation purpose. Many parts of India experience the acute shortage of water for different purposes and such problems of water crises are likely to become more severe and serious and will continue to escalate into the 21st century (Biswas 1991, Choubey 1991, Allen et al. 1996, Tiwari 2001, Khan et al. 2005, Soni 2007). The groundwater is an extremely useful source to meet local water demand, may it be drinking or domestic, industrial as well as irrigational. The subsurface geology governs the occurrence, distribution and the movement of groundwater. Hence, various studies on interrelationship between water quality and subsurface geology have been carried out (Rawat & Viswanathan 1990, Taranekar 1993, Gupta 1996, Singh et al. 2010). The present paper is an attempt to understand the hydrogeochemical behavior of groundwater from WGAMG'0 watershed of Chandrapur District, Maharashtra, India. In addition, it has also been attempted to ascertain suitability of groundwater for drinking and irrigation use.

STUDY AREA

Study area covers 109.81 sq. km area of Chandrapur district and is located 85 km south-east of Nagpur city. It is included in the Survey of India toposheet number 55 P/6 between longitude 79°31'00" and 20°36'00" N (Fig. 1). The area experiences tropical dry sub-humid climate. The summer months are much hot (maximum temperature 45°C) while winter is mild (minimum temperature 10°C). The GSDA has categorized the watershed as WGAMG'0. The watershed details are given in Table 1.

GEOLOGY AND HYDROGEOLOGY

The generalized geological succession of the rocks encountered in the study area is given in Table 2. The Arachaean rocks form the basement complex. The overlain Talchir for-

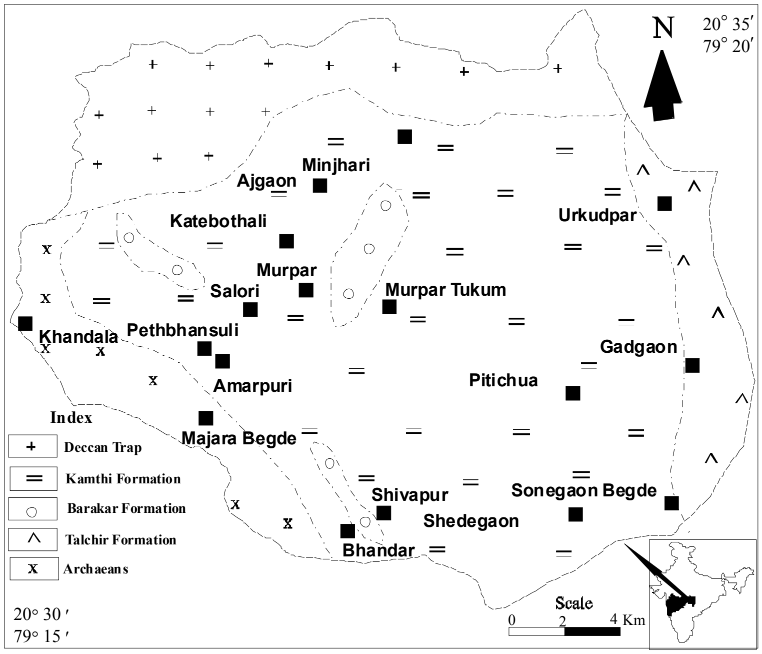

Fig. 1: Location and geological map of the study area.

mation in the area comprises older unstratified deposits (boulder beds) and younger stratified deposits. The unstratified deposit represents the poorly sorted, laterally discontinuous bodies, which vary in thickness from 0.5 to 2.0 m. The Barakar formation is composed of the low angle stratified sedimentary partings and coal seams. In the Kamthi formation the sandstones predominate over clay-claystones and carbonaceous shales. These sandstones (1.0 to 4.0 m thick) are yellowish brown to white, coarse to fine grained and friable. In the WGAMG'0 watershed the Deccan trap basalts cover the northern boundary of the study area. In general, Deccan basalt flows are thick, tabular and sheet like form and have the large areal extent.

In the study area the occurrence of groundwater from quartz-mica schist and phyllites of the Archaean is mainly controlled by the degree of weathering, joints and fractures. The dugwells penetrating in these rocks range in depth between 8 to 15 mbgl. The diameters of the dugwells range between 3 to 5 m. The dugwells penetrating Gondwana rocks range in depth between 5 to 15 mbgl. The diameters of the dugwells range between 3 to 6 m. The wells piercing these, have the discharge of 50 to 300 m^3/day (GSDA, 2005, 2009). The Basaltic lava flows are vesicular in nature and possess deep weathering as well as joints. The average depth of dugwells varies from 9 to 15 mbgl and the yield ranges from 75 to 100 m^3/day. The borewells penetrating deeper aquifers have good yields ranging from 150 to 250 m^3/day. The wells piercing aquifers in alluvial areas have discharge between 100 to 300 m^3/day, though in a few cases higher yields are observed (GSDA 2009).

