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Evaluation of shallow groundwater suitability for irrigation purposes: A case study from Doornfontein area, South Africa

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Abstract: The present study aims at evaluating the quality of shallow groundwater (SGW) and its suitability for irrigation purpose in the most urbanised part of Johannesburg city, South Africa. The SGW samples were collected in three consecutive years and analysed for 20 selected physicochemical parameters, and heavy metals. The results were compared with the South African water quality, and Food and Agricultural Organization irrigation water quality guidelines, and standard indices derived from laboratory outputs. The results of the study show that all physiochemical parameters and heavy metals were within the limits set by both guidelines for irrigation purposes, except for potassium (3.58 mg·dm^{-3}) and manganese levels (3.152 mg·dm^{-3}). The calculated irrigation parameter values of sodium adsorption ratio (*SAR*), sodium percentage (Na%), residual sodium carbonate (*RSC*), magnesium hazard (*MH*), Kelly's ratio (*KR*) and permeability index (*PI*) were within the permissible range of irrigation water quality standards. The findings of this study provide helpful information for decision-makers such as utilisation of the studied groundwater for irrigation uses.

Keywords: irrigation, Johannesburg, physico-chemical parameters, shallow groundwater, water quality

INTRODUCTION

Groundwater is important resource for water supply for domestic, agricultural, and industrial activities, and ecosystem services in many arid and semi-arid regions including South Africa. Since it is less susceptible to drought, higher quality due to its natural purification process, less susceptible to surface contaminants, less vulnerable to seasonal and perennial variations, it is more reliable than surface waters (Paul *et al.*, 2019). However, in recent years, the characteristics of this vital resources have been influenced by both natural and anthropogenic factors. The various natural determining factors include weathering of rocks and weathering regime, geology, rock-water interaction, quantity and quality of recharge water (Sethy *et al.*, 2016; Mora *et al.*, 2017). Also climatic conditions, available groundwater volume in the host rock, the residence time and its circulation rate of the groundwater, and the aquifer chemistry determine the characteristics of the groundwater (Dinka, 2020). Most importantly, groundwater at shallow depth is facing increasing threats due to above-ground anthropogenic actions linked to population growth, unrestrained urbanisation, industrialisation, uncontrolled waste disposal, and poor land use management (Appelo and Postma, 2005; Malaza, 2017). In most urban areas, such as Johannesburg, groundwater at shallow depth faces extra pressure because urban areas host many industries and high population, resulting in the release of large volumes of wastes that deteriorates groundwater quality (Naicker, Cukrowska and McCarthy, 2003; Abiye, Mengistu and Demlie, 2011; Abiye *et al.*, 2015). Hence, evaluation of groundwater quality for irrigation purpose is important and necessary for present and future groundwater quality management.

A water intended for irrigation purposes must be a good quality to maintain the health of both plants as well as the soil to be irrigated. Suitable irrigation water can result in maximum yield if the proper management of water and soil are practiced. However, the application of unsuitable water for irrigation leads to yield reduction and deteriorate the soil physical properties (Ayers and Westcot, 1985). Moreover, high Ca and Mg contents can result in the blockage of drip emitters due to their scaling effects, and poor quality water also leads to the high bacterial counts and nutrients that promote algal growth (Shatanawi and

Fayyad, 1996). The main influencing factors of irrigation water are: the total salts content, % of Na to other main cations (Ca, Mg, and K), concentration of B or other toxic elements to plants (Ketata *et al.*, 2012). Irrigation water with high salinity causes salinization of soils and a reduction in plant yield and also affects the infiltration rate of the soil (Şahin Kiy and Arslan, 2021).

The water supply for irrigation should be tested periodically to determine its quality by considering important irrigation water quality parameters in relevance to the yield and quality of crops, the productivity of the soil and protection of the natural environment (Al-Tabbal and Al-Zboon, 2012). These parameters applied in the evaluation of irrigation water consist of chemical and certain physical characteristics of water and include electrical conductivity (*EC*), total dissolved solids (*TDS*), sodium adsorption ratio (*SAR*), sodium percentage (*SP*), residual sodium carbonate (*RSC*), magnesium adsorption ratio (*MAR*), permeability index (*PI*), and Kelley's ratio (*KR*) (Ayers and Westcot, 1985; Al-Tabbal and Al-Zboon, 2012; Bouderbala, 2017; Ghalib, 2017).

