www.czasopisma.pan.pl PAN www.journals.pan.pl

JOURNAL OF WATER AND LAND DEVELOPMENT

e-ISSN 2083-4535

Polish Academy of Sciences (PAN) Institute of Technology and Life Sciences – National Research Institute (ITP – PIB)

JOURNAL OF WATER AND LAND DEVELOPMENT
DOI: 10.24425/jwld.2022.140789
2022, No. 53 (IV–VI): 138–142

Assessment of groundwater quality and their vulnerability to pollution using GQI and DRASTIC indices

Siti Mardiana[1)] ✉, Rabeya Anzum[2)], Ngakan Ketut Acwin Dwijendra[3)], Ahmad Azhar Mansoor Al Sarraf[4)], Anton Timoshin[5)], Elena Sergushina[6)], Iskandar Muda[7)], Natalia Zhilnikova[8)], Yasser Fakri Mustafa[9)], Evgeny Tikhomirov[10)]

[1)] Universitas Medan Area, Faculty of Agriculture, Medan, 20223, North Sumatera, Indonesia

[2)] International Islamic University, Department of Electrical and Computer Engineering, Kuala Lumpur, Malaysia

[3)] Udayana University, Faculty of Engineering, Bali, Indonesia

[4)] Sawah University, College of Health and Medical Technology, Department of Medical Laboratory, Ministry of Higher Education and Scientific Research, Al-Muthanna, Samawa, Iraq

[5)] I.M. Sechenov First Moscow State Medical University (Sechenov University), Department of Propaedeutics of Dental Diseases, Russia

[6)] National Research Ogarev Mordovia State University, Republic of Mordovia, Saransk, Russia

[7)] Universitas Sumatera Utara, Faculty Economic and Business, Department of Doctoral Program, Medan, Indonesia

[8)] Saint Petersburg State University of Aerospace Instrumentation (SUAI), Institute of Fundamental Training and Technological Innovations, Russia

[9)] University of Mosul, College of Pharmacy, Department of Pharmaceutical Chemistry, Iraq

[10)] Bauman Moscow State Technical University, Department of Economics and Management, Russia

RECEIVED 10.09.2021 ACCEPTED 06.12.2021 AVAILABLE ONLINE 29.06.2022

Abstract: Surface and groundwater resources are two important sources in meeting agricultural, urban, and industrial needs. Random supply of surface water resources has prevented these resources from being a reliable source of water supply at all times. Therefore, groundwater acts as insurance in case of water shortage, and maintaining the quality of these resources is very important. On the other hand, studying vulnerability and identifying areas prone to aquifer pollution seems necessary for the development and optimal management of these valuable resources. Identifying the vulnerabilities of the aquifer areas to pollution will lead to a greater focus on preserving those areas. Therefore, groundwater quality assessment was performed in this study using the groundwater quality index (*GQI*), and groundwater vulnerability to pollution was assessed using the DRASTIC index. *GQI* is developed based on the values of six quality parameters (Na^+, Mg^{2+}, Ca^{2+}, SO_4^{2-}, Cl^-, and *TDS*). The DRASTIC index is developed based on the values of seven parameters (depth to the water table, net recharge, aquifer media, soil media, topography, impact of vadose zone, hydraulic conductivity). The zoning of both indexes has been done using geographic information system (GIS) software. The results show that the *GQI* of the region was about 93, and its DRASTIC index was about 86. Therefore, the quality of aquifer groundwater is excellent, and its vulnerability to pollution is low.

Keywords: DRASTIC index, groundwater quality, groundwater quality index (*GQI*), groundwater vulnerability

INTRODUCTION

Excessive population growth, climate change, and limited water resources have led to over-exploitation of aquifers and irreparable damage [Afshar *et al.* 2021]. In addition to severe water levels in aquifers, natural pollution sources and human pollution pose a serious threat to groundwater [Chatterjee *et al.* 2018; Naderi, Raeisi 2018].

