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Evaluation of Groundwater Quality Utilizing Integrated Physicochemical Parameters and Indexing Approaches

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Abstract

Water is a vital natural component to human existence and also is necessary for many various fields. The research location is in a region prone to water scarcity due to lack of rainfall and poor distribution. The water condition for irrigation practices is a complicated problem that depends on the interactions of numerous aspects of groundwater management considerations under the principles of sustainability. To achieve the evaluation of groundwater quality for agriculture, this study utilized irrigation water quality indices (IWQIs), which include sodium percent (Na %), sodium absorption ratio (SAR), permeability index (PI), and magnesium hazards (MH). For that, 37 groundwater samples were obtained, and conventional analytical approaches were utilized to quantify the physical and chemical features. The physical and chemical features showed that the main ions contents were recorded as sequences: ($Na^{+} > Ca^{2+} > Mg^{2+}$) and ($SO_4^{2-} > HCO_3^{-} > Cl^{-}$). The geochemical characteristics for the obtained groundwater samples showed Na-K-Cl-SO_4 and Ca-Mg-Cl-SO_4 water facies under effect of precipitation and rock-water interaction factors. The mean values of the IWQIs for Na%, SAR, PI, and MH showed, correspondingly, 63.17, 6.51, 71.94, and 47.82, respectively. Therefore, using physical and chemical properties and multi-indexing approaches to evaluate groundwater quality and its regulating processes is efficient and feasible.

Keywords: Agricultural, Groundwater, Water quality, Geochemical facies.

Introduction

The water catastrophe was brought on by population growth, increased food consumption, and inadequate water sources in many areas of the world (**Tiri et al., 2018**). Around the world, groundwater sources are used for agriculture and domestic purposes. Egypt is situated in a desert region of North Africa (**Ahmed and Ali, 2011**), where there is little groundwater available and it is primarily obtained from the Nile River. In many desiccated and deserted areas, where surface water is scarce and groundwater is frequently used for cultivation (**Li and Qian, 2018**). Since the middle of the 20th century, groundwater resources have significantly declined in quantity and quality in many deserts and semi-deserts of the world as a result of human-induced processes, manufacturing and farming expansion, expanding growing populations, poor sanitation, pollutant drainage, insufficient appropriate water quality management, seasonal rainfall patterns, and a host of other factors (**Li et al., 2017, Adimalla and Wu, 2018**). Typically, the particular characteristics of the catchment matrix multiplication such as, precipitation, dissolution, geological framework, aquifer properties, and human behaviors have a considerable impact on groundwater quality (**Yang et al., 2016; Pazand et al., 2018**). Groundwater classification for particular uses, hydrochemical data processing-based groundwater chemistry and the study of numerous chemical reactions actually establish with an understanding of the different categories of water (**Jalali, 2007; Mondal et al., 2011**). The different types and concentrations of compounds present in groundwater are greatly influenced by geological, climatic, and human influences. Groundwater's chemical composition is the product of long-term interactions with its environment (**Everest and Özcan, 2019, Sajil and James, 2019**). A variety of hydrogeochemical activities, including ion-exchange actions, precipitation, and dissolving, control the chemical constitute of groundwater in shallow floodplain basins (**Apodaca et al., 2002**). Planning, producing, delivering, and effectively managing water resources constitute every activity necessary for the administration of availability of water. In fact, as a result of a rising population, increased manufacturing activity, excessive fertilizer use in crop inputs, and extensive farming, both the quantity and quality of groundwater are deteriorating. When assessing water supplies for irrigation, the physicochemical properties of groundwater are crucial. So, irrigation water may also build up salts and other dangerous substances in the soil and change their physical and structural properties, which can have a negative impact on agricultural production and security of food (**Arslan and Akun, 2019**). The characteristics of groundwater and the factors that govern water quality are represented by its physicochemical parameters, or physical and chemical features (**Zhang et al., 2018; Mgbenu and Egbueri, 2019**). The groundwater chemistry can be utilized as a marker to distinguish between water for agriculture and other types of water (**Vasanthavigar et al., 2010**). The Irrigation water quality indices (IWQIs) have emerged as one of the most effective approaches for identifying water suitability for irrigation. The IWQIs are very effective and precise ways to evaluate the availability of water quality and provide information on general water quality. Assessing the irrigation water quality can assist the decision-maker to create quick understanding, thereby reducing the impact on cultivated land (**Mohammed, 2011**). So, the IWQIs are crucial for determining the water quality and viability for irrigation (**Subba Rao, 1997; Magesh et al., 2013**). The IWQIs are indexing methods that show the cumulative impact of several factors on the overall integrity of the water quality. The improper use of groundwater in order to satisfy the needs of different areas is exacerbated by the lack of fresh surface water. For appropriateness of water for the various objectives, the quality of groundwater is equivalently significant as its amount. The goals of this research are to determine the groundwater facies and the geochemical factors influencing on water quality using physicochemical characteristics, and assess the viability of groundwater for agriculture using IWQIs.