MATERIALS AND METHODS

The hydrogeochemical survey for systematic sampling in the study area was carried out during pre-monsoon season (May-June) of 2016. The grids were plotted on the study area and the 14 samples were collected from dugwells (penetrating shallow aquifers) in one liter polyethylene bottles. The chemical parameters were analyzed using the standard hydrogeochemical analytical techniques (APHA 1995). The temperature, pH and electrical conductivity were measured with respective analytical instruments. The parameters like calcium (Ca^{++}), magnesium (Mg^{++}), chloride (Cl^-) and bicarbonate (HCO_3^-) were determined by titration while sodium (Na^+) and potassium (K^+) were measured by flame photometer. Sulphate (SO_4^-), nitrate (NO_3^-) and fluoride (F^-) were determined by using UV-visible spectrometer. The analytical precision was maintained by running a known standard after every 5 samples.

The results were evaluated in accordance with the World Health Organization guidelines (WHO 1997) and standard specifications of Bureau of Indian Standards (BIS 1991). The determination of hydrochemical facies was carried out as per the Piper trilinear diagram (Piper 1953) using Aquachem 4.0 software. Presentation of geochemical data in the form of graphical chart was performed by US salinity diagram (1954). The suitability of groundwater from study

Table 1: The salient features of WGAMG'0 watershed (after GSDA 2011).

Sr.No.	Salient features	Particulars
1	Recharge from rain fall during monsoon season	1053.12 Hactare metre (Ham)
2	Area suitable for groundwater recharge	1086.47 Ham
3	Natural discharge	54.32 Ham
4	Net groundwater availability	1032.14 Ham
5	Existing gross groundwater draft for irrigation	147.65 Ham
6	Net groundwater for future irrigation	8.3.85 Ham
7	Stage of groundwater development (2011)	14.31 Ham
8	Category of watershed	Safe

Table 2: Geological setup of the study area (after Raja Rao 1982).

Age	Group/Formation	Lithology
Recent	-	Alluvial gravel, soil
Eocene	Deccan Trap	Thoeliitic basalt
....	Unconformity	....
Cretaceous	Lameta formation	Limestone, Chert and silicified sandstone
....	Unconformity	....
Upper PermianLower Triassic	Kamthi	Yellow and buff Sandstones, yellow Clay
....	Unconformity	....
Lower Permian	Barakar	Fined to course grained sandstone, grey shales and coal seams
Upper carboniferous	Táchira	Fined grained sandstones and shales
....	Unconformity	....
Proterozoic	Sullavai	Quartzite
....	Unconformity	....
Archean	-	Metamorphites

Table 3: Drinking water standards with range in study area samples.

Sr. No.	Physio-chemical parameters	Range in study area Min.	Max.	Average	WHO (1997) Desirable Limit	Permissible Limit	BIS (2003) Desirable Limit	Permissible Limit
1	pH	7.3	8.1	7.7	6.5	8.5	6.5	8.5
2	EC	845	1132	988.5	-	-	-	-
3	TDS	541	724	632.5	500	1500	500	2000
4	TH	281	616	462.5	100	500	300	600
5	Ca^{2+}	74.4	106.8	90.6	75	200	75	200
6	Mg^{2+}	18.5	89.6	54.05	50	150	30	100
7	Na^{+}	3.1	56.4	29.75	-	200	-	-
8	K^{+}	4.6	27.6	16.1	-	-	-	-
9	HCO_3^-	325	566	445.5	600	250	1000	
11	SO_4^{2-}	6.3	56.1	31.2	200	400	200	400
12	NO_3^-	75.4	258.3	166.85	-	45	-	45
13	F^-	0.2	0.9	0.55	-	1.5	-	1.0

- No limit has been prescribed; *All values in mg/L except pH and EC (µS/m at 25ºC).

area was checked for irrigation purpose using the Sodium Absorption Ratio (SAR), Percent Sodium (%Na), Residual Sodium Carbonate (RSC), Soluble Sodium Percentage (SSP), Mg Ratio (MR), Corrosivity Ratio (CR), Kelley's Ratio (KR) and Permeability Index (PI).

