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WATER QUALITY INDEX OF SHALLOW AND DEEP GROUNDWATER DURING WET AND DRY SEASON OF PESHAWARBASIN

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ABSTRACT

The main objective of this study was to estimate the suitability of shallow and deep groundwater wells for human and animal consumption from water quality index for irrigation and drinking purpose. A total of 95 groundwater samples at 1.5 to 30 m depths were collected in triplicate during wet and dry seasons. All samples were analyzed for pH, EC, TDS, SO_4^{2-}, HCO_3^{-1}, CO_3^{-2},Cl^{-1}, Ca^{2+}, Mg^{2+}, Na^{+} , Fe^{+3} and K^{+} The result of this study showed that according to water quality index (WQI) of WHO all groundwater samples were categorized as good water and considered suitable for drinking apart from a few exceptions. The Sodium Adsorption Ratio of all groundwater was less than 10. Some of the groundwater showed more than 2.5 meq L^{-1} of Residual Sodium Carbonate. This suggests that groundwater is suitable for irrigation purpose in all seasons.

KEY WORDS: *Groundwater quality index: Seasonal Variations: Classification: Suitability: Drinking: Irrigation*

INTRODUCTION

Groundwater is a suitable source for drinking and irrigation purposes. However groundwater suitability for drinking and irrigation is affected due to increase in industrialization and urbanization over the last several decades[1,2]. As a consequence of this considerable portion of inorganic and organic contaminants enters into the groundwater, hence its suitability for drinking and irrigation remained unanswered. In addition to that successive application of mineral fertilizers to soils can become a source of groundwater contamination[3]. In a study[4] found that the concentrations of NO_3 and Cl ranged from 0.3 to 155 and 10 to 464 mg L^{-1} in groundwater samples collected from densely populated and agricultural areas. They concluded that increase in industrialization; urbanization and successive application of mineral fertilizers are deteriorating the groundwater quality. Addition of excessive amount of gypsum to salts and dissolution of gypsum releases SO_4^{2-} and CO_3^{2-} content in groundwater thus changes the sodium adsorption ratio and residual sodium carbonate of groundwater hence become unsuitable for irrigation practices. In a study[5] it is reported that sulphate and nitrate content in groundwater was increased from 8 to 69 and 0.5 to 1 mg L^{-1} in groundwater samples collected from tube wells located in the agricultural fields. The study concluded that this is more likely because of successive application of mineral fertilizers to soils and downward leaching of such compounds into groundwater.

Apart from anthropogenic activities that cause deterioration of groundwater quality, seasonal variations may also contribute significantly in degrading the groundwater quality due to groundwater recharge. During high rainy season because of rainfall recharge waters, dissolution of saline sediments usually occurs and results in groundwater having high content of Ca-HCO_3 and Ca-Cl-HCO_3[6,7] Similarly in dry season when evaporation exceeds precipitation, upward movement of salts usually occur and surface salinity is commonly observed in dry areas.

Groundwater is a primary source of water for human and animals. Nevertheless, requirement and quality of groundwater cannot be ignored since industrial revolution and intensive urbanization. Like other growing cities in the developing world, Peshawar is also facing the same problems where groundwater quality is slowly and gradually affected due to increase in industrialization and urbanization. Several previous studies such as[8,9,10] were focused on understanding the impact of industrialization on groundwater chemical and physical characteristics. However, very little information is available on understanding groundwater suitability for drinking and irrigation purposes. This study aimed to evaluate groundwater suitability for drinking and irrigation purposes and then to estimate the impact of seasonal changes on groundwater quality. For that purpose shallow and deep groundwater samples were collected within

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Peshawar Basin and analyzed for physical and chemical characteristics according to standard methods[10]. Suitability of groundwater for drinking purpose was determined from water quality index as suggested by WHO whereas use of groundwater for irrigation practices is estimated from Sodium Adsorption Ratio, Na content and Residual Sodium Carbonate. The effect of seasonal variation of groundwater quality was also estimated.

METHOD AND MATERIALS

SITE LOCATION

PESHAWAR BASIN AQUIFERS

The southwestern part of Peshawar basin is composed of thick layers of gravel with sand followed by clay and then sand, whereas the central part is comprised loess and lucastrine sediments with a thickness more than 15m. However, aquifer in the northwest is comprised several beds of gravel with sand with depth up to 46 m Figure 1[11].