Materials and Methods

Study area description

The study region is situated between longitude (25^0 53′ 30″ to 26^0 06′ 38″ N) and latitude (32° 17′ 00″ to 32° 31′ 30″ E), as represented in Fig. 1. The structurally regulated Nile valley system usually serves as a representation of the research area's geomorphology. The research area's geomorphological setting can be split into four sections: the limestone plateau, drainage basins, Pediment plain, and the River valley plain, which arranged from south to north (**Said, 1981; Farrag, 1982**). The primary groundwater aquifer in the research region is

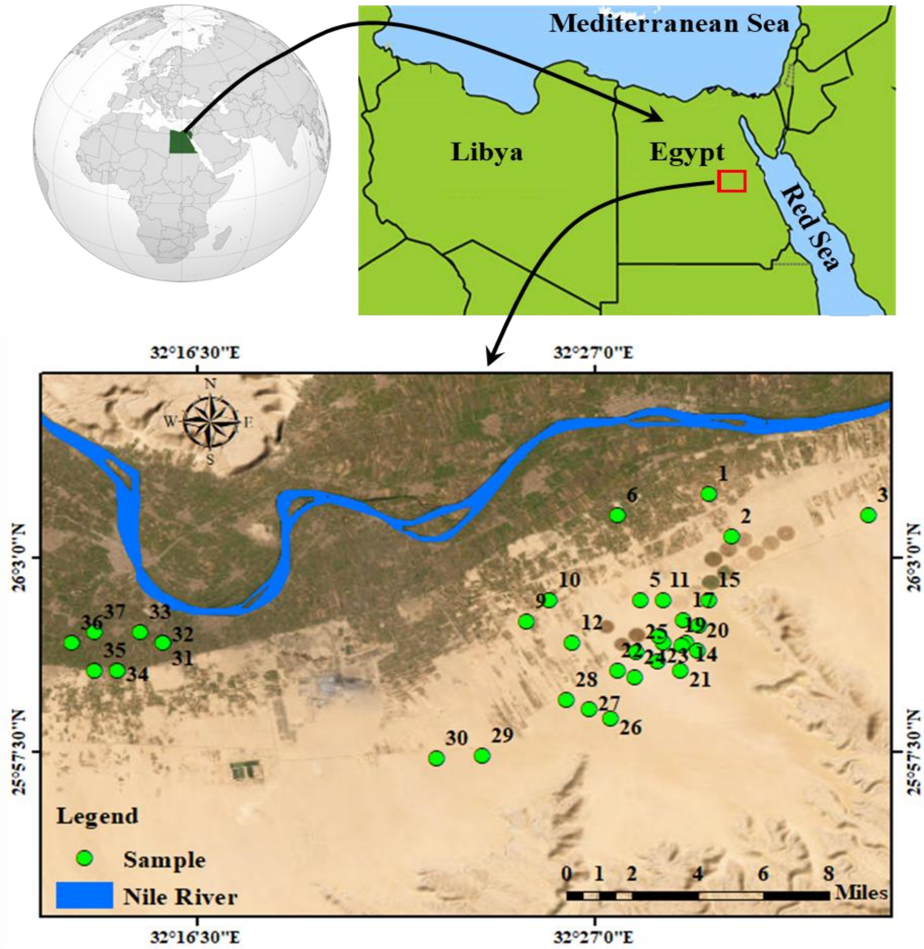

Fig. 1. Site of the studied region with collected samples.