Natural pollution sources are resources that exist without human intervention in nature and cause groundwater pollution [Li *et al.* 2021; Shafiee 2018]. The most famous of these resources can be saltwater, arsenic, and carbonates mentioned [Bandara *et al.* 2018; Dehbandi *et al.* 2019]. The infiltration of seawater into coastal aquifers and the contamination of their freshwater is an example of saline pollution. The discovery of arsenic in the groundwater supply system is an important issue in public health.

Sources of human pollution are resources that are directly or indirectly related to humans and their activities. These sources can be divided into urban, industrial, and agricultural pollution sources [Eshtawi *et al.* 2016; Xu *et al.* 2021]. Accumulation of waste at ground level, wastewater treatment plants, urban surface runoff, and cemeteries are among the sources of urban pollution [Margot *et al.* 2015].

Given the importance of groundwater, assessing the quality of these resources is one of the most important factors that should be considered when assessing the proper development of an area [Kivits *et al.* 2018]. Groundwater quality should be defined based on the physical and chemical variables associated with water use [Asif 2018; Ezenwaji, Ezenweani 2019; Shea *et al.* 2019]. Although the concept of groundwater quality seems clear, how to study and evaluate it requires some tricks. The chemical composition of groundwater includes a measure of its suitability as a water source for human and animal use, irrigation, and industrial purposes.

According to various existing standards, acceptable and unacceptable values are defined for each variable that if the water exceeds this standard, it must be treated before use. Many researchers have proposed measuring groundwater quality index (*GQI*). *GQI* is one of the valid indicators for identifying groundwater quality [Jha *et al.* 2020; Nzama *et al.* 2021; Rahmany, Patmal 2021; Ren, Khayatnezhad 2021]. This index makes the combination of water data with different available qualities understandable and provides a way to summarise the general conditions of groundwater quality. In fact, the *GQI* combines various water quality parameters (Na^+, Mg^{2+}, Ca^{2+}, SO_4^{2-}, Cl^-, and *TDS*) to provide the final index value that can be used for spatial comparisons. In addition to the quality of groundwater resources, identifying and analysing the vulnerability of groundwater aquifers to identify areas that are most exposed to pollutants has become an important element for the sound management of water resources and land use planning. In this regard, the DRASTIC index is one of the most widely used indices, which is obtained from the weight composition of seven important sub-indices [Arya *et al.* 2020; Moges Dinka 2021]. The acronym DRASTIC represents seven parameters used in the model, i.e., *D* (depth to water), *R* (net recharge), *A* (aquifer media), *S* (soil media), *T* (topography), *I* (impact of the vadose zone media), and *C* (hydraulic conductivity of the aquifer).

Therefore, this study investigates groundwater quality assessment with *GQI* and groundwater vulnerability assessment with DRASTIC index. Here, geographic information system (GIS) capabilities are used to zoning the *GQI*. Also, using the capabilities of this software, the direction of groundwater flow has been used to determine the direction of pollution.

MATERIALS AND METHODS

GROUNDWATER QUALITY INDEX (*GQI*)

The overall assessment of groundwater quality is based on a comparison of the concentrations of the main ions with the WHO standard using the *GQI* quality index. To calculate this index at any point of the aquifer, Equations (1)–(3) should be used.

$$C_{\text{new}}(i) = \frac{C_i - C_{i(\text{WHO})}}{C_i + C_{i(\text{WHO})}} \quad (1)$$

$$R_i = 0.5C^2_{\text{new}}(i) + 4.5C_{\text{new}}(i) + 5 \quad (2)$$

$$GQI = 100 - \left[\frac{W_i R_i}{6}\right] \quad (3)$$

where: i = qualitative parameter index (Na^+, Mg^{2+}, Ca^{2+}, SO_4^{2-}, Cl^-, and *TDS*), $C_{i(\text{WHO})}$ = maximum allowable concentration provided by the World Health Organization (WHO) for the qualitative parameter i, C_i = parametric concentration of i, $C_{\text{new}}(i)$ = normalised concentration of qualitative parameter i (value between –1 and 1), R_i = quality parameter rating (value between 0 and 10), and W_i = the relative weight of the i-th parameter is equal to the average rank of each of the ranked parameters.