GEOLOGY OF PESHAWAR BASIN

Peshawar basin is an in tra mountain basin (>5500 km^2) situated at the southern margin of the Himalayas and northwest of the Indus plain in the Khyber PakhtoonKhwa (KPK) of Pakistan. It is bounded by the mountain ranges of Khyber in the west and northwest, Attock Cherat in the south and Swat in the north and northeast while the Indus river borders its southeastern side where it is open for discharge of water. Peshawar, the capital city of KPK Nowshera, Charsadda and Mardan are the major cities of this basin. River Kabal its tributaries and river Swat drain and irrigate the basin . The Peshawar basin has Quaternary flanglomerates along the margins of the basin while the central part of the basin is generally covered with fluvial micaceous sand, gravels and lacustrine deposits. On the basis of varying lithologies, Quaternary sediments, soils and hosting aquifers, the Peshawar basin are classified as Peshawar piedmont, Peshawar floodplain and Peshawar lacustrine sediments, soils and aquifers respectively[11].

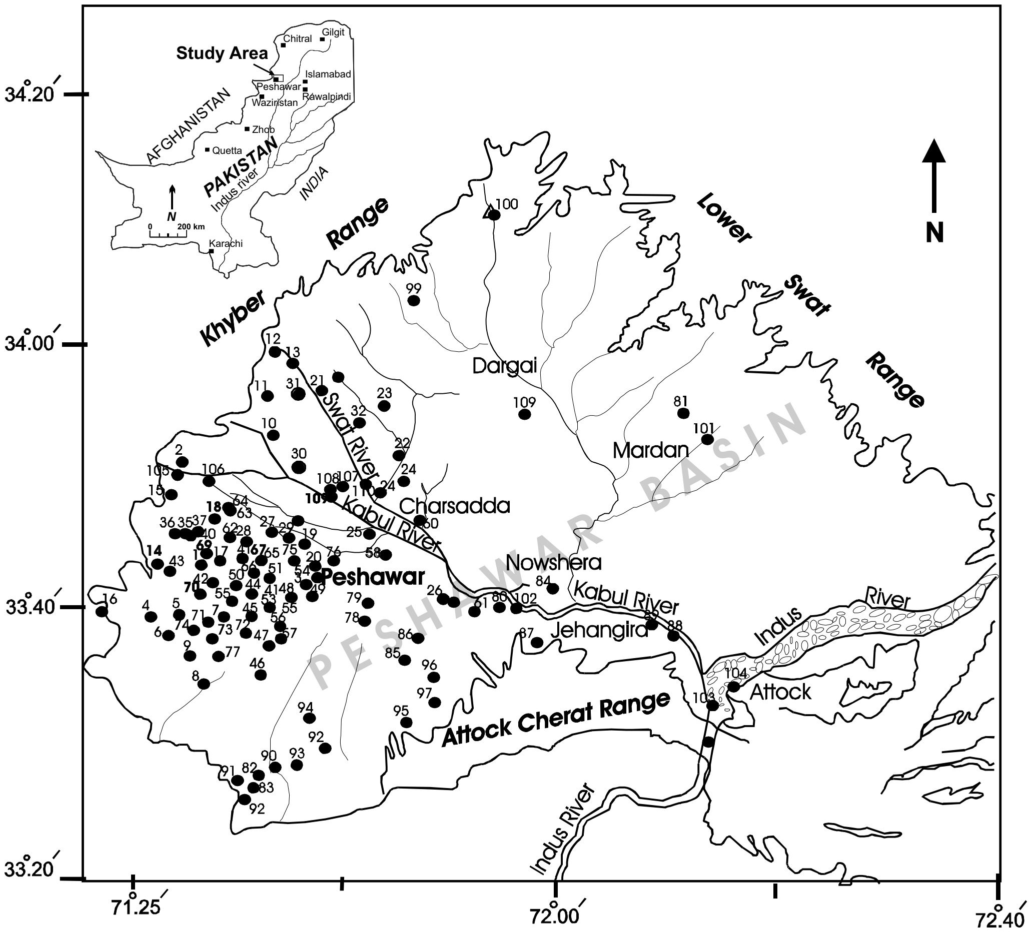


Figure 1. The location of water samples from Peshawar basin[12].

The central part was composed of thick fluvial and lacustrine sediments of calcite, quartzite, dolomite and limestone which were deposited from Kabul and Indus rivers over the last several years[3].

PeshawarBasin is drained by Kabul, Swat, Bara rivers and Kalapani nala. Kabul river is the main drainage source in the west and central part of Peshawar Basin and all other rivers diverted to Kabul river. Bara river drains the south of the Basin whereas Swat river drains the Basin in the northwest. Groundwater is used for drinking and irrigation purposes. Groundwater table fluctuates during rainy and dry seasons. The climate of the Basin varies from semi-arid to sub humid to subtropical. Rainfall ranges from 340 to 630 mm[13].