represented through the Quaternary deposits. The alluvial sediments, which are primarily mud, silt, and sand intercalations, form up the quaternary aquifer, which is constructed from top semi-confined layer sediments, unconsolidated sediments of terrestrial origin represented in the Nile Floodplain, and adjacent wadi deposits (**Masoud, 2010**).

The depth to groundwater wells was measured using a sounder instrument based on data obtained from 37 groundwater wells, and ranged from 68 m at the River Nile border to 499 m in the south. The ground elevations values were measured using GPS device and the groundwater table was determined, which varied from 30 m to 84.9 m and the groundwater flow path map was created, which moves from south to north (Fig. 2).

Sampling and analytical techniques

A number of physical and chemical criteria have been established for assessing hydrogeochemical properties and groundwater quality. Utilizing a multi-parameter professional plus portable instrument, numerous physical and chemical variables for the groundwater samples were analyzed in-suit, including pH, EC, and TDS. Following filtering, the water samples were gathered in 500 mL polyethylene vials and kept in a 4 °C freezer. Standard analytical methods were used for the chemistry investigation (APHA, 2012). Titration methods were used to quantify the main cations and anions, including calcium (Ca^{2+}), magnesium (Mg^{2+}), chloride (Cl^{-}), bicarbonate (HCO_3^{-}) and carbonate (CO_3^{2-}). Sulfate (SO_4^{2-}) was quantified using a UV spectrophotometer, while sodium (Na^{+}) and potassium (K+) ions were identified using a flame photometer. In order to quality monitoring, ion balance evaluations

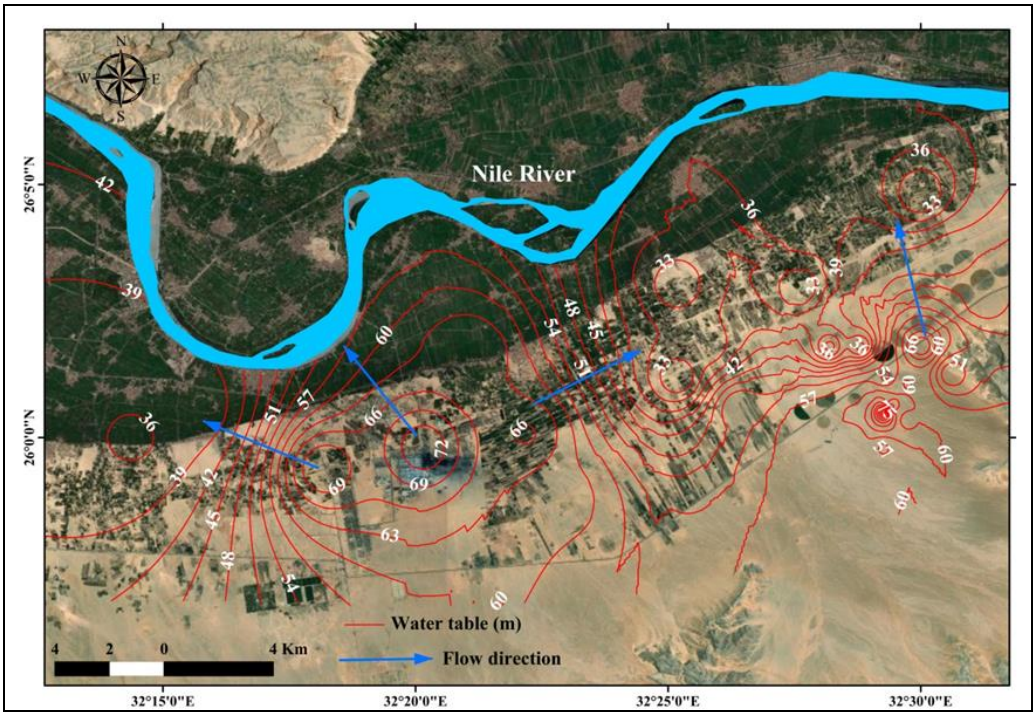

Fig. 2. The different groundwater flow paths.

were done and the ion equilibrium error, which was within (5%), was used to calculate the analytical accuracy of the ion test.