Water intended for irrigation neither cause yield reduction nor deteriorate the soil physical properties (Ayers and Westcot, 1985). It is, therefore, important to evaluate the shallow groundwater composition, quality and the suitability for various purposes. These can be achieved through comparing analysis results of various parameters with the available standards/guidelines (both national and international) and the integration of different indices derived from measured water quality parameters.

In this study area, there have been no other studies conducted to assess the suitability of groundwater for irrigation uses except the scanty unpublished report (Holland, 2013). The aim of this study was thus to evaluate the shallow groundwater quality of Doornfontein area based on physicochemical and trace elements. The specific objective is to assess the groundwater suitability for irrigation purposes by using different standard indices and diagrams.

MATERIALS AND METHODS

STUDY AREA

The study area is located at the coordinates of S26°11'43.89", E28° 03'21.15" under the basements of Perskor building, the city of Johannesburg, South Africa (Fig. 1). The multiyear average precipitation of the study area is about 690 mm per annum, mostly concentrated in the summer months. The summer rainfall in the area is significant in its contribution to groundwater recharge (Abiye, Mengistu and Demlie, 2011). The dry season corresponds to the lowest average temperatures, where July has the lowest recorded temperature values. The summer rainfall period corresponds to a warmer temperature, where February has the hottest temperatures. Hydrologically, DFC campus is located at the upstream side of the A21C quaternary catchment about 1725 m a.s.l. and near to the regional surface water divide line located at about 650 m south of DFC. The natural topography of the study area is characterised by moderate sloping elevation gradually decreasing from south to north. The Doornfontein campus is mostly underlain by basaltic lava, agglomerate, and tuff from Klipriversberg subgroup and quartzites, conglomerates, and shales of the West Rand group. The rocks of quartzites, shale, minor/subordinate conglomerates of Government Subgroup in the south and Hospital Hill Subgroup in the north, which both forms of part of the West Rand Supergroup are also available around the study area. According to the Johannesburg hydrogeological map of 1:500,000 scales (Barnard, 1999), and explanatory note (Barnard, 2000). Groundwater in the area surrounding the Doornfontein Campus is associated with class B (fractured) and intergranular and fractured low yielding shallow aquifer and considered as minor aquifers with yields of between 0.5 and 2 $dm^3 \cdot s^{-1}$ (DWS, 2016).

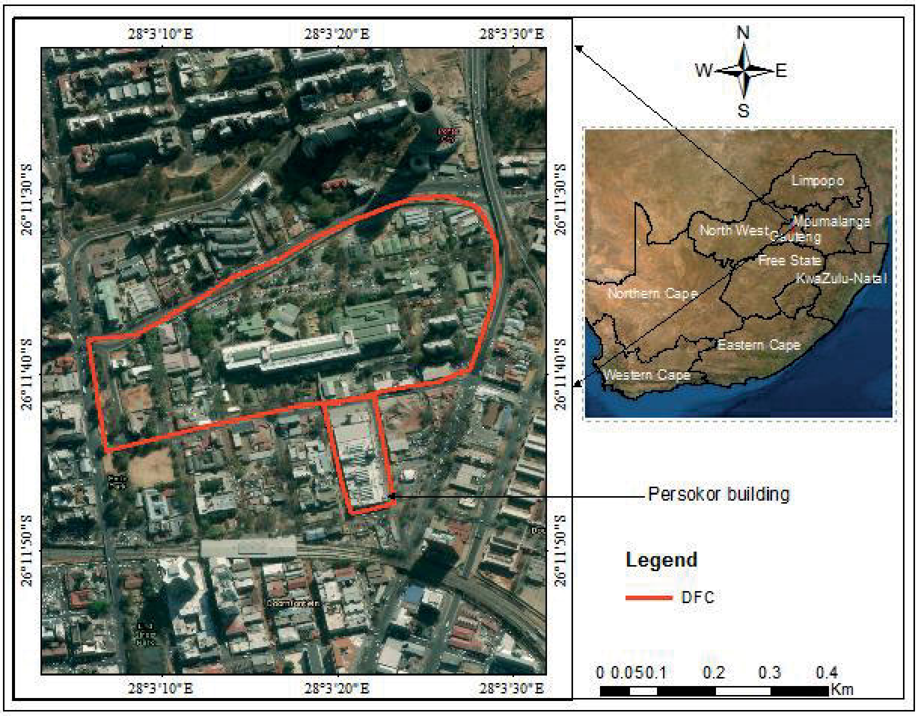

Fig. 1. Location of the study area; source: own elaboration based on Google Earth