PHYSICO-CHEMICAL PARAMETERS

Physical parameters: The most common physical parameters measured in the field at the time of sampling are EC, pH and Eh, which provide useful preliminary information of the area. The groundwater is generally colourless, odourless and the taste varies according to location. The physico-chemical data of groundwater samples are presented in Table 3.

The pH value of the groundwater samples of the study area is from 7.3 to 8.1, which indicates that the groundwater samples collected from the dugwells are dominantly alkaline. Generally, it is due to the ion exchange and dispersion process taken place within the aquifer (Handa 1975, Sanchez-Perez et al. 1999). The most desirable limit of EC for drinking purpose is 1500 µS/cm (WHO 2004). For the study area, the values of electrical conductivity (EC) for the groundwater collected from the dugwells vary from 845 to 1132 µS/cm. The TDS content from deeper aquifers of the study area varies from 596 to 724 mg/L. Dufor & Becker (1964) classified the water as 0-60, soft; 61-120, moderately hard; 121-180, hard and >180, very hard water. As per this classification none of the samples of the study area is under soft category, as the total hardness (TH) of the water samples of the study area ranges from 281 to 616 mg/L in the aquifers.

Major cation chemistry: The Ca^{2+} content in shallow aquifers ranges between 74.4 and 106.8 mg/L. The concentration of Mg^{2+} for shallow aquifer varies from 18.5 to 89.6 mg/ L. The chief sources of Mg^{2+} in the natural water are magnesium-bearing minerals in rock and secondary sources are domestic and industrial wastes. In the study area, the Na^{+} concentration ranges from 3.1 to 56.4 mg/L while the K^{+} concentration ranges from 4.6 to 27.6 mg/L. According to Marghade et al. (2010) the weathered rock forming minerals like sodium plagioclase, potash plagioclase, halite and anthropogenic sources like domestic and animal waste are responsible for the higher concentration of Na^{+} and K^{+} in groundwater. Handa (1975) and Jackes et al. (2005) have reported increased Na^{+} content with decreasing Ca^{2+} concentration on alkaline water conditions. Similar observations are noted in the study area.

Major anion chemistry: The major anions analyzed include bicarbonate, chloride, sulfates, nitrate, fluoride, carbonate, and phosphates. The anion chemistry of groundwater samples from the study area is dominated by HCO_3^-, Cl^-, SO_4^{2-} and NO_3^-. The HCO_3^- concentration ranges from 325 to 566 mg/L. In the groundwater, the primary source of HCO_3^- is the dissolution of minerals like calcite and dolomite. In addition, the dissolution of CO_2 gas through anoxic biodegradation of organic matter derived from industrial and domestic waste in deeper aquifers (Canter 1997, Jeong 2001). Chloride concentration from the study area ranges from 12.3 to 34.1 mg/L. The high Cl^- concentrations in groundwater come from weathering of minerals like halite and the domestic effluents, fertilizers as well as leachates from landfills are the sources. The excess of Cl^- in the water is usually considered as pollution (Loizidou & Kapetanions 1993) and is indicative of groundwater contamination. The SO_4^{2-} concentration varies between 6.3 and 56.1 mg/L. NO_3^- concentration in the study area ranges from 75.4 to 258.3

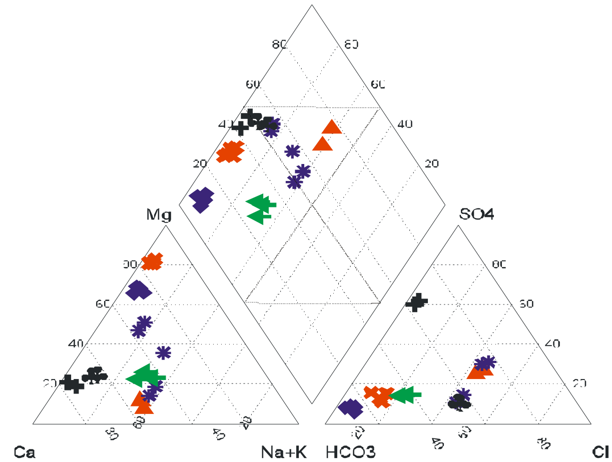

Fig. 2: Piper trilinear diagram for groundwater samples of study area.