Irrigation water quality indices (IWQIs)

To assess the quality of groundwater for aquaculture, the IWQIs were employed. In this study, IWQIs can be used to identify the appropriateness of groundwater at each site using eight measured variables. The suitability of water for agricultural purposes is determined by its physical and molecular characteristics, particularly the amount of dissolved salts (**Sundaray et al., 2009; Haritash et al., 2016**). The suitability of irrigation water is typically assessed based on the existence of dangerous dissolved ions or products and, in some exceptional cases, based on the plant nutrition (**FAO, 2008**). Therefore, the availability of groundwater for irrigation was assessed in relation to the physical and chemical water characteristics using the cited IWQIs (Table 1), such as Na%, SAR, PI, and MH values (**Rajankar et al., 2010; Kumar et al., 2007**).

Table 1. The IWQIs, equations and documented references.

IWQIs	Formula	References
Na%	$[(Na^{+}+K^{+})/(Ca^{2+}+Mg^{+2}+Na^{+}+K^{+})]X100$	Todd (1980)
SAR	$[Na^{+}/\sqrt{\ } (Ca^{2+}+Mg^{2+})/2]X100$	Richards (1954)
PI	$[(Na^{+}+K^{+}+\sqrt{(}\ HCO_3^{-} + CO_3^{2-})/(\ Ca^{2+}+ Mg^{2+}+ Na^{+}+ K^{+})]X100$	Doneen (1964)
MH	$[(Mg+ \times 100) / (Ca^{2+} + Mg^{2+})]$	Paliwal (1972)

Results and discussion
Physical and chemical features

Minimum, maximum, average, and standard deviation of physical and chemical factors were computed for determining the hydrogeochemical properties of groundwater samples in the research region (Table 2).

Table 2. Description of physical and chemical features for the obtained samples expressed in mg/L.

parameter	pH	TDS	Na^+	Mg^{2+}	Ca^{2+}	K^+	HCO_3^-	SO_4^{2-}	Cl^-
Max.	8.05	2096	397.1	97	332.23	7.17	390	472.9	755.12
Min.	6.60	176.56	9.46	8	11.2	0.5	12.32	30	10.81
Avg.	7.16	1045.47	244.70	33.87	65.02	3.34	106.87	210.36	362.43
S.D.	0.47	392.71	98.86	17.85	52.91	1.71	104.23	114.20	168.58

The pH contents of the obtained samples located between 6.6 and 8.05, which reflected high alkalinity and suitability for irrigation according to Ayers and Westcot (1985). The total salinity values of water points were located from 176.56 mg/L to 2096 mg/L. According to Hem (1995), the salinity contents of the obtained water points indicated that about 38% of samples were fresh water (< 1000 mg/L), while 62% of the samples were divided as brackish water. The contents of Ca^{2+} ions in the study area ranged between 11.2 mg/L and 332.23 mg/L with an average of 65.02 mg/L. The K^+ concentrations were recorded the values between 0.5 mg/L to 7.17 mg/L, with an average of 3.34 mg/L. The Mg^{2+} values were ranged between 8 mg/L and 97 mg/L, with an average of 33.87 mg/L. The Na^+ concentrations were varied from 9.46 mg/L to 397.1 mg/L, with an average of 244.7 mg/L. The HCO_3^- content ranged between 12.32 mg/L and 390 mg/L, with an average of 106.87 mg/L. The Cl^- content ranged between 10.81 mg/L and 755.12 mg/L, with an average 362.43 mg/L. The SO_4^{2-} content in groundwater wells varied from 30 mg/L to 472.9 mg/L, with an average of 210.36 mg/L. Generally, the findings of the groundwater analysis, which conducted to identify groundwater variability for irrigation, showed slightly saline to salt water. The physical and chemical features of the obtained water samples indicated that salt tolerance plants should be avoided by considering irrigated soil properties, permeability, and soil sodicity risks, according to **Ayers and Westcot, 1994**.