SAMPLE COLLECTION AND ANALYSIS

A total of 16 SGW samples were collected from the basements of Persokor building for three consecutive years (2018, 2019 and 2020). The sampling locations are shown in Table 1. The samples were collected from lower and upper basement pumping wells after an automatic pumping system was immediately stopped. All samples were collected in acid-washed 0.5 dm^3 clean HDPE (high-density polyethylene) bottles after two to three times of rinsing with the same water and preserved airtight to avoid evaporation. The sampling bottles were immediately labelled with permanent ink, recorded in the datasheet and loaded into an ice bucket container for the delivery. New hand gloves were used to avoid cross-contamination during sampling. Physical parameters such as temperature, electrical conductivity (*EC*), total dissolved solids (*TDS*) and pH were measured onsite using calibrated HI 98129COMBO pH/*EC*/*TDS*/°C Tester with standard solutions whereas the analysis for water samples haven conducted at the SANS accredited Water Lab Pvt limited Pretoria for the following parameters: pH, *EC*, *TDS*, major ions (HCO_3^-, CO_3^-, Cl^-, SO_4^{2-}, F^-, NO_3–N, Na^+, K^+, Ca^{2+}, Mg^{2+}), and heavy metals (Al, Fe, Mn, Se, Zn, As, Hg) were analysed in the lab.

In order to confirm the reliability of the chemical analysis, the charge balance between the sum of cations and sum of anions was estimated by (Eq. 1) using Microsoft Excel and the software package AQUACHEM. The calculated charge ratio of total cations and anions of groundwater samples were below the acceptable limit of ±10% (Adimalla and Wu, 2019):

$$I.B. = \frac{\sum \text{cations} - \sum \text{anions}}{\sum \text{cations} + \sum \text{anions}} 100 \tag{1}$$

where: *I.B.* = ionic balance (%), the sum of major cations and anions is expressed as $meq \cdot dm^{-3}$.

The sampling locations are shown in Table 1.

Table 1. Sampling locations of the study site

Sample code	Latitiude	Longitude	Elevation (m a.s.l.)	Location
003	−26.196259	28.055996	1714.71	lower basement, pump eye N7
005	−26.195937	28.05611	1715.01	lower basement, pump eye N9
006	−26.195895	28.055855	1714.60	lower basement, pump eye N6
009	−26.195502	28.055714	1720.43	upper basment, pump eye 1

Source: own elaboration.

ASSESSMENT FOR IRRIGATION PURPOSE

The SGW suitability for irrigation purposes was evaluated using three methods.

- **Suitability based on individual parameters**

The already established standard limits of the Food for Agricultural Organization (FAO) guidelines for irrigation water quality (Ayers and Westcot, 1985) and South African SAWQ guidelines for agriculture: Irrigation (DWAF, 1996) were used to compare the analysed physicochemical and trace elements for the suitability assessment. The comparison was made to establish whether the pollution level of SGW was above the locally and internationally accepted standards in addition to making reliable conclusions.

- **Suitability based on standard derived indices**

The SGW suitability for irrigation purposes was evaluated based on standard agricultural indices commonly considered for protection of soil, plants and the environment. The sodium adsorption ratio (*SAR*), sodium percentage (Na%), residual sodium carbonate (*RSC*), magnesium hazard (*MH*), Kelly's ratio (*KR*), and permeability index (*PI*) were calculated by using the standard equations described in Table 2. The indices calculation considers the concentrations of major ions: Na^+, Mg^{2+}, Ca^{2+}, K^+, HCO_3^- and CO_3^{2-} ions.

- **Suitability based on graphical diagrams**

The graphical diagrams of Richard (1954) and Wilcox (1955) were also applied for the classification of SGW samples for quality assessment.

RESULTS AND DISCUSSION

IRRIGATION WATER SUITABILITY BASED ON INDIVIDUAL PARAMETERS

The results of the mean concentrations of considered parameters are compared with irrigation water quality guideline values of FAO (Ayers and Westcot, 1985) and presented in Table 3.

Physical parameters

- **pH**

The acceptable pH levels of water for irrigation uses ranges from 6.5–8.4 (Ayers and Westcot, 1985). Irrigation water with lower pH values (pH < 6) will be corrosive to pipes and equipment which subsequently results in the reduction of pipe strength, service life, and leakage of hazardous materials such as mercury, arsenic, and cadmium that may cause health problems (Fendekova *et al.*, 2010). Also, higher pH (pH > 8.2), may indicate the presence of excess Na, Ca, Mg, HCO_3^- and CO_3^{2-} concentrations as HCO_3^- and CO_3^2 are hydroxyl generating ions. The pH values in this study fall within the acceptable ranges recommended by Ayers and Westcot (1985) and DWAF (1996).