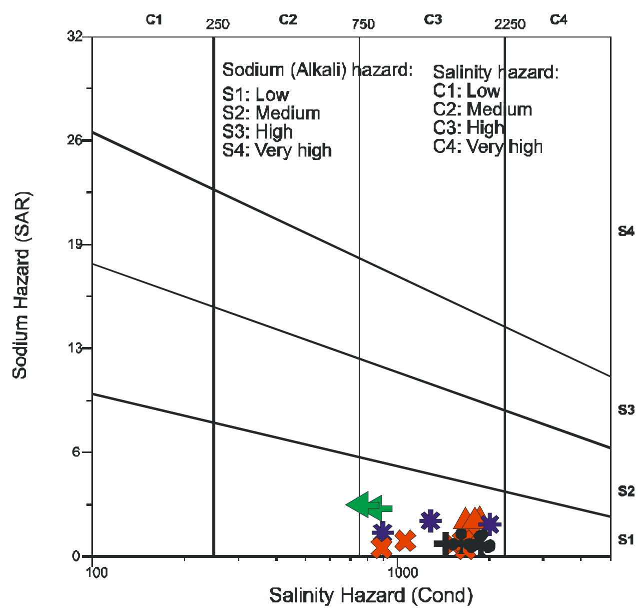

Fig. 3: U.S. Salinity diagram of groundwater samples from study area.

mg/L. Appelo & Postma (1993) are of opinion that the chief sources of nitrates in water are the biological fixation, atmospheric precipitation, usage of fertilizer and industrial sewage.

Bureau of Indian Standards has suggested permissible limit of F^- in drinking water as 1.0 mg/L (BIS 2003), which is lower than maximum tolerance limit (1.5 mg/L) of F^- in drinking water as specified by World Health Organization (WHO 1984). The sole source of fluorosis is the excessive fluoride intake through the groundwater (WHO 1984, Dev Burman et al. 1995, Subba Rao 2003). This disease is encountered in geographic areas with high content of fluorine in water and hence the disease stays largely endemic (Deshkar & Deshmukh 1998). The F^- content in the study area ranges from 0.2 to 0.9 mg/L.

HYDROCHEMICAL FACIES

The diagnostic chemical properties of water are presented by various methods, the most common of which are the hydrochemical facies, e.g., the Piper (1944) trilinear diagram (Fig. 2). This diagram is useful in screening and sorting large numbers of chemical data, which makes interpretation easier. Furthermore, a Piper diagram can define the patterns of spatial change in the water chemistry among geological units, along a line of section or along a path line (Domenico & Schwartz 1998).

The plot of the chemical data on Piper's trilinear diagram shows that groundwater in all lithological variants indicate the dominance of alkaline earths (Ca^{++} + Mg^{++}) over the alkalies (Na^+ + K^+). The groundwater from the Gondwana Supergroup of rocks is of Ca-Mg-SO_4-HCO_3 type. The groundwater samples collected from other geological formations show mixed character of Ca-Na-Cl, Ca-Mg-Ca-Cl, Mg-Ca-Na-HCO_3 and Mg-Ca-Na-Cl-HCO_3 water facies.

ROCK-WATER INTERACTION

The processes which are responsible for the generation of solutes can be deciphered by the compositional relations among the dissolved chemical species. The Ca^{++} and HCO_3^- as well as Mg^{++} and HCO_3^- show positive correlation between these ions because these cations have common tendency to combine with HCO_3^- as noted by Todd (1982). The Na^+/ Cl^- molar ratios in most of the groundwater samples are more than 1, which indicates that silicate weathering reactions may be the sources for Na^+ in the study area (Meyback 1987, Marghade et al. 2010). In addition, Ca^{++} and Mg^{++} exchange Na^+ at the ion exchangeable sites of the clay minerals, resulting in decrease of Ca^{++} and Mg^{++} and the increase of Na^+ in groundwater (Marghade et al. 2010). The earlier mentioned scatter diagrams bring out the negative correlation of both Ca^{++} with Na^+ as well as Mg^{++} with Na^+ clearly corroborate that Ca^{++} and Mg^{++} exchange Na^+ at the ion exchangeable sites (Murkute 2011). The feldspars, pyroxenes and amphiboles are the sources of Ca^{++} in groundwater samples from Deccan Trap while the feldspars, calcite and clay minerals are the probable sources of Ca^{++} from the gneiss and sedimentary rock (Hem 1970, Todd 1982, Murkute & Badhan 2011). The principal sources of Mg^{++} in natural water are the magnesium-bearing minerals like dolomite from nearby limestones (Singh et al. 2010, Marghade et al. 2010) while the feldspars, and clay minerals are the probable sources for Na^+ and K^+. SO_4^{2-} is generally derived from the oxidative weathering of sulphate bearing minerals like pyrite (FeS_2), which is a very common secondary mineral in the Gondwana coals and associated sediments (Singh et al. 2010). The F^- concentration in groundwater depends upon the degree of weathering and leaching of fluoride bearing minerals from the rocks and soils (Ramesam & Rajagopalan 1985, Murkute & Badhan 2011).