Geochemical facies and controlling factors

As stated by Piper schematic (piper 1994), the groundwater samples indicated Na-K-Cl-SO_4 and Ca-Mg-Cl-SO_4 water facies (Fig. 3). Furthermore, Gibbs (1970) suggested a diagram in which the main anion-cation ratio is displayed against the value of TDS to describe the interplay between water chemical constituents and aquifer matrix. In particular, the Gibbs diagram showed that precipitation and rock-water interaction mechanisms affected on groundwater quality in the research region (Fig. 4). As a result of leaching processes, the groundwater resources in the investigated region can be used to irrigate moderate salt resistant crops and is suggested for medium to high permeability soils.

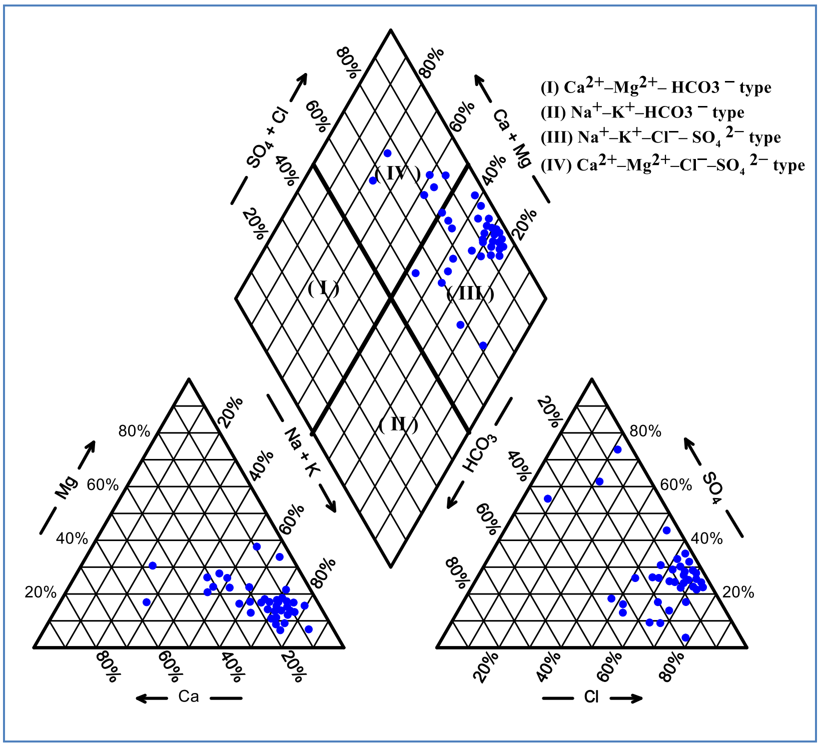

Fig.3. The Piper trilinear schematic plot indicating groundwater facies.