- **Electrical conductivity (*EC*)**

Irrigation water with high salinity affects the accessibility of water to plants. Application of salty water causes changes in the structure of the soil, its permeability and its aeration, affecting directly the growth of plants (Boubguira *et al.*, 2021). Furthermore, excess salt in irrigation water increases osmotic pressure of water to plants which subsequently decreases plant's root water absorption, which results in a physiological drought condition (Bhat *et al.*, 2018). According to Wilcox (1955) in Table 3 the *EC* levels in this study range from 328–670 $\mu S \cdot cm^{-1}$, with a mean of 539.17 $\mu S \cdot cm^{-1}$ and fall in medium suitability range for irrigation use.

Major cations

Sodium ion is the first major ion in the cation chemistry of the groundwater samples. The observed concentration of Na^+ fluctuates between 27 to 57 $mg \cdot dm^{-3}$, with a mean value of

Table 2. Equations for calculating agricultural indices, ranges and classification of irrigation water

Parameter	Equation	Range	Classification	Reference
Electrical conductivity (*EC*) (μS·cm^{-1})	–	<250	excellent	Wilcox (1955)
		250–750	good	
		750–2250	permissible	
		2250–5000	doubtful	
		>5000	unsuitable	
TDS (mg·dm^{-3})	–	0–1000	freshwater	Freeze and Cherry (1979)
Total hardness (*TH*) (mg·dm^{-3})	–	0–75	soft	Sawyer McCarty and Parkin (2003)
		75–150	moderately hard	
		150–300		
Sodium absorption ratio (meq·dm^{-3})	$SAR = \frac{\mathrm{Na}}{\sqrt{\frac{\mathrm{Ca+Mg}}{2}}}$	<10	excellent	Richard (1954)
		10–18	good	
		18–26	doubtful	
		>26	unsafe	
Residual sodium carbonate (meq·dm^{-3})	$RSC = \left(\mathrm{HCO}^{-} + \mathrm{CO}^{2-}\right) - \left(\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+}\right)$	<1.25	safe	Eaton (1950)
		1.25–2.50	marginally suitable	
		>2.50	unsuitable	
Soluble sodium percentage (meq·dm^{-3})	$SSP = \frac{(\mathrm{Na} + \mathrm{K})}{\mathrm{Ca} + \mathrm{Mg} + \mathrm{Na} + \mathrm{K}} 100$	<20	excellent	Wilcox (1955)
		20–40	good	
		40–60	permissible	
		60–80	doubtful	
		>80	unsafe	
Magnesium adsorption ratio (meq·dm^{-3})	$MAR = \frac{\mathrm{Mg}^{2+}}{\mathrm{Ca}^{2+}+\mathrm{Mg}^{2+}} 100$	<50	suitable	Szabolcs and Darab (1964)
		>50	unsuitable	
Kelley's ratio (meq·dm^{-3})	$KR = \frac{\mathrm{Na}^{+}}{\mathrm{Ca}^{2+}+\mathrm{Mg}^{2+}}$	<1	suitable	Kelley (1963)
		>1	unsuitable	
Permeability index (%)	$PI = \frac{\mathrm{Na}+\sqrt{\mathrm{HCO_3}}}{\mathrm{Ca} + \mathrm{Mg} + \mathrm{Na}} 100$	>75	good	Doneen (1964)
		25–75	suitable	
		<25	not suitable	

Source: own elaboration.

Table 3. Comparative results of analysed parameters for irrigation purpose

Parameter	Minimum	Maximum	Mean	Standard deviation	FAO guideline1)	SA guideline2)
pH	6.60	8.20	7.50	0.42	6.5–8.4	6.5–8.4
EC	328	670	538.75	123.21	0–2250	≤400
TDS	160	449	327.20	95.85	0–2000	≤40
Mg^{2+}	8	26	17.38	5.21	0–61	
Ca^{2+}	15	44	30.19	9.99	0–400	
Na^{+}	27	57	37	7.79	0–920	≤70
K^{+}	1.6	5	3.44	1.13	0–2	
$\mathrm{SO_4}^{2-}$	<2	92	46.20	30.66	0–960	
$\mathrm{HCO_3}^{-}$	48.72	263	153.26	84.87	0–610	

cont. Tab. 3

Parameter	Minimum	Maximum	Mean	Standard deviation	FAO guideline[1)]	SA guideline[2)]
Cl^-	32	77	51.88	15.50	0–1065	≤100
NO_3^-N	0.2	16	7.68	5.99	0–10	≤5
Al	BDL	0.217	–	–	**5**	≤5
Fe	0.027	11.47	2.194	4.03	**5.0**	≤5.0
Mn	0.210	4.88	3.125	1.69	**0.20**	≤0.02
Se	0.001	0.005	0.003	0.002	**0.02**	≤0.02
Zn	0.028	0.956	0.169	0.283	**2**	≤1.0
As	0.001	0.002	0.001	0.001	0.10	≤ 0.1
Hg	0.001	0.003	0.002	0.001	–	–