The maximum allowable concentration provided by the World Health Organization for Na^+, Mg^{2+}, Ca^{2+}, SO_4^{2-}, Cl^-, and *TDS* are 200, 300, 300, 250, 250, and 1000 mg·dm^{-3}, respectively [Khodabakhshi *et al.* 2015]. In order to evaluate the groundwater quality of the study area, the value of the index in the eight existing wells should be calculated, and the average of the calculated indices should be presented as the index of the whole region. Then, the groundwater status of the region should be determined (water quality: excellent: 91 < *GQI* < 100, good: 71 < *GQI* < 90, medium: 51 < *GQI* < 70, bad: 26 < *GQI* < 50, very bad: 0 < *GQI* < 25).

GROUNDWATER QUALITY INDEX ZONING IN GIS

In this project, the direction of groundwater flow was obtained using software Geographic Information System (GIS).

DRASTIC INDEX

DRASTIC index is one of the important indicators to assess the vulnerable areas of the aquifer against pollution (very high: DRASTIC > 200, high: 161 < DRASTIC < 200, medium: 121 < DRASTIC < 160, low: 61 < DRASTIC < 120, very low: 1 < DRASTIC < 60). The value of this index can be calculated using Equation (4):

$$\text{DRASTIC index} = D_w D_r + R_w R_r + A_w A_r + S_w S_r + T_w T_r + I_w I_r + C_w C_r \quad (4)$$

where: D = depth to the water table, R = net recharge, A = aquifer media, S = soil media, T = topography, I = impact of vadose zone, C = hydraulic conductivity, r = a numerical rank between 1 and 10, which belongs to each criterion's subdivisions, w = the weight of each drastic criterion (between 1 and 5 depending on its effect on pollution). The information required to calculate this index for well number 1 is shown in Table 1.

Table 1 Parameters determining the DRASTIC index along with their amount, rank, and weight in well No. 1

Parameter	Status or amount	Rank	Weight
Depth to the water table	40 m	1	5
Net recharge	30.2 mm	1	4
Aquifer media	compacted sandstone	7	3
Soil media	clay room	3	2
Topography	slope equal to 4%	9	1
Impact of vadose zone	clay with low sand	4	5
Hydraulic conductivity	15.93 m per day	4	3

Source: own elaboration.

GROUNDWATER FLOW DIRECTION IN GIS

The direction of groundwater flow indicates the direction of pollution transfer. Therefore, it is important to know about it. In this project, the direction of groundwater flow has been obtained using software GIS.

RESULTS AND DISCUSSION

CALCULATION OF GROUNDWATER QUALITY INDEX AND DRASTIC INDEX

In order to measure the groundwater quality index, first the values of quality parameters in the control points should be measured. Table 2 shows the concentration of qualitative parameters in each of the wells in the study area.

Using Equations (1) and (2), normalised concentration (C_{new}) and quality parameter rating (R) values were obtained for all quality parameters in all wells (Tabs. 3, 4). By placing the values presented in Table 4 in Equation (3), the *GQI* value for all wells is presented in the last column of Table 4. Due to the fact that the *GQI* in all wells is between 90 and 100, so the quality of groundwater in this aquifer in eight wells is appropriate. However, as can be seen in Table 4, the value of the *GQI* has the highest value in well No. 2 and the lowest value in well No. 5. This means that the groundwater quality in well No. 2 is higher than all wells. Also, the groundwater quality in well No. 5 is lower than all wells. According to Equation (2), the larger R_i is the higher concentration of the qualitative parameter. On the other hand, according to Equation (3), the larger R_i is the smaller value of the *GQI*. In the case of well No. 5, the values of R_{Mg}, R_{Ca}, R_{Cl} and R_{TDS} are higher than all wells. This means that the presence of high amounts of Mg, Ca, Cl and *TDS* in well No. 5 compared to other wells has reduced the quality of groundwater in this well. Therefore, it is recommended that most of the