SUITABILITY OF GROUNDWATER

Groundwater suitability for drinking purposes: In the present work, specifications recommended by Bureau of Indian Standards (BIS 2003), World Health Organization (WHO 1997) have been used for studying the quality of groundwater for drinking and irrigation purposes (Table 3).

The maximum acceptable concentration of TDS in groundwater for a domestic purpose is 500 mg/L and excessive permissible limit is 2,000 mg/L (BIS 2003). Presence of total dissolved solids (TDS) above desirable limit of 500 mg/L (WHO 1997, BIS 2003) cause gastrointestinal irritation and decreases palatability. TDS further indicates the salinity behavior of groundwater. In the present area, 100% samples fall in the range of 500-1000 mg/L indicating that water samples are permissible for drinking (Davis & Dewiest 1966). According to the classification suggested by Freeze & Cherry (1979), all groundwater samples are of freshwater in nature. The desirable limit of hardness (as $CaCO_3$) suggested by WHO (1997) is 200 mg/L, which can be extended up to 600 mg/L in case of non-availability of any alternate water source. All samples of the study area belong to a very hard type based on Dufor & Becker (1964) classification.

Groundwater suitability for irrigation purposes: In the present study, the suitability of groundwater has been checked for irrigation purpose using the sodium adsorption ratio (SAR) and the US Salinity Laboratory diagram (1954) (Fig. 3). In addition, the percent sodium (%Na), corrosively ratio (CR) and permeability index (PI) have also been estimated which decides its suitability for irrigation purpose (Table 4).

Sodium adsorption ratio (SAR): Sodium adsorption ratio is a measure of the suitability of groundwater for agriculture irrigation, because sodium concentration can reduce the soil permeability and soil structure (Todd 1982). SAR is a measure of alkali/sodium hazard to crop and it is estimated by the following formula: $SAR = Na/\sqrt{[(Ca+Mg)/2]}$.

The calculated values of SAR in the study area vary from 0.06 to 1.05. The classification of groundwater based on SAR values shows that 14 samples are of excellent to good category, which are suitable for irrigation purposes.

US salinity laboratory diagram: The chemical data of the

Table 4: Parameters of suitability of groundwater for irrigation.

Sample Location	SAR	% Na	CR	PI
Peth Bhanusali	0.09	4.29	0.11	32.99
Majra	0.16	9.21	0.11	49.41
Murpar 1	0.06	5.24	0.27	27.88
Shivapur	0.35	9.80	0.15	37.83
Bandar	0.31	9.14	0.19	38.95
Murpar 2	0.53	13.68	0.23	35.52
Minjhari	0.69	22.76	0.22	47.44
Minjhari	0.42	14.14	0.15	46.65
Shedegaon 1	0.23	6.76	0.14	30.56
Shedegaon 2	0.65	16.06	0.22	30.97
Sonegaon	0.85	20.95	0.36	35.78
Pitichuwa	0.99	20.25	0.32	33.42
Gadgaon	0.83	18.76	0.17	36.52
Urkudpar	1.05	22.65	0.30	37.58

study area is plotted in salinity hazards vs sodium hazards diagram of U.S. Salinity Laboratory Staff (1954), which is widely used for judging the water quality for irrigation. The diagram classifies the water quality into sixteen areas to access the degree of suitability of water for irrigation, in which salinity hazards (C) is divided into four sub-areas, such as low salinity hazards (C1, <250 µs/cm), medium salinity hazards (C2, 250-750 µs/cm), high salinity hazards (C3, 750-2250 µs/cm) and very high salinity hazards (C4, >2250 µs/cm); and the sodium hazards (S) also into four sub-areas, such as low sodium hazards (S1<10), medium sodium hazards (S2, 10 to 18), high sodium hazards (S3, 18 to 26) and very high sodium hazards (S4, >26). C4S3 indicates water of high salinity hazards and low to high sodium hazards, which can be suitable for plants, after taking special soil management measure, such as good drainage, leaching and addition of organic matter. C3S2 is considered as moderate quality to irrigate semi tolerant crops and the water falling in the areas of C4S1 and C4S3, as poor quality to irrigate plants of high tolerance only. The US salinity diagram of the study area samples has been depicted in Fig. 3.