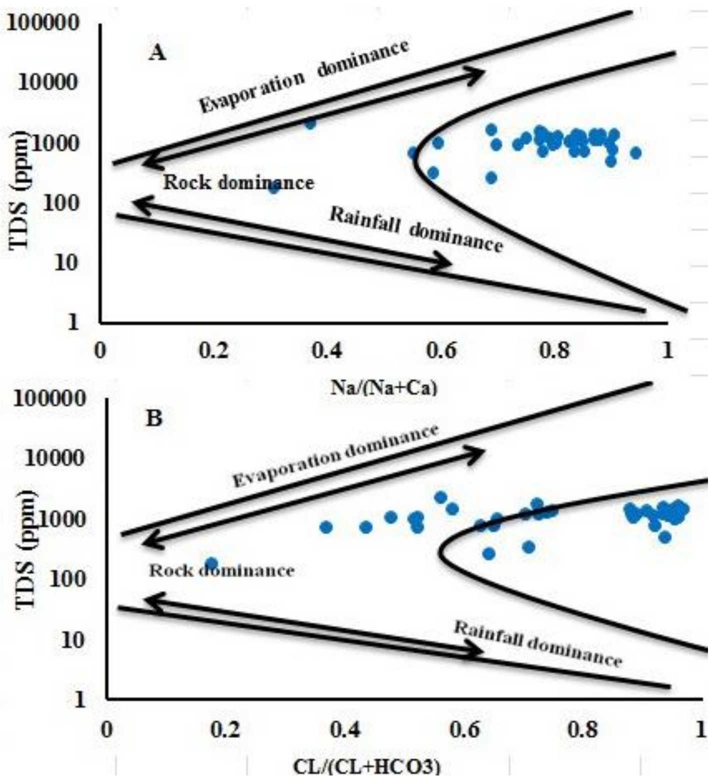

Fig.4. The Gibbs plot indicating geochemical controlling processes.

Evaluation of groundwater for irrigation

Groundwater availability for agriculture was identified using the cited IWQIs, which included the Na%, SAR, PI, and MH values in relation to the physicochemical variables, as indicated in Table 3.

The Na% is a critical measure for identifying the availability of groundwater for agricultural. Furthermore, high Na^{+} contents in comparison to Ca^{2+} and Mg^{2+} lowers soil permeability because Na^{+} ions appear to be absorbed by clay particles, substituting Ca^{2+} and Mg^{2+} ions, causing impairment and lowering soil permeability. In addition, Na % values located from 22.089 to 86.35 and only one sample was unsuitable for irrigation purposes. The Na% results revealed that about 60 % of the groundwater samples were doubtful, while 30 % were excellent, and about 10 % were good water for irrigation (**Wilcox, 1955**). Moreover, the values of SAR located from 0.43 to 14.75, with a mean value of 6.51. According to SAR classification, about 97% of the groundwater samples fall in excellent class for irrigation purposes.

In addition, the PI values located from 35.72 to 98.12 with mean value of 71.94. Approximately 75% of the water samples were good water class I, while about 25% were good water class II for irrigation. Finally, the MH is another parameter tested for assessing groundwater for irrigation. According to **Paliwal, 1967**, the MH value less than 50% reveals suitable water for agricultural, while the MH value more than 50 % reveals unsuitable water for agricultural. The MH values of the collected samples located from 25.012 to 79.57, with a mean value of 47.82. According to the MH results, around 40% of the water samples were unsuitable for irrigation, while about 60% of the water samples were acceptable for irrigation (Table 3).

Table 3. Groundwater quality categorization according to IWQIs.

IWQIs	Sample range				Range	Water category	Samples (%)
	Min.	Max.	Mean	S.D.			
Na %	22.089	86.35	63.17	14.42	< 20	Excellent	30%
					20 - 40	Good	10%
					40 - 60	Permissible	Nil
					60 - 80	Doubtful	60%
					> 80	Unsuitable	Nil
SAR	0.43	14.75	6.51	2.83	< 10	Excellent	97%
					10 - 18	Good/safe	3%
					18 - 26	Doubtful/moderate	Nil
					> 26	Unsuitable	Nil
PI	35.72	98.12	71.94	12.38	>75%	Good-Class I	75%
					25% - 75%	Good-Class II	25%
					< 25%	Unsuitable-Class III	Nil
MH	14.42	2.83	47.82	11.91	< 50%	Suitable	60%
					>50%	Unsuitable	40%

Conclusions

To assess the suitability of groundwater for agricultural associated with the processes that regulate it, physical and chemical characteristics combined with the IWQIs were utilized for the obtained groundwater samples in the study area. According to the physicochemical features of the obtained groundwater samples, the main ion concentrations have been identified in order: ($Na^+ > Ca^{2+} > Mg^{2+}$ and $SO_4^{2-} > HCO_3^- > Cl^-$). Under the impact of precipitation and rock-water interaction processes, groundwater samples showed Na-K-Cl-SO_4 and Ca-Mg-Cl-SO_4 water facies. The mean values of the IWQIs such as, Na%, SAR, PI, and MH were 63.17, 6.51, 71.94, and 47.82, respectively. According to the findings of various IWQIs, the most groundwater samples were appropriate for agricultural uses, with respect physicochemical properties. In addition, salinity tolerance crops should be avoided, and crops with intermediate to high salt sensitivity should be irrigated in loose soil with no compacted layers. As a result, combining physicochemical parameters and IWQIs is an effective and adaptable strategy that gives a clear image of groundwater quality and regulating processes.