Table 2. Concentration of qualitative parameters of wells in the study area

Well number	Na^+	Mg^{2+}	Ca^{2+}	SO_4^{2-}	Cl^-	*TDS*
	mg·dm^{-3}					
1	68.16	23.2	84.0	38.4	194.07	622.67
2	13.57	23.4	48.0	40.8	37.28	305.00
3	32.28	21.6	66.67	72.0	37.87	491.33
4	12.96	25.6	50.67	54.4	26.03	324.67
5	54.97	41.6	96.67	67.2	195.25	698.67
6	46.08	21.2	66.0	84.8	61.53	470.00
7	34.12	20.8	59.33	78.4	59.17	402.33
8	27.60	31.2	58.0	62.4	85.20	447.00

Explanation: *TDS* = total dissolved soilds. Source: own study.

Table 3. Normalised values of quality parameters of wells in the study area (mg·dm^{-3})

Well number	$C_{\text{Na new}}$	$C_{\text{Mg new}}$	$C_{\text{Ca new}}$	$C_{\text{SO4 new}}$	$C_{\text{Cl new}}$	$C_{TDS\ \text{new}}$
1	−0.492	−0.856	−0.563	−0.734	−0.126	−0.233
2	−0.873	−0.855	−0.724	−0.719	−0.740	−0.533
3	−0.722	−0.866	−0.636	−0.553	−0.737	−0.341
4	−0.878	−0.843	−0.711	−0.643	−0.811	−0.510
5	−0.569	−0.756	−0.513	−0.576	−0.123	−0.177
6	−0.625	−0.868	−0.639	−0.493	−0.605	−0.361
7	−0.709	−0.870	−0.670	−0.523	−0.617	−0.426
8	−0.757	−0.812	−0.676	−0.601	−0.492	−0.382

Explanation as in Tab. 2. Source: own study.

Table 4. Rated values of quality parameters and groundwater quality index (*GQI*) of wells in the study area

Well number	R_{Na}	R_{Mg}	R_{Ca}	R_{SO4}	R_{Cl}	R_{TDS}	*GQI*
1	2.908	1.513	2.627	1.967	4.441	3.981	92.45
2	1.453	1.517	2.004	2.021	1.942	2.745	95.03
3	2.011	1.479	2.339	2.665	1.955	3.523	94.00
4	1.433	1.563	2.053	2.315	1.678	2.836	94.96
5	2.602	1.882	2.825	2.573	4.454	4.217	91.99
6	2.381	1.471	2.327	2.901	2.461	3.443	93.60
7	2.063	1.462	2.210	2.785	2.413	3.173	93.98
8	1.878	1.677	2.187	2.478	2.908	3.353	93.79

Explanation as in Tab. 2. Source: own study.

protection be in the areas around well No. 5. Artificial recharging of well No. 5 with higher quality water can increase the value of the index around this well [Valhondo *et al.* 2020]. In the case of well No. 2, the low concentration of Ca and *TDS* parameters has increased the groundwater quality in this well.

The *GQI* of the study area is obtained by averaging the index in eight control wells. The value of the regional index is equal to 93.72. Obviously, the quality of groundwater in the study area is also good.

By performing the descriptions mentioned in section "Groundwater quality index (*GQI*)" using GIS software, the *GQI* zoning in the aquifer range was obtained as Figure 1. According to Figure 1, the central part of the study area has better groundwater quality. It seems, this is because there is less groundwater abstraction in this area.