[1)] Ayers and Westcot (1985) – usable ranges.
[2)] DWAF (1996) – target water quality range.
Explanations: parameters are expressed in mg dm^{-3}, except *EC* (in μS·cm^{-1}) and pH; BDL = below detection limit; bolded values = recommended maximum concentration.
Source: own study.

37 mg·dm^{-3}. The observed Ca^{2+} content in shallow groundwater samples varies from 15 to 44 mg·dm^{-3}, with an average value of 30.19 mg·dm^{-3}. The concentrations of Mg^{2+}, on the other hand, ranged from 8 to 26 mg·dm^{-3} with a mean of 17.38 mg·dm^{-3}. The observed concentrations of Na^+, Ca^{2+}, and Mg^{2+} ions remain within the maximum permissible limits of both guideline values for irrigation water quality (Ayers and Westcot, 1985; DWAF, 1996). However, the mean concentrations of K^+ (3.58 mg·dm^{-3}) exceeded the threshold value of 2 mg·dm^{-3} (Ayers and Westcot, 1985). High concentration of potassium ion found in the water could have been induced by leachates and from sewage leakages. A major concern of high potassium concentrations in irrigation water is its deleterious effects on soil hydraulic properties, which has harmful effects on infiltration, water availability and plant growth (Oster, Sposito and Smith, 2016).

Major anions

Among the anions, HCO_3^- is the major anion in this study, and its content varies from 49.72 to 263 mg·dm^{-3} with a mean value of 155.26 mg·dm^{-3}. On the other hand, the analysed concentration of carbonates (CO_3^{2-}) in this study was below the laboratory detection limit. The measured HCO_3^- value is well below the recommended maximum permissible value of 500 mg·dm^{-3} (Ayers and Westcot, 1985). The chloride ion (Cl^-) is the second major anion in shallow groundwater samples in this study, and its content fluctuated between 32 and 77 mg·dm^{-3}, with a mean value of 51.88 mg·dm^{-3}. SO_4^{2-} is the third major anion in this assessment with concentrations varying from 2 to 92 mg·dm^{-3}, with a mean value of 46.2 mg·dm^{-3}. The observed content of NO_3^-N in shallow groundwater ranged from 0.2 to 16 mg·dm^{-3} with a mean value of 7.68 mg·dm^{-3}. All considered major anions were well below the recommended maximum permissible values set by Ayers and Westcot (1985) and DWAF (1996) for irrigation purposes.

Trace elements

Trace elements are essential for growth of plants; however, when present at higher concentrations in irrigation water, it cause damage to both plants and the soil (Jeong, Kim and Jang, 2016). Some of the analysed trace elements in this study are depicted in Table 3. From Table 3, aluminium (Al) content varied from below instruments detection ability to 0.217 mg·dm^{-3}. This value falls below the maximum permissible value of 5 mg·dm^{-3} (Ayers and Westcot, 1985). Irrigation water with higher concentration of Al can cause non-productivity in acid soils (pH < 5.5) (Ayers and Westcot, 1985). The iron (Fe) concentration in the studied water ranged from 0.027 to 11.14 mg·dm^{-3} with a mean value of 2.194 mg·dm^{-3}. The recorded average Fe concentration is below maximum recommended concentration of Fe in water used for irrigation, 5.0 mg·dm^{-3} (Ayers and Westcot, 1985; DWAF, 1996). The manganese (Mn) concentration ranged from 0.21 to 4.88 mg·dm^{-3}, with an average value of 3.152 mg·dm^{-3}. The recorded concentration values in all sampling rounds were found above the maximum permissible values of 0.2 mg·dm^{-3} recommended by FAO (Ayers and Westcot, 1985), and DWAF (1996). Irrigation water containing elevated concentration of Mn can be toxic to several crops especially for soils that have acidic and poor drainage properties (Jeong, Kim and Jang, 2016). Also, the use of irrigation water with high Mn levels can cause formation of dark scale in water pipes as well as blackish staining in plumbing fixtures and clogging issues in irrigation systems (mostly in emitters). The higher observed concentrations in the study area may be attributed to the dissolution of manganese bearing rocks, industrial effluents and sewage leakages around the sampling sites. The concentration of selenium (Se) varies between 0.001 and 0.005 mg·dm^{-3} with a mean value of 0.003 mg·dm^{-3}. These results fall below the maximum concentration limits of 0.02 mg·dm^{-3} (Ayers and Westcot, 1985; DWAF, 1996). Selenium is toxic to plants at concentrations as low as 0.025 mg·dm^{-3} and toxic to livestock if forage is grown in soils with relatively high levels of added Se (Ayers and Westcot, 1985).

