Asian Journal of Water, Environment and Pollution, Vol. 18, No. 2 (2021), pp. 85–89.
DOI 10.3233/AJW210022

Aquifer (Hydrogeological) Study of Southern Areas of Prayagraj, India

Brajesh K. Dwivedi
Environmental Sciences, Botany Department, University of Allahabad, Prayagraj - 211002 (India)
✉ drbkdwivedi2@gmail.com

Received December 11, 2018; revised and accepted March 25, 2021

Abstract: The physical and chemical characteristics of spring and well water samples were studied for two years to assess the origin of groundwater and determine the factors driving the geochemical composition. The ionic speciation and mineral dissolution/precipitation were calculated. Water wells, characterising groundwater circulation at shallow depths are moderate to high mineralised waters of Na-HCO_3 type. In contrast to the shallow environment, the CO_2-rich, deeper water is of the Ca-HCO_3-SO_4 type and undergoes significant changes in the baseline chemistry along flow lines with increasing residence time. The main factors controlling the groundwater composition and its seasonal variations are the geology, because of the presence of carbonate formations, the elevation and the rate of karst development. In both groups, the carbonate chemistry was a diagnostic approach. The super-saturation with respect to calcite indicates CO_2 degassing, occurring either inside the aquifer in open conduits or at the outlet in reservoirs. Interaction between groundwater and surrounding rocks is believed to be the main process responsible for the observed chemical characteristics of groundwater in the study area. Mathematical equations were also derived involving the hydro geological variables for better prediction of the aquifer.

Key words: Aquifer, hydrogeological, carst, carbonate chemistry, ground water quality.

Introduction

The demand was for a more integrated assessment of water reservoirs that could evaluate various and wide-reaching impacts of anthropogenic activities on the aquatic environment (Chovanec et al., 2000; Dwivedi and Pandey, 2003 a,b; Dwivedi and Srivastava, 2015; Pandey and Dwivedi, 2002). These activities, including wastewater discharge, changes of habitat structure and connectivity aspects, as well as altered flow regimes, are often complex and difficult to describe directly in terms of ecological repercussions of hydrological status (Dwivedi, 2017; Dwivedi, 2016; Dwivedi and Srivastava, 2017 a,b; Gazendam et al., 2016; Uduma et al., 2017).

In this connection, water stored in karst aquifers represents an important source of drinking water in many countries around the world where the importance of water quality on human health has recently attracted much attention (Gazendam et al., 2007). In the developing world, 80% of all diseases are directly related to poor drinking water and unsanitary conditions (Olajire and Imeokparia, 2001). These aquifers are also used for irrigation. For all these reasons, water resources must be managed in a sustainable way (Bakalowicz, 2005). Since the significance of karst aquifers as an important water resource and valuable ecosystems is growing worldwide, these hydrological systems are receiving rapidly increasing attention from the scientific, engineering and regulatory communities. Due to the many challenges related to their characterisation and management, such aquifers require good knowledge and comprehension of groundwater characteristic (Bonacci et al., 2009; Goldscheider and Drew, 2007). One of the advantages of bigger karst springs is sufficient amounts of water also during the time of low waters. On the other hand, these springs have large catchments and their effective protection against pollution is a great challenge. As a result, the water quality of these springs is often not good (Ravbar and Kova, 2006). The study area lies in the southern region of Prayagraj (Allahabad) district and is susceptible to various threats common in both growing urban areas and developing agricultural areas and also processes that are responsible for the groundwater quality.

Methodology

Geological and Hydrogeological Description

The study area is a part of the down slope of Vindhya Plateau near southern areas of Prayagraj at the boundary of Madhya Pradesh and precisely constitutes a part of the Sohagi mountains. The southern region of Prayagraj district consisting of 10 surrounding villages has seen a great deal of growth in the past decade, with the establishment of a new NTPC plant, industries and farms. It is situated 35 km far from Prayagraj city. It extends to about 60 km^2 and is characterised by precipitation of <1027 mm/year. Its highest recorded temperature is 48°C and the lowest is –2°C. The stratigraphic characteristics marking the study area (Figure 1) show a diversity of facies predominantly limestone and marly limestone; these formations are thick and rich in fossils and have greatly contributed to the acceleration of erosion for these host rock aquifer. The dense and thick-bedded limestone in some location of the study area has numerous joints and fractures, indicates that karst developed in the carbonate aquifer to some degree.