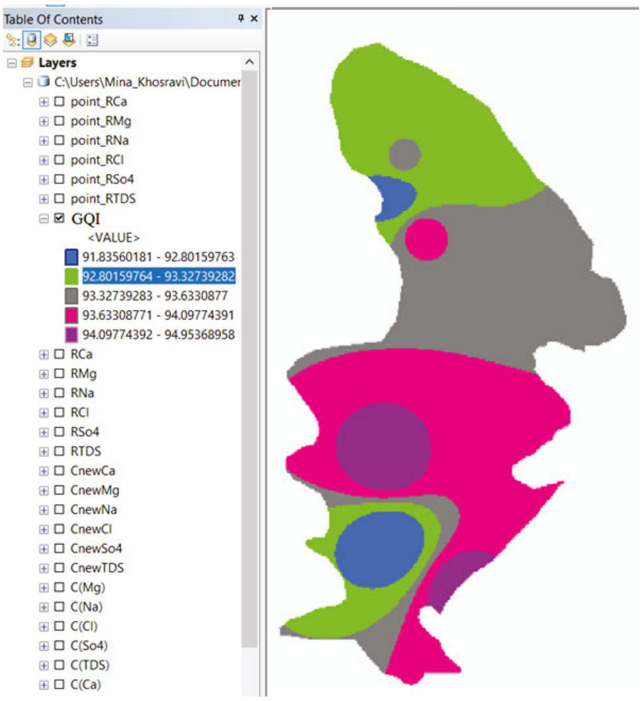

Fig. 1. Groundwater quality index (*GQI*) zoning in GIS software; source: own study

The DRASTIC index values for wells No. 1–8 were calculated as 77, 101, 79, 68, 74, 98, 91, and 101, respectively. The arithmetic mean of these values is considered as the DRASTIC index of the study area. Therefore, the DRASTIC index for the study area is 86.125. According to DRASTIC index classification, the study aquifer is in the low vulnerability category. In addition, the DRASTIC index value for well No. 8 is higher than other wells. Therefore, the protection of the areas around this well is of greater importance.

OBTAINING THE DIRECTION OF GROUNDWATER FLOW IN GIS

Groundwater always flows more from the hydraulic head to the less hydraulic head. Therefore, if a part of the aquifer is contaminated, information about the flow direction helps a lot in the contamination process [Asadi *et al.* 2007; Nas, Berktay 2010]. In this regard, using GIS software, knowing that the flow lines perpendicular to the lines are potential, the direction of groundwater movement in the aquifer was obtained [Jha *et al.* 2020]. Figure 2 shows the direction of flow in the northern part of the aquifer. According to Figure 2, the direction of groundwater flow is mainly from north to south. Therefore, preventing the contamination of northern wells and also applying management strategies in case of contamination can help maintain the quality of groundwater in the region.

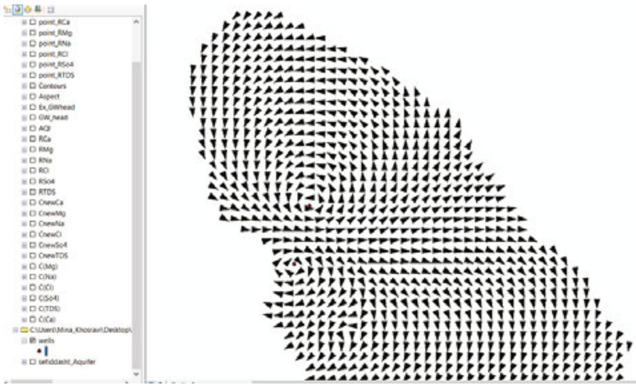

Fig. 2. The direction of groundwater flow in the study aquifer; source: own study

CONCLUSIONS

According to the contents and calculations mentioned in this study, the groundwater quality index (*GQI*) of the region was about 93, and its DRASTIC index was about 86. Therefore, the quality of groundwater in the aquifer is excellent for studies, and its vulnerability to pollution is low. Therefore, the aquifer is generally in good condition. This means that the quality of groundwater is desirable for its use, and groundwater is not contaminated with foreign elements. On the other hand, if an area of the aquifer is contaminated, the potential for groundwater contamination is low. Of course, it is necessary to mention that in order to accurately assess the vulnerability of the aquifer, it is necessary to obtain the DRASTIC index zoning in the aquifer. If an area of the aquifer was more vulnerable to contaminants, by detecting the direction of flow, it is possible to identify potential points of contamination and apply its management strategies. The results showed that the direction of groundwater flow is from north to south. Therefore, it is recommended that the northern region be more vigilant than the southern region in order to prevent the southern parts from being infected as soon as possible if the northern parts become infected. In addition, well No. 8 has the highest vulnerability compared to other existing wells. Therefore, preventing contamination of the areas around this well should be a priority.