The concentrations of Zn ranged from 0.028 to 0.956 mg·dm^{-3} (mean 0.169 mg·dm^{-3}), whereas arsenic (As) concentration varies from 0.001 to 0.002 mg·dm^{-3} (average 0.0014 mg·dm^{-3}). The recorded values of both Zn and As fall below the maximum permissible concentrations of 2.0 and 0.1 mg·dm^{-3} respectively (Ayers and Westcot, 1985). The both last-mentioned elements have side effects of stem chlorosis and root growth suppression (Jeong, Kim and Jang, 2016). Both FAO and DWAF did not set guideline values of Hg specified for water to be used for irrigation purpose. However, the recorded Hg concentration were slightly lower than the recommend maximum concentrations (0.002 mg·dm^{-3}) set in Israel and Greece, but higher than the guideline values (0.001 mg·dm^{-3}) set by Korea and Italy (Jeong, Kim and Jang, 2016).

IRRIGATION WATER QUALITY BASED ON DERIVED INDICES

In addition to individual parameter-based assessment, the suitability of groundwater for irrigation purpose is assessed based on indices derived from the analysed parameters. The calculated indices of *SAR*, Na%, *RSC*, *MH*, *KR* and *PI* are presented in Table 4.

Table 4. Summary of the calculated irrigation water quality indices

Index	Number of samples	Min.	Max.	Mean	*SD*
SAR	16	0.98	2.08	1.36	0.26
Na%	16	27.33	47.66	37.65	6.86
RCS	16	–2.32	1.43	–0.50	1.27
MH	16	42.27	55.27	48.85	3.38
KR	16	0.36	0.87	0.59	0.17
PI	16	53.87	84.76	69.51	11.39

Source: own study.

Sodium adsorption ratio (*SAR*)

Excess concentrations of Na^+ in irrigation water can be a problem for both the soil and the crop to be irrigated. When groundwater containing higher Na^+, concentration is used continuously for irrigation purpose, it affects the soil physical properties, particularly making the soil hard and compact when dry, as a result, the soil become impervious for water infiltration. The excess of Na is counterbalanced by Ca^{2+} and Mg^{2+} when present in the soil in sufficient quantities; otherwise, good management practices may be required to maintain the soils with high *SAR* (Salifu *et al.*, 2017). According to Richard (1954) classification systems, the SGW samples of this study are classified as excellent water as the *SAR* value of all sample which ranged between 0.98 to 2.08 meq·dm^{-3}, with a mean value of 1.36 meq·dm^{-3} are less than 10 meq·dm^{-3}. The SGW of the study area is, therefore, suitable for irrigation.

Residual sodium carbonate (*RSC*)

The *RSC* is a parameter used as an indicator of the bicarbonate and carbonate hazards in irrigation water. It is the difference between the weak acids (HCO_3^- and CO_3^{2-}) and those of alkaline earth (Ca and Mg). *RSC* normally influences the *EC*, pH, and *SAR* of the irrigation water. The regular use of water with high *RSC* will lead to burning of plant leaves and reduces the yield of crops. When the concentrations of weak acids are higher than alkaline earth in the soil, they tend to cause Ca^{2+} and Mg^{2+} precipitation due to more concentration of water in the soil. Subsequently, the general extent of Na^+ in the water is expanded as $NaHCO_3$, which destroys the permeability of soil (Salifu *et al.*, 2017). The calculated *RSC* ranged from –2.32 to 1.43, with mean values of –0.50. Since the mean *RSC* values fall below 1.25, there are no carbonate and bicarbonate hazards of the water samples. Thus, groundwater is suitable for irrigation.