The US salinity classification shows that the water of the study area belongs to C2-S1 (very minor concentrations), and C3-S1 (major concentrations) classes. Thus, in general, the groundwater from the study area can be used for irrigation without any hazard.

Sodium percent (% Na): The sodium in irrigation waters is usually denoted as percentage of sodium. According to Wilcox (1955), in all natural waters % Na is a common parameter to access its suitability for irrigation purposes. The sodium percent (% Na) values were obtained by using the following equation: $\% Na = Na + K / (Ca + Mg + Na + K) \times 100$

Seventy one percent of the groundwater samples of the study area fall in the excellent category and rest 29% of the samples fall in the good category. Thus, all of the samples from the study area are safe for irrigation purpose.

Corrosivity ratio (CR): Corrosivity ratio (CR) (in mg/L) is calculated by the following formula: $CR = [(Cl^- / 35.5) + 2 (SO_4^{2-} /96)] / 2(HCO_3^- + CO_3^{2-} /100)$. The CR values ≤ 1 is considered as good and > 1 indicates corrosive nature of water, hence water should not be transported through the metal pipes (Ryner 1994, Raman 1985). In the study area, all the samples have CR values ≤ 1, which indicates that groundwater is good for irrigation.

Permeability index (PI): The long-term use of irrigation water affects the soil permeability. It depends on various factors like total soluble salt, sodium, calcium, magnesium, and bicarbonate content of the water. Doneen (1964) classified irrigation waters into three classes based on the PI. The PI has been computed and plotted on Doneen chart and is formulated as: $PI = [(Na^+ + \sqrt{HCO_3^-})/(Ca^{++} + Mg^{++} + Na^+)]$. According to the PI, the samples are classified as class I, class II and class III orders, where the class I and class II waters are categorized as good for irrigation and the class III water is unsuitable for irrigation. The study area waters can said to be good for irrigation.

DISCUSSION AND CONCLUSIONS

The pH value of the groundwater samples of the study area indicates the dominantly alkaline nature. It is due to the ion exchange and dispersion process taken place within the aquifer. The sole sources of Mg^{2+} in the natural water are magnesium-bearing minerals in rock and secondary sources are domestic and industrial wastes. The weathered rock forming minerals like sodium plagioclase, potash plagioclase, halite and anthropogenic sources like domestic and animal waste are responsible for the higher concentration of Na^+ and K^+ in groundwater. The anion chemistry of groundwater samples from the study area is dominated by HCO_3^-, Cl^-, SO_4^{2-} and NO_3^-. In the groundwater, the primary source of HCO_3^- is the dissolution of minerals like calcite and dolomite. The high Cl^- concentrations in groundwater come from weathering of minerals like halite and the domestic effluents, fertilizers as well as leachates from landfills are the sources. The excess of Cl^- in the water is usually considered as pollution and is indicative of groundwater contamination. The chief sources of nitrates in water are due to biological fixation, atmospheric precipitation, usage of fertilizer and industrial sewage.

The plot of the chemical data on Piper's trilinear diagram brings out that groundwater in all lithological variants has the dominance of alkaline earths ($Ca^{++} + Mg^{++}$) over the alkalies ($Na^+ + K^+$). The groundwater from the Gondwana Supergroup of rocks is of Ca-Mg-SO4-HCO_3 type.

The groundwater samples collected from other geological formations show mixed character of Ca-Na-Cl, Ca-Mg-Ca-Cl, Mg-Ca-Na-HCO_3 and Mg-Ca-Na-Cl-HCO_3 water facies.

The Na^+/Cl^- molar ratios in most of the groundwater samples are more than 1, which indicates that silicate weathering reactions may be the sources for Na^+ in the study area. In addition, Ca^{++} and Mg^{++} exchange Na^+ at the ion exchangeable sites of the clay minerals, resulting in decrease of Ca^{++} and Mg^{++} and the increase of Na^+ in groundwater. The feldspars, pyroxenes and amphiboles are the sources of Ca^{++} in groundwater samples from Deccan Trap while the feldspars, calcite and clay minerals are the probable sources of Ca^{++} from the gneiss and sedimentary rock. The principal sources of Mg^{++} in natural water are the magnesium-bearing minerals like dolomite from nearby limestones.