Sampling and Analysis

The experimental work has been carried out in two phases; firstly, the field study and secondly the laboratory work. Groundwater samples were collected for geochemical analysis at different depths from six production wells penetrating the shallow aquifer and four springs. The periodic samplings were carried out in monsoon, winter and summer seasons with three replicates in two consecutive years 2015-2016 and 2016-2017. The site of sampling is selected randomly by considering the population, location and source of pollutions. The temperature, conductivity and pH were measured in the field. Electrical conductivity and water temperature were measured using an Orion 240 pH-meter regularly calibrated using two standard buffers following the standard procedures (APHA, 2010). Major cation concentrations (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}) together with PO_4^{3-} were determined using an atomic absorption spectrophotometer. Calibrations for cation analyses were performed using appropriately diluted standards, and both laboratory and international reference materials were used as checks for accuracy. The analyses of

Figure 1: Site of the studied area (Southern areas of Prayagraj in India). S/P1- Shankargarh shallow pond, S/P2-Lohgara Pond, S/P3-Neebi Shallow pond, S/P4- Kanchanpur pond, GW1- Bara khas well, GW2-Gajapur well, GW3- Tikri well, GW4- Banna well, GW5-Rigwan Mod and GW6-Madrhawell.

bicarbonate, concentration of chloride and sulphate were determined using standard methods (APHA, 2010) with a spectrophotometer (Perkins).

Results and Discussions

Understanding the groundwater quality is important as it is the main factor determining its suitability for drinking, domestic, agricultural, and industrial purposes (Fehdi et al., 2008). The chemical composition of the water samples collected from the study area is given in Table 1.

Groundwater Chemistry

The different water samples have been classified according to their chemical composition, based on the concentration of the four major anions bicarbonate, sulphate, chloride and nitrate and on the four major cations sodium, potassium, calcium and magnesium. Using the software Diagrammes (Simler, 2004) water samples of the study aquifer system are plotted on the Scholler-Berkaloff diagram (Figure 2) to make a comparison between the different water types and to show the effect of mixing between water. Table 1 and Figure 2 show that the overall chemical character falls within (i) the moderate to slightly high mineralised waters of Na-HCO_3 type and (ii) deeper waters of the Ca-HCO_3-SO_4 type. The first water type changed continuously due to the influence of many factors: First, the water-rock interaction of the aquifer material with mainly carbonate facies and second, the influence of human activities such as irrigation returns flow and over exploitation of the aquifer system. The result is indicated by a rapid increase in sodium, sulphate and chloride concentrations in the aquifer. By following the direction of groundwater flow, the water changes its chemistry and becomes more saline, whereby the high sodium concentration is usually an indication of the cation-exchange process.

Water-rock Interaction Process

Some cases also revealed that the interactions between groundwater and surrounding rocks are mostly the main processes responsible for the observed chemical characteristics of ground waters in the study area (Rouabhia et al., 2009). Evaluation of such processes requires the description of the mean mineral assemblage of the rocks in which water is found, and the identification of the chemical reactions responsible for the geochemical evolution of ground waters (Ravbar and Kova, 2006). From available studies in the literature, such reactions generally include chemical weathering of rock-forming minerals, dissolution–precipitation of secondary carbonates and ion exchange between water and clay minerals (Fehdi et al., 2008). Two approaches, mathematical and graphical, are generally used for the resolution of hydro geochemical problems. The mathematical approach is often used for the calculation of saturation indices with respect to mineral phases, thus providing some indication upon the equilibrium state between groundwater and surrounding minerals rock assemblage.

Saturation indices express the extent of chemical equilibrium between water and mineral phases in the matrix of the aquifers and could be regarded as a measure of dissolution and/or precipitation processes relating to the water-rock interaction.

Table 1: Chemical (mg/L) of shallow pond/ground water (well) from the study area

Samples	*pH*	*TDS*	NO_3^-	HCO_3	SO_4^{2-}	Cl^-	Na^+	K^+	Mg^{2+}	Ca^{2+}	PO_4^{3-}
S/P1	7.90	507	6.20	195.60	38.24	62.90	82.20	4.70	17.14	78.76	1.60
S/P2	7.90	597	5.80	285.90	95.22	63.00	81.20	4.70	27.34	79.76	1.70
S/P3	8.00	607	6.20	295.60	95.24	65.90	70.20	5970	28.74	89.00	1.90
S/P4	7.90	598	5.20	201.60	97.24	68.90	87.20	5.70	37.34	81.70	1.70
GW1	7.50	507	3.20	185.60	85.24	83.90	90.20	7.70	45.34	111.36	1.20
GW2	7.50	607	7.20	175.60	95.24	89.90	80.20	11.60	38.34	99.33	0.90
GW3	7.40	598	5.20	195.60	101.24	79.90	69.20	8.70	23.34	142.76	2.70
GW4	7.30	609	7.20	201.60	135.24	83.90	64.20	5.70	28.34	166.66	2.70
GW5	7.43	740	6.20	295.60	235.24	134.90	75.20	6.70	38.34	234.12	3.10
GW6	7.40	607	5.20	215.60	135.24	83.90	70.20	5.70	28.34	189.76	1.70