REFERENCES

Afshar A., Khosravi M., Molajou A. 2021. Assessing adaptability of cyclic and non-cyclic approach to conjunctive use of groundwater and surface water for sustainable management plans under climate change. Water Resources Management. No. 35(11) p. 3463–3479. DOI 10.1007/s11269-021-02887-3.

Arya S., Subramani T., Vennila G., Roy P.D. 2020. Groundwater vulnerability to pollution in the semi-arid Vattamalaikarai River

Basin of south India thorough DRASTIC index evaluation. Geochemistry. Vol. 80(4), 125635. DOI 10.1016/j.chemer.2020.125635.

Asadi S.S., Vuppala P., Reddy M.A. 2007. Remote sensing and GIS techniques for evaluation of groundwater quality in municipal corporation of Hyderabad (Zone-V), India. International Journal of Environmental Research and Public Health. Vol. 4(1) p. 45–52. DOI 10.3390/ijerph2007010008.

Asif M.A. 2018. A theoretical study of the size effect of carbon nanotubes on the removal of water chemical contaminants. Journal of Research in Science, Engineering and Technology. Vol. 6(04) p. 21–27. DOI 10.24200/jrset.vol6iss04pp21-27.

Bandara U.G.C., Diyabalanage S., Hanke C., van Geldern R., Barth J. A., Chandrajith R. 2018. Arsenic-rich shallow groundwater in sandy aquifer systems buffered by rising carbonate waters: a geochemical case study from Mannar Island, Sri Lanka. Science of the Total Environment. Vol. 633 p. 1352–1359. DOI 10.1016/j.scitotenv.2018.03.226.

Chatterjee R., Jain A.K., Chandra S., Tomar V., Parchure P.K., Ahmed S. 2018. Mapping and management of aquifers suffering from over-exploitation of groundwater resources in Baswa-Bandikui watershed, Rajasthan, India. Environmental Earth Sciences. Vol. 77(5), 157. DOI 10.1007/s12665-018-7257-1.

Dehbandi R., Abbasnejad A., Karimi Z., Herath I., Bundschuh J. 2019. Hydrogeochemical controls on arsenic mobility in an arid inland basin, Southeast of Iran: The role of alkaline conditions and salt water intrusion. Environmental Pollution. Vol. 249 p. 910–922. DOI 10.1016/j.envpol.2019.03.082.

Eshtawi T., Evers M., Tischbein B. 2016. Quantifying the impact of urban area expansion on groundwater recharge and surface runoff. Hydrological Sciences Journal. Vol. 61(5) p. 826–843. DOI 10.1080/02626667.2014.1000916.

Ezenwaji E.E., Ezenweani I.D. 2019. Spatial analysis of groundwater quality in Warri Urban, Nigeria. Sustainable Water Resources Management. Vol. 5(2) p. 873–882. DOI 10.1007/s40899-018-0264-2.

Jha M.K., Shekhar A., Jenifer M.A. 2020. Assessing groundwater quality for drinking water supply using hybrid fuzzy-GIS-based water quality index. Water Research. Vol. 179, 115867. DOI 10.1016/j.watres.2020.115867.

Khodabakhshi N., Asadollahfardi G., Heidarzadeh N. 2015. Application of a GIS-based DRASTIC model and groundwater quality index method for evaluation of groundwater vulnerability: a case study, Sefid-Dasht. Water Science and Technology: Water Supply. Vol. 15(4) p. 784–792. DOI 10.2166/ws.2015.032.