TDS indicates the salinity behavior of groundwater. In the present area, 100% samples are permissible for drinking. The classification of groundwater based on SAR values shows that 14 samples are of excellent to good category, which are suitable for irrigation purposes. The US salinity classification shows that water of the study area belongs to C2-S1 (very minor concentrations), and C3-S1 (major concentrations) classes. Thus, in general, the groundwater from the study area can be used for irrigation without any hazard. In the study area, all the samples have CR values ≤ 1, which indicates that groundwater is good for irrigation. Long-term use of irrigation water affects soil permeability. According to the PI, the samples are classified as class I, class II and class III orders where, the class I and class II waters are categorized as good for irrigation and the class III waters is unsuitable for irrigation.

ACKNOWLEDGMENTS

Author thanks Sr. Geologist, GSDA, Nanded District, for their help during sample collection, software processing, and sample analyses. The first author acknowledges the partial funding of UGC SAP DRS-II sanctioned to P.G. Department of Geology, RTM Nagpur University, Nagpur.

REFERENCES

Allen, S.K., Allen, J.M. and Lucas, S. 1996. Concentration of containments in surface water samples collected in west-central impacted by acid mine drainage. Environ. Geol., 27: 34-37.

APHA 1995. Standard Methods for the Examination of Water and Wastewater. 19th Edn., Americal Health Association, Washington DC, USA.

Appelo, C.A.J. and Postama, D. 1993. Geochemistry, Groundwater and Pollution. AA Balkema Publ., Rootterdam, pp. 536.

BIS 1991. Bureau of Indian Standards IS: 10500, Manak Bhavan, New Delhi, India.

BIS 2003. Indian Standard Drinking Water Specifications. IS: 10500, Edition 2.2 (2003-2009). Bureau of Indian Standards, New Delhi.

Biswas, A.K. 1991. Water for sustainable development in the 21st century. 7th World Congress on Water Resources, Rabat Morrocco, pp. 13-18.

Canter, L.W. 1997. Nitrates in Groundwater: Lewis publisher, New Tork.

Choubey, V.D. 1991. Hydrological and environmental impact of coal mining, Jhria coal field, India. Enviorn. Geol., 17: 185-194.

Davis, S.N. and Dewiest, R.J.M. 1966. Hydrogeology. Wiley, New York.

Deshkar, S.M., Deshmukh, A.N. and Vali, S.A. 1998. Safe limit of fluoride content in drinking water in different climatic zones of India. Indian Jour. Envir. Health, 2: 17-20.

Dev Burman, G.K., Singh, B. and Khatri, P. 1995. Hydrogeochemical study of groundwater having high fluoride content in Chandrapur District of Vidharbha region, Maharashtra. Gondwana Geol. Magazine, 9: 71-80.

Domenico, P.A. and Schwartz, F.W. 1990. Physical and Chemical Hydrogeology. John Wiley & Dons, New York, pp. 824.

Doneen, L.D.C. 1964. Notes on water quality in agricuture, published as a water science and engineering paper 4001. Dept. of Water Science and Engg., Univ. of California, USA.

Dufor, C.N. and Becker, E. 1964. Public water supplies of the 100 largest cities in the U.S. U.S. Geological Survey Water Supply. Paper no.1812, pp. 364.

Freeze, R.A. and Cherry, J.A. 1974. A. 1979. Groundwater. Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 604.

GSDA 2005. Dynamic groundwater resouces of Maharashtra as on March 2004. Groundwater Surveys and Development Agency, Govt. Of Maharashtra and Central Ground Water Board, Ministry of water Resources, Government of India, pp. 332.

GSDA 2009. Dynamic groundwater resources of Maharashtra detailed report (as on 2007-08). Groundwater Surveys and Development Agency, Water Supply and Sanitation Department, Government of Maharashtra and Central Ground Water Board, Central Region, Nagpur, pp. 228.

GSDA 2011. Dynamic Groundwater Resources of Maharashtra Detailed Report. Groundwater Surveys and Development Agency, GoM & Central Ground Water Board, Central Region, Nagpur, GoI, Ministry of Water Resources, Government of India.

Gupta, B.L. 1999. Engineering Hydrology. 3rd Ed. Runoff, pp. 46-56.

Handa, 1975. Geochemistry and genesis of fluoride-containing groundwater in India. Ground Water, 13: 275-281.

Hem, J.D. 1970. Study and interpretation of the chemical characteristics of the natural water. USGS Water Supply Paper, 1459: 286.

Jackes, G., Bhattacharya, P., Chaudhary, V. and Singh, K.P. 2005. Controls on the genesis of high-fluoride groundwaters in India. Applied Geochemistry, 20: 221-228.