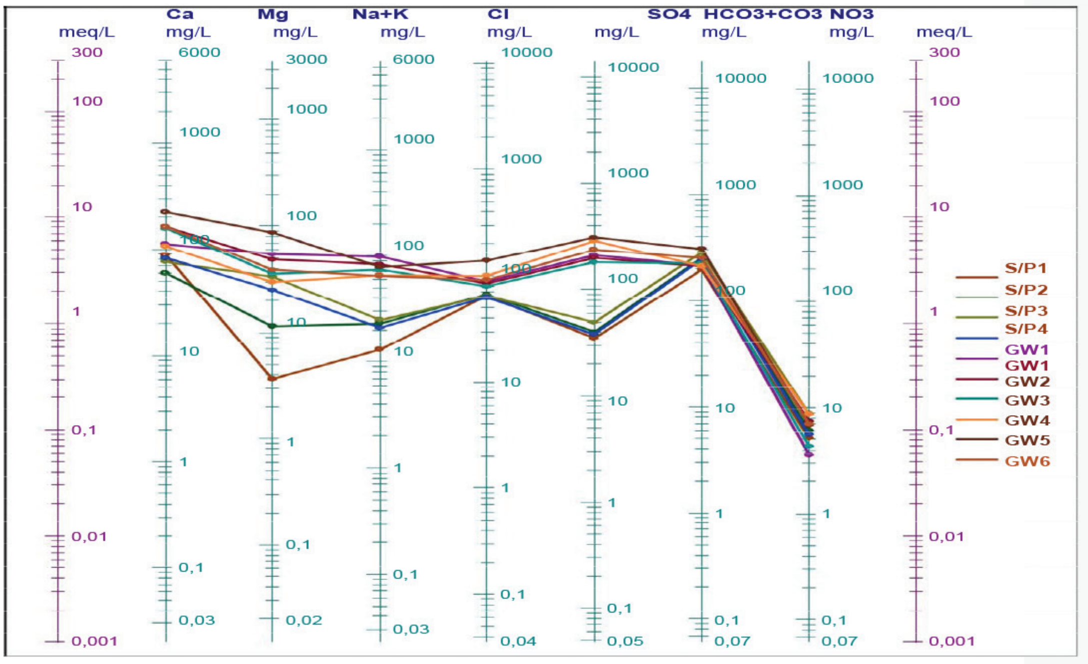

Figure 2: Scholler-Berkaloff diagram of groundwater samples in the study area.

The degree of saturation can be evaluated according to the following equation:

$SI = \log (K_{IAP}/K_{sp})$,

where K_{IAP} = The ionic activity product of the ions,

K_{sp} The solubility product of the mineral, and

SI = The saturation indices.

If SI < 0, the water is under saturated with respect to a certain mineral which means that the water is still able to dissolve that specific mineral. If SI > 0, the water is oversaturated with respect to that mineral and the mineral will precipitate. If SI = 0, water is in equilibrium.

The computer geochemical program PHREEQC-2 version 2.10 (Appelo et al., 1999) was used to calculate the ionic speciation of the waters, the ionic activities, the theoretical PCO_2 and most importantly, the saturation indices of calcite, aragonite, dolomite, gypsum and anhydrite. Table 2 depicted significant results are that all the groundwater samples were found to be saturated with respect to calcite, dolomite, and aragonite but undersaturated with respect to gypsum and anhydrite.

Table 2: Saturation indices (SI) of groundwater sample

Water ample	*SI calcite*	*SI ragonite*	*SI dolomite*	*SI gypsum*	*SI anhydrite*
S/P1	0.32	0.18	-0.85	-1.79	-2.11
S/P2	-0.21	0.09	-.0.65	-1.90	-2.12
S/P3	0.22	0.09	-0.23	-1.45	-1.98
S/P4	0.14	0.18	-0.15	-1.01	-1.12
GW1	-0.19	-0.09	-0.28	-0.98	-1.21
GW2	0.16	-0.32	-0.13	-0,85	-1.10
GW3	-0.07	-0.18	-0.98	-0.81	-1.17
GW4	-0.09	0.20	-0.78	-0.67	-1.11
GW5	0.29	-0.17	-0.04	-0.71	-0.91
GW6	-0.11	-0.29	-.098	-0.76	-1.02

Conclusion

In the present study, the sampled ponds/springs and wells in Shankargarh (Prayagraj) were characterised in terms of hydrogeological factors, hydrogeochemical compositions and the conceptual underground flow systems. Water wells, characterising groundwater circulation at shallow depths were moderate to highly mineralised waters of Na-HCO_3 type and in contrast, shallow environment, the CO_2-rich, deeper waters are of the Ca-HCO_3-SO_4 type and significantly changed in the baseline of the geochemistry of the study site. These two hydrogeological systems were defined in the study area as follows: (1) a deep water system, which is related to the extensive and deep circulation of meteoric water in the regional flow system where the influence of shallow waters is relatively small and (2) a shallow system, which is related to shallow circulation and other inferred from the observation of mineral assemblage and hydrological strata. The result would provide important insight into the local government and then make an effective policy for water management in drought prone areas of Shankargarh (Prayagraj), India.