Kivits T., Broers H.P., Beeltje H., van Vliet M., Griffioen J. 2018. Presence and fate of veterinary antibiotics in age-dated groundwater in areas with intensive livestock farming. Environmental Pollution. Vol. 241 p. 988–998. DOI 10.1016/j.envpol.2018.05.085.

Li A., Mu X., Zhao X., Xu J., Khayatnezhad M., Lalehzari R. 2021. Developing the non-dimensional framework for water distribution formulation to evaluate sprinkler irrigation. Irrigation and Drainage. DOI 10.1002/ird.2568.

Margot J., Rossi L., Barry D.A., Holliger C. 2015. A review of the fate of micropollutants in wastewater treatment plants. Wiley Interdisciplinary Reviews: Water. Vol. 2(5) p. 457–487. DOI 10.1002/wat2.1090.

Moges S.S., Dinka M.O. 2021. Assessment of groundwater vulnerability using the DRASTIC model: A case study of Quaternary catchment A21C, Limpopo River Basin, South Africa. Journal of Water and Land Development. DOI 10.24425/jwld.2021.137094.

Naderi M., Raeisi E. 2018. Management strategies of a critical aquifer under the climate change in Jahrum of South-Central Iran. Sustainable Water Resources Management. Vol. 4(4) p. 1077–1090. DOI 10.1007/s40899-018-0245-5.

Nas B., Berktay A. 2010. Groundwater quality mapping in urban groundwater using GIS. Environmental Monitoring and Assessment. Vol. 160(1) p. 215–227. DOI 10.1007/s10661-008-0689-4.

Norouzi H., Moghaddam A.A. 2020. Groundwater quality assessment using random forest method based on groundwater quality indices (case study: Miandoab plain aquifer, NW of Iran). Arabian Journal of Geosciences. Vol. 13(18), 912. DOI 10.1007/s12517-020-05904-8.

Nzama S.M., Kanyerere T.O.B., Mapoma H.W.T. 2021. Using groundwater quality index and concentration duration curves for classification and protection of groundwater resources: relevance of groundwater quality of reserve determination, South Africa. Sustainable Water Resources Management. Vol. 7(3), 31. DOI 10.1007/s40899-021-00503-1.

Rahmany N.A., Patmal M.H. 2021. Impact of solar heating technology installation on reduction of greenhouse gas emissions in Kabul city. International Journal of Innovative Research and Scientific Studies. Vol. 4(2) p. 53–61. DOI 10.53894/ijirss.v4i2.56.

Ren J., Khayatnezhad M. 2021. Evaluating the stormwater management model to improve urban water allocation system in drought conditions. Water Supply. Vol. 21(4) p. 1514–1524. DOI 10.2166/ws.2021.027.

Shafiee S.A. 2018. Investigating the study of green chemistry and its achievements in protecting the environment and preventing pollution. Journal of Research in Science, Engineering and Technology. Vol. 6(01) p. 36–40. DOI 10.24200/jrset.vol6iss01pp36-40.

Shea A., Violin C.R., Wallace C., Forster B.M. 2019. Teaching water quality analysis using a constructed wetlands microcosm in a non-science majors environmental science laboratory. Pedagogical Research. Vol. 4(4), em0046. DOI 10.29333/pr/5945.

Valhondo C., Martínez-Landa L., Carrera J., Díaz-Cruz S.M., Amalfitano S., Levantesi C. 2020. Six artificial recharge pilot replicates to gain insight into water quality enhancement processes. Chemosphere. Vol. 240, 124826. DOI 10.1016/j.chemosphere.2019.124826.

Xu Y.-P., Ouyang P., Xing S.-M., Qi L.-Y., Khayatnezhad M., Jafari, H. (2021). Optimal structure design of a PV/FC HRES using amended Water Strider Algorithm. Energy Reports. Vol. 7 p. 2057–2067. DOI 10.1016/j.egyr.2021.04.016.