Sodium percentage (%Na) and magnesium hazard (*MH*)

Sodium percentage is a vital parameter normally used to evaluate the fitness of groundwater for irrigation uses. Irrigation water with a higher concentration of Na^+ in relation to Ca^{2+} and Mg^{2+} reduce soil permeability as Na^+ ions tend to get absorbed by clay particles, displacing Mg^{2+} and Ca^{2+} ions through the base exchange process, thus causing deflocculation and impairment of the tilth and permeability of soils (Adimalla and Wu, 2019). This exchange process affects the physical soil properties such as breakage of soil structure, and reduces the soil permeability and aeration, making the soil difficult for plant growth. The %Na in water in this study area was estimated in the range of 27.33 to 47.66% (mean 37.65%). According to Wilcox (1955) classifications, the estimated %Na fall under good (between 20 and 40%) and permissible water (between 40 and 60%) for irrigation purpose and hence suitable for agricultural use.

The *MH* introduced by Szabolcs and Darab (1964) is an important parameter, which helps to indicate possible hazardous effects of magnesium during the irrigation water quality assessment. Magnesium ion is an important nutrient for growth of plants and its shortage causes yellowing and reduction in growth and yield of crops. The both previously mentioned ions maintain a state of equilibrium in most waters (Mondal *et al.*, 2016; Salifu *et al.*, 2017). However, elevated concentrations of Mg^{2+} can be triggered by exchangeable Na^+ in irrigated soils and thus may hurt the crop yield as the soil becomes more alkaline. Moreover, excess Mg^{2+} concentrations in irrigation water can be toxic to plants due to reduced availability of K^+ in soils (Adimalla and Wu, 2019). The *MH* values of this study ranged from 42.27 to 55.27, with an average value of 48.85%. The *MH* values of the studied groundwater samples except for one sample fall below 50%, indicating suitability of groundwater for irrigation.

Kelly's ratio (*KR*) and permeability index (*PI*)

Kelly's ratio, irrigation water quality index introduced by Kelley (1963). is an essential variable which aids to assess irrigation water suitability depending on the relative concentrations of Na^+ versus Ca^{2+} and Mg^{2+} in the water. The calculated *KR* values vary from 0.36 to 0.87 (mean 0.59). These *KR* values were all below one, indicating that less concentration Na relative to Ca and Mg. The results suggest that the studied groundwater is suitable water for irrigation purpose.

Permeability index is also a vital index for classifying irrigation water based on the concentrations of the Ca^{2+}, Mg^{2+}, Na^+ and HCO_3^- (Doneen, 1964). Higher or lower *PI* will have side effects in agricultural activities. High *PI* coupled with subsurface features would favour widespread contamination of groundwater whereas lower *PI* restricts movement of water and nutrient required for plant growth. In this study, the *PI* range from 53.87 to 84.76%, mean 69.51% (Tab. 4, Fig. 2). The calculated *PI* values are classified as type I (>75%) and II (25–75%) – Figure 2, which shows that the water is suitable for irrigation uses.

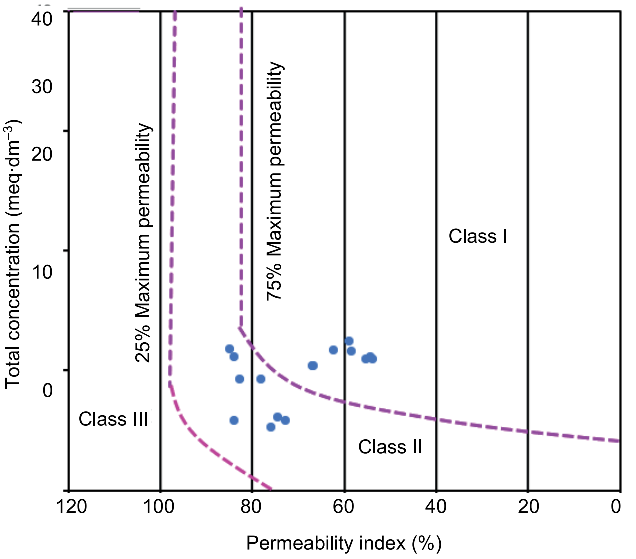

Fig. 2. Classification of irrigation water based on the permeability index; source: own study

CLASSIFICATION BASED ON STANDARD DIAGRAMS

Richard's diagram

A plot of *SAR* values as alkalinity hazard and electrical conductivity (*EC*) values as salinity hazard on Richard (1954) diagram (Fig. 3) can also be used to classify irrigation water. This diagram classifies salinity hazard (*EC*) and Na hazard (*SAR*) into different classes as follows; low (C1-S1), medium (C2-S2), high (C3-S3), very high (C4-S4) high salinity and Na hazard, respectively. Water with *SAR* and *EC* values within C1-S1 and C2-S2 levels are suitable for irrigation, whereas, those under C3-S3, and C4-S4 require treatment prior to being used for irrigation (Gevera *et al.*, 2020). According to this classification, the SGW samples fall under medium salinity-low sodium content section (C2-S1) – Figure 3. Thus, the groundwater of the study can be used for irrigating all types of soils.