SAMPLE COLLECTION AND ANALYSIS

Groundwater samples were collected randomly from northeast, central and southern sites of Peshawar Basin. The depth of tube well (deep groundwater) was more than 30m and dug well (shallow groundwater) with depth of less than 1.5m. Groundwater samples were collected twice in a year during the months of January and June from 95 sampling points within Peshawar Basin (Figure 1). About 200 mL of shallow (less than 1.5m) and deep (more than 30m) groundwater samples were collected from dug well and tube well and were placed in 250 mL plastic bottles. About 100 mL of subsample was removed from bulk sample and placed in 150 mL of plastic bottles and was acidified with 1 mL of HNO_3 (5%) and stored in the referegerators in laboratory for further analysis.

The pH, EC, TDS, major cation and anions such as Ca, Mg, K, Fe, Na, HCO_3, SO_4, Cl, CO_3 in groundwater samples was determined by the method as described by American Public Health Association[11]. TDS was analyzed by the volumetric titration method.

All data were analysed by multifactorial analysis of variance (ANOVA) using the software package "Excel 2003"[14]. Breakdown of ANOVA,s was carried out to show significant differences between the samples for selected subsets of data. Confidence values (p) are given in titles of all tables for least significant differences where shown. In tables different letters within columns are significantly different at the 5% level of probability.

RESULTS AND DISCUSSIONS

The pH of shallow groundwater in wet and dry season ranged from 5.2-8.6 and 5.1 to 8.9 whereas pH of deep groundwater ranged from 4.5 to 9.9 and 5.1 to 10.1 in both seasons. pH was significantly different ($p<0.05$) between shallow and deep groundwater in dry season. The pH of some deep groundwater (Sample No's 56, 57, 60, 72, 82) was less than 4.5 and was acidic in dry season and this is more likely because of the dissolve minerals derived from acidic rocks. Whereas exceptionally high level of pH 10.1 was noted in deep groundwater samples No 5 collected from industrial estates of Peshawar Basin. The pH values of all shallow and deep groundwater samples were within the maximum permissible limits for groundwater as recommended by[15,16] apart from a few exceptions. EC in shallow and deep ground water ranged from 65 to 1828 and 52 to 1108 mS cm^{-1}. All groundwater samples have EC less than 1400 mS cm^{-1} (15) except for deep groundwater samples No 26, 33, 58 and 76. It was noted that EC was significantly greater ($p<0.05$) of some deep groundwater samples collected in dry season than wet season. Total dissolved solids of shallow and groundwater samples remained within the maximum permissible limits of 1000 mg L^{-1} as recommended by[15]. Only deep groundwater sample No 58 shows TDS greater than maximum permissible limits (1000 mg L^{-1}). However, TDS of shallow groundwater was significantly greater ($p<0.05$) than deep groundwater (Table 1).

HYDROGEOCHEMICAL CHARACTERISTICS OF GROUNDWATER

Scatter diagram of Ca+Mg vs SO_4^- + $HCO_3^-$is presented in Figures 2a-c. Scattered diagram of shallow groundwater in wet season shows that Ca+Mg are in high content in water than SO_4^- + HCO_3^-. This suggests an extra source of dissolution of silicate minerals in water[17]. However, reverse was observed in dry season of shallow groundwater table where SO_4^- + HCO_3^- is dominant in water than Ca+Mg. The result of this study is in agreement with the findings of other studies[18-22]. However, during wet season Ca-Cl-$HCO_3$was in abundance in both groundwater samples. This agrees with the findings of (6) that Ca-HCO_3 content is indirectly related with the EC content of groundwater. During wet seasons EC is low because of recharge of groundwater hence Ca-HCO_3 content increases whereas during dry season when evaporation is greater EC is greater and groundwater is not recharge therefore Ca-Cl-HCO_3 content is in abundance in groundwater. They concluded that this is more likely because of the recharge process rather than geochemical characteristics of groundwater. The result of this study is not in agreement with the findings of another study[23] who reported that the groundwater was enriched with Cl during monsoon season.

CALCIUM AND MAGNESIUM CONTENT OF SHALLOW AND DEEP GROUNDWATER

The data presented in Table 2 shows that Ca content ranged from 10 to 76 and 9 to 90 mg L^{-1} in shallow and deep groundwater during wet season whereas in dry season Ca content ranged from 16 to 88 and 12 to 93 mg L^{-1}in both groundwater. However the mean content of Ca was greater in shallow groundwater in dry season than wet season. Calcium content in both groundwater remained within the maximum permissible limits for Ca of groundwater (200 to 500 units) in both seasons (15:16). However, Ca content reached to maximum >90 mg L^{-1} in one of the deep groundwater. This support the contention that the geochemical features of the aquifer reflects the compositions of cations in groundwater. This agrees with the findings[12] that calcite and dolomite are the dominant bedrocks of most of the aquifer system of Peshawar Basin hence groundwater is dominated with Ca.