References

Adimallah, N. and Wu, J. 2018. Groundwater quality and associated health risks in a semi-arid region of south India: Implication to sustainable groundwater management, Human and Ecological Risk Assessment 25(1):1-26 DOI: 10.1080/10807039.2018.1546550.

Ahmed, A.A., Ali, M.H. 2011. Hydrochemical evolution and variation of groundwater and its environmental impact at Sohag. Egypt Arabian Journal of Geosciences 4:339–352. doi:10.1007/s12517-009-0055-z.

APHA, 1995. Standard Methods for the Examination of Water and Wastewater. 19th ed. American Public Association, Washington, DC, USA.

Apodaca, L.E., Jeffrey, B.B., Michelle, C.S. 2002. Water quality in shallow alluvial aquifers, Upper Colorado River Basin, Colorado. J Am Water Res Assoc V. 38(1):133–143.

Arslan, B. and Akun, E. 2019. Management, contamination and quality evaluation of groundwater in North Cyprus. @Elsevier B.V. Agricultural Water Management Volume 222, 1 August 2019, Pages 1-11.

Ayers, R., Westcot, D. 1985. Water quality for agriculture. FAO Irrigation and Drainage Paper 29 Rev. 1. Food and Agriculture Organization of the United Nations, Rome.

Everest, T. and Özcan, H. 2019. Applying Multivariate Statistics for Identification of Groundwater Resources and Qualities in NW Turkey. Envrion. Monit Assess, 191, 47.

Doneen, L.D. 1964. Water quality for agriculture. Department ofIrrigation, University of California, Davis. 48.

FAO, 2008. Guide for laboratory establishment for plant nutrient analysis. FAO, Rome.

Farrag, A. A. 1982. Hydrogeological studies on the Quaternary water-bearing sediments in the area between Assiut and Aswan M Sc Thesis Geol Dept, Assiut Univ, Egypt.

Gibbs, R. J. 1970. Mechanism controlling world water chemistry. Science, 170, 1088–1090.

Haritash, A.K., Gaur, S.and Garg, S. 2016. Assessment of water quality and suitability analysis of River Ganga in Rishikesh, India. Appl Water Sci 6:383–392.

Hem, J.D. 1995. Study and interpretation of the chemical characteristics of natural water. USGS, Water Supply Paper, 264, 117-120.

Jalali, M. 2007. Salinization of ground water in arid and semiarid zones: An example from Tajarak, western Iran. Environ Geol 52:1133–1149.

Kumar, M., Kumari, K., Ramanathan, A. and Saxena, R. 2007. A comparative evaluation of groundwater suitability for irrigation and drinking purposes in two intensively cultivated districts of Punjab. India Environmental Geology 53:553–574. doi:10.1007/s00254-007-0672-3.

Li, P., Tian, R. and Xue, C. 2017. Progress, opportunities and key fields for groundwater quality research under the impacts of human activities in China with a special focus on western China. Environ Sci Pollut Res 24(15):13224–34. doi:10.1007/s11356-017-8753-7.

Li, P. and Qian, H. 2018. Water resources research to support a sustainable China. Int J Water Resour D 34(3):327–36. doi:10.1080/07900627.2018.1452723.

Magesh, N.S., Jitheshlal, K.V., Chandrasekar, N. and Jini, K. V. 2013. Geographical information system-based morphometric analysis of Bharathapuzha river basin, Kerala, India. Appl Water Sci 3, 467–477.

Masoud, A.M.A. 2010. Evaluation of hydrogeological conditions in some areas along Sohag-Aswan Desert Road using Geographic Information Systems M.Sc. Thesis, Fac. Of Science , Sohag Univ., p:231.