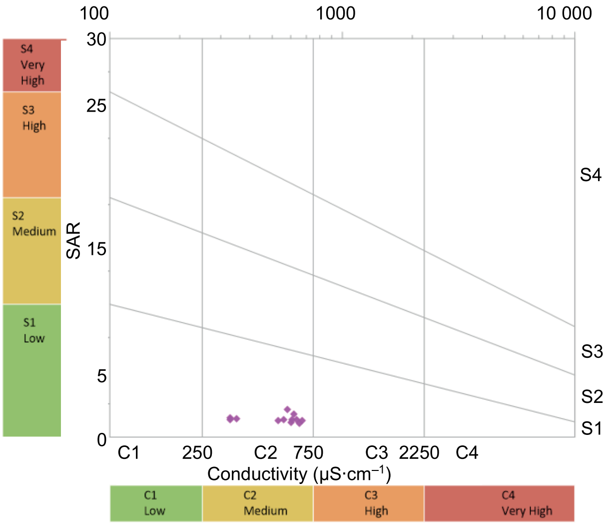

Fig. 3. Plot of sodium adsorption ratio (*SAR*) versus electrical conductivity (*EC*) for classifying irrigation waters using Richard's diagram; source: own study

Wilcox diagram

The Wilcox (1955) diagram (Fig. 4) was further applied to rate irrigation water suitability based on the relationship between %Na and *EC* as high levels of any is harmful to plants. The Wilcox (1955) plot categorise irrigation water into excellent to good (class I), good to permissible (class II), permissible to doubtful (class III); doubtful to unsuitable (class IV) and unsuitable (class V) (Bhatti *et al.*, 2019). In this study, the plot shows that both %Na and *EC* have low values and fall within the "excellent to good" category hence the groundwater quality in the study area with regards to %Na and *EC* is suitable for irrigation (Fig. 4).

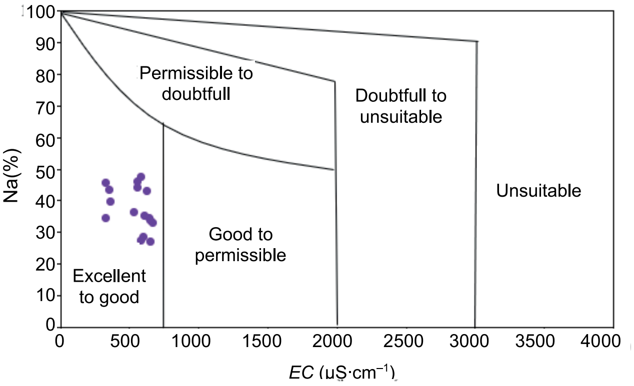

Fig. 4. Plot of sodium percentage against electrical conductivity (*EC*) for classification of irrigation water based on Wilcox diagram; source: own study

CONCLUSIONS

This study has attempted to assess the quality of SGW under the heavily urbanised environment to evaluate its suitability for agricultural use. The results of analysed physicochemical parameters and trace elements of water samples were compared with the already established FAO and South African irrigation water quality guidelines and standard agricultural water quality indices. According to the analysed results, most of physicochemical, and trace elements are found within the tolerable limits for agricultural uses; however, potassium (3.58 mg·dm^{-3}) and manganese levels (3.152 mg·dm^{-3}) exceeded the recommended values for irrigation purpose and hence require pre-treatment. Based on the empirical water quality indices of *SAR*, %Na, *RSC*, *KR*, and *PI*, water is generally suitable for irrigation uses. Moreover, in the Richards and Wilcox diagrams, the SGW samples fall under medium salinity-low sodium content section (C2-S1), and excellent to good category, respectively, indicating the suitability of water for irrigation uses. However, the levels of manganese and potassium, and other parameters such as crop type and pattern, soil type, irrigation frequency also determine the suitability of groundwater and need to be considered accordingly. The study gives valuable information for the current status of groundwater, which is an essential input for urban water resources management. It further contributes to the availability of water quality data for the study site, which is important for future studies.

CONFLICT OF INTEREST

The authors declare no competing interests.

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