Acknowledgement

The author is extremely grateful to the Co-ordinator, Environmental Sciences, Department of Botany, University of Allahabad, for the support and encouragement during the course of this work.

References

APHA, AWWA and WPCT (2010). Standard methods for examination of waste water, 27th edition. American health association water works association and water pollution control federation, New York.

Appelo, C., Williemsen, A. and G. Beekmanhe (1999). Calculations and observations on salt water intrusion, II. Validation of a geochemical model with laboratory experiments. *Journal of Hydrology*, **120:** 225-250.

Bakalowicz, M. (2005). Karst groundwater: A challenge for new resources. *Journal of Hydrology*, 13:148-160.

Bonacci, O., Pipan, T. and D.C. Culve (2009). A framework for karst ecohydrology. *Environmental Geology*, **56:** 891-900.

Chovanec, A., Jager, P., Jungwirth, M., Koller-Kreimel, V., Moog, O., Muhar, S. and S. Schmutz (2000). The Austrian way of assessing the ecological integrity of running waters: A contribution to the EU Water Framework Directive. *Hydrobiologia*, **422/423:** 445-452.

Dwivedi, B.K. and G.C. Pandey (2002). Physico-chemical factors and algal diversity of two ponds (Girija Kund and Maqubara pond) Faizabad. *Pollution Research*, **21(3):** 365-374.

Dwivedi, B.K. and G.C. Pandey (2003a). Complex dynamics of toxin producing algal species and primary productivity in two water ponds of Faizabad. *Environmental Biology*, **24(1):** 55-61.

Dwivedi, B.K. and G.C. Pandey (2003b). An approach to improve water quality through photosynthetic bacteria. *Nature Environment and Pollution Technology*, **2(2):** 145-152.

Dwivedi, B.K. and A.K. Srivastava (2015). Ecological-integrity of running water at Allahabad city. *Bioherald*, **5(1-2):** 63-68.

Dwivedi, B.K. (2016). Ecological integrity of river water quality: In relation to primary productivity and cyanotoxin occurrence. *International Journal of Advanced Biological Sciences*, **3(3):** 200-207.

Dwivedi, B.K. (2017). Potential risk assessment of cyanotoxin for water resources. *International Journal of Current Microbiology and Applied Sciences,* **7(2):** 3604-3616.

Dwivedi, B.K. and A.K. Srivastava (2017a). Diatoms as indicator of pollution gradients of the river Ganga, Allahabad. *International Journal of Current Microbiology and Applied Sciences*, **6(7):** 4323-4334.

Dwivedi, B.K. and A.K. Srivastava (2017b). An approach to assess potential heavy metal in the sediments transport of river Ganga channel. *International Journal of Current Research in Biosciences and Plant Biology*, **4(12):** 106-115.

Fehdi, Ch., Rouabhia, A. and F. Baali (2008). The hydrogeochemical characterization of Morsott-El Aouinet aquifer, Northeastern Algeria. *Environmental Geology*. Springer, Berlin. doi:10.1007/ s00254-008-1667-4.

Gazendam, E., Gharabaghi, B., Ackerman, J. and H. Whiteley (2016). Integrative neural networks models for stream assessment in restoration projects. *Journal of Hydrology*, **536:** 339-350.

Goldscheider, N. and D. Drew (2007). Methods in karst hydrogeology. Taylor & Francis, London, p. 264.

Olajire, A.A. and F.E. Imeokparia (2001). Water quality assessment of Osun river: Studies on inorganic nutrients. *Environment and Monitoring Assessment*, **69(1):** 17-28.

Pandey, G.C. and B.K. Dwivedi (2002). The toxins of cyanobacteria: Emerging water quality problem. *In:* Ecology of polluted water (ed. Kumar). Asish Publishing House, New Delhi. pp. 395-405.

Ravbar, N. and G. Kova (2006). Karst water management in Slovenia in the frame of vulnerability mapping. *Acta Carsologica*, **35(2):** 73-82.

Rouabhia, A., Baali, F. and Ch. Fehdi (2009). Impact of agricultural activity and lithology on groundwater quality in the Merdja area, Tebessa, Algeria. *Arabian Journal of Geosciences*. Springer, Berlin. doi:10.1007/ 12517-009-0087-4.

Uduma, U.A., McBean, E.A. and B. Gharabaghi (2017). Risk assessment of cyanobactria-toxins for small water treatment plants with lake water intakes. *International Journal of Water Research and Environment Engineering*, **9(6):** 121-126.