Mgbenu, C.N. and Egbueri, J.C. 2019. The hydrogeochemical signatures, quality indices and health risk assessment of water resources in Umunya district, southeast Nigeria. Appl Water Sci 9:22. https://doi.org/10. 1007/s1320.1-019-0900-5.

Mohammed, M.N. 2011. Quality assessment of Tigris river by using water quality index for irrigation purpose, European Journal of Scientific Research, 571: 15-28.

Mondal, N.C., Singh, V.P. and Singh, V.S. 2011. Hydrochemical characteristic of coastal aquifer from Tuticorin, Tamilnadu, India. Environ Monit Assess 175:531–550.

Paliwal, K.V. 1967. Effect of gypsum application on the quality of irrigation waters. Madras Agric. J., 59, 646-647.

Pazand, K., Khosravi, D., Ghaderi, M. R. and Rezvanianzadeh, M. R. 2018. Identification of the hydrogeochemical processes and assessment of groundwater in a semi-arid region using major ion chemistry: A case study of Ardestan basin in Central Iran. Groundwater for Sustainable Development, 6, 245–254.

Piper, A.M. 1944. A graphic procedure in the geochemical interpretation of water-analyses. EOS Trans Am Geophys Union 25(6):914–928. https://doi.org/10.1029/TR025i006p00914.

Rajankar, P.N., Tambekar, D.H. and Wate, S.R. 2010. Groundwater quality and water quality index at Bhandara District. Environ Monit Assess 179: 619–625. doi:10.1007/s10661-010-1767-y.

Richards, L.A. 1954. Diagnosis and Improvement of Saline and Alkali Soils; U.S. Department of Agriculture, Washington, D.C., USA.

Said, R. 1981. The geological evolution of the River Nile. Springer-Verlag, New York Inc, U.S.A, p. 151.

Sajil Kumar, P.J. and James, E.J. 2019. Geostatistical and Geochemical Model-Assisted Hydrogeochemical Pattern Recognition along the Groundwater Flow Paths in Coimbatore District, South India. Envrion. Dev. Sustain., 21, 369–384.

Subba Rao, N. 1997. Studies on water quality index in hard rock terrain of Guntur district, Andhra Pradesh, India. National Seminar on Hydrology of Precambrian Terrains and hard rock areas. pp. 129–134.

Sundaray, S.K., Nayak, B.B. and Bhatta, D. 2009. Environmental studies on river water quality with reference to suitability for agricultural purposes: Mahanadi river estuarine system, India—a case study. Environ Monit Assess 155:227–243.

Tiri, A., Belkhiri, L. and Mouni, L. 2018. Evaluation of surface water quality for drinking purposes using fuzzy inference system. Groundwater for Sustainable Development, 6, 235–244.

Todd, D.K. 1980. Groundwater hydrology, 2nd edn. Wiley, New York, p 535.

Vasanthavigar, M, Srinivasamoorthy, K., Vijayaragavan, K., Rajiv, Ganthi, R., Chidambaram, S., Anandhan, P., Manivannan, R. and Vasudevan, S. 2010. Application of water quality index for groundwater quality assessment: Thirumanimuttar sub-basin, Tamilnadu, India. Environ Monit Assess 171:595–609.

Wilcox, L.V. 1955. The quality of water for irrigation use. US Department of Agriculture, Washington, DC, Technical Bulletin, p. 19.

Yang, Q., Li, Z., Ma, H., Wang, L. and Martin, J. D. 2016. Identification of the hydrogeochemical processes and assessment of groundwater quality using classic integrated geochemical methods in the Southeastern part of Ordos's basin, China. Environmental Pollution. https://doi.org/10 1016/j.envpol.2016.08.017.

Zhang, X., Hu, B.X., Wang, P., Chen, J., Yang, L. and Xiao, K. 2018. Hydrogeochemical evolution and heavy metal contamination in groundwater of a reclaimed land on Zhoushan Island. Water 10(3): 316–338. https://doi.org/10.3390/w10030316.