Jeong, C.H. 2001. Effect of landuse and urbanization on hydrochemistry and contamination of groundwater from Tajon area, Korea. J. Hydro., 253: 194-210.

Khan, R., Israili, S.H., Ahmad, H. and Mohan, A. 2005. Heavy metal pollution assessment in surface water bodies and its suitability for irrigation around the Nayevli Lignite mines and associated industrial complex, Tamil Nadu, India. Mine Water Environ., 24: 155-161.

Loizidou, M. and Kapetanions, E.G. 1993. Effect of leachate from landfills on underground water quality. Science of the Total Environment, 128: 69-81.

Marghade, D., Malpe, D.B. and Zade, A.B. 2010. Geochemical characterization of groundwater from northeastern part of Nagpur urban, Central India. Environmental Earth Science, 62(7): 1419-1430.

Meyback, 1987. Global chemical weathering of surfacial rocks estimated from river dissolved loads. Amer. J. Sci., 287: 401-428.

Murkute, Y.A. and Badhan, P.P. 2011. Fluoride contamination in groundwater from Bhadravati Tahsil, Chandrapur District, Maharashtra. Natural Environment Poll. Tech., 10(2): 255-260.

Piper, A.M. 1944. A graphical procedure in the geochemical interpretation of water analyses. Eos, Transactions American Geophysical Union, 25(6): 914-928.

Piper, A.M. 1953. A Graphic Procedure in the Geochemical Interpretation of Water Analysis. Washington D.C.: United States Geological Survey

Raja Rao, C.S. 1982. Coal resources of Tamilnadu. Andhra Pradesh, Orrisa and Maharashtra. Bull. Geol. Surv. India Ser. A, 45: 66-90.

Raman, V. 1985. Impact of corrosion in the conveyance and distribution of water. J. Int. Water Asso., 15(11): 115-121.

Ramesam, V. and Rajgopalan, K. 1985. Fluoride ingestion into the natural waters of hard-rock areas of Peninsular India. J. Geol. Soc. India. 26: 125-132.

Rawat, N.S. and Viswanathan, S. 1990. Assessment of water quality deterioration in some coal mines of northeastern coalfields and Jharia coalfields. J. Min. Met. Fuels., 132: 15-21.

Ryner, J.W. 1944. A new index for determining amount of calcium carbonate scale formed by water. J. Amer. Water Asso., 36: 472-486.

Sanchez-Perez, J.M., Trémolières, M., Grosshans, Y., Hartz, D., Hranitsky, R. and Killian, P. 1999. Role de la zone non saturée du sol dans le transfert de nitrates vers les eaux souterraines en zone alluviale inondable. Proceedings of the 24emes Journées scientifiques du Groupe Francophone Humidimétrie et Transfert en Milieux Poreux, GFHN, Paris, France.

Singh, A.K., Mahato, M.K., Neogi, B. and Singh, K.K. 2010. Quality assessment of minewater in the Raniganj coalfield area, India. Mine Water and the Environment, 29(4): 248-262.

Soni, A.K. 2007. Evaluation of hydrogeological parameters associated with limestone mining: A case study from Chandrapur India. Mine Water and the Environment, 26(2): 110-118.

Subba Rao, N. 2003. Groundwater quality: Focus on fluoride concentration in rural parts of Guntur District, Andhra Pradesh, India. Hydro. Sci. J., 48(5): 835-847.

Taranekar, P.S. 1993. Study of environmental implications of water quality with special reference to geology and mining activities in parts of Nagpur and Bhandara districts of Maharashtra. Unpublished Ph.D. Thesis, Nagpur University 175.

Tiwari, R.K. 2001. Environment impact of coal mining on water regime and its managment. Water Air Soil Pollut., 132: 185-199.

Todd, D.K. 1982. Ground Water Hydrology. Second Edition, John Wiley & Sons, pp. 535.

US Salinity Laboratory Staff 1954. Diagnosis and Improvement of Saline and Alkali Soils. U.S. Dept Agriculture, Agriculture Handbook.

WHO 1984. The Guideline for Drinking Water Quality Recommendations. World Health Organization, Geneva.

WHO 1997. The Guideline for Drinking Water Quality, Health Criteria and Other Supporting Information. World Health Organization, Geneva.

WHO 2004. Guidelines for Drinking-Water Quality: Recommendations (Vol. 1). World Health Organization, Geneva.

Wilcox, L V. 1955. The quality of water for irrigation use. U.S. Department Agriculture, Technical Bull. No. 962, pp. 40.