Magnesium content of shallow and deep groundwater ranged from 18 to 85 mg L^{-1} (Table 1). Magnesium content remained within the reported value for Mg according to (15; 16). Nevertheless shallow groundwater sample No 77 has Mg content of 180 mg L^{-1} but some of deep groundwater and most of the shallow groundwater showed Mg content greater than 50 mg L^{-1}. The greater content of Mg in deep groundwater is most probably because of the bed rocks. High content of Mg (180 mg L^{-1}) in shallow and deep groundwater of this study than maximum permissible limits for Mg (100 mg L^{-1}) (16) revealed the contention that dissolution of gypsum added significant portion of Mg to groundwater. The results of this study agree with the findings of another study[24]. They reported that Mg content was more than 322 mg $L^{-1}$and concluded that this is because of dissolution of calcite, gypsum and dolomite from source rocks.

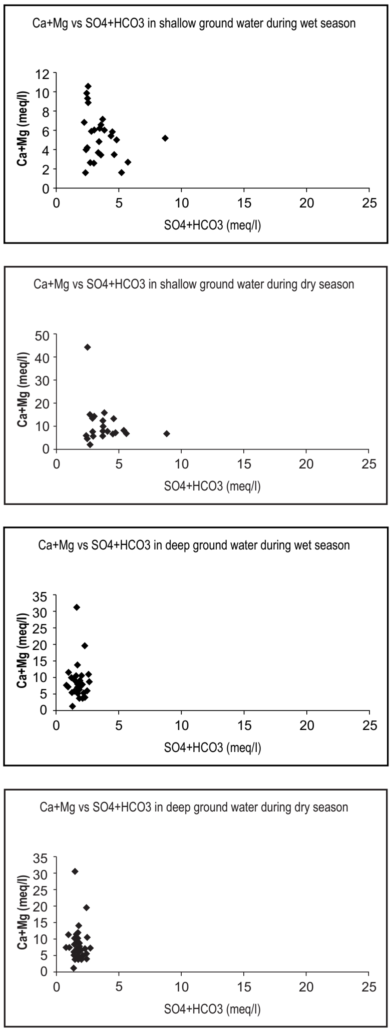
SODIUM, POTASSIUM AND IRON CONTENT IN SHALLOW AND DEEP GROUNDWATER

Sodium content in shallow and groundwater ranged from 22 to 83 and 9 to 193 mg L^{-1}. in both seasons. The average content of Na in deep groundwater remained within the permissible limits for Na in groundwater (200 mg L^{-1}) (15).

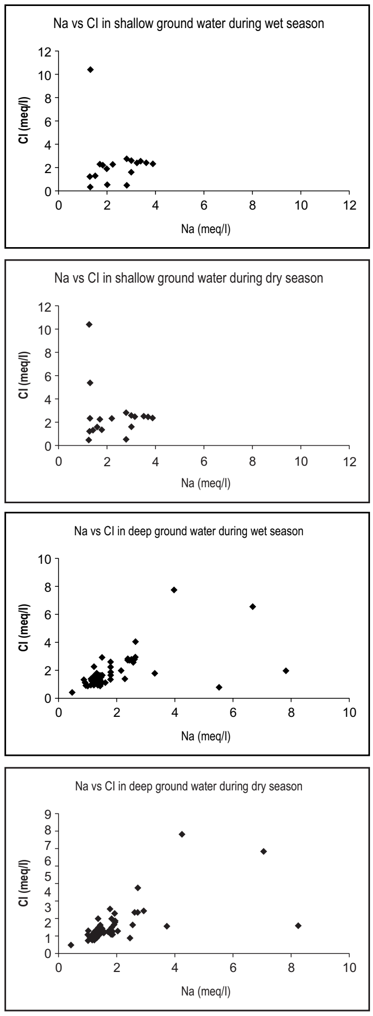
Table 1. Physical and chemical characteristicsof shallow and deep groundwater of the aquifers of Peshawar Basin during wet and dry seasons.

Parameters	Shallow groundwater		Deep groundwater	
Seasons	Wet season	Dry season	Wet season	Dry season
pH	5.2-8.9 (6.9)*	5.1-8.6 (7.7)	4.5-9.9 (6.9)	5.1-10.1 (7.2)
EC (m S/cm)	578-619 (598)	540-590 (564)	424-454 (438)	540-549 (545)
TDS (mg/L)	356-382 (370)	371-382 (376)	270-282 (276)	271-270 (270)
SO_4 (mg/L)	8-1355 (162)	9-1350 (160)	6-1313 (96)	8-1306 (98)
Cl (mg/L)	14-901 (119)	16-902 (122)	12-234 (65.29)	15-234 (66.31)
HCO_3 (mg/L)	61-423 (194)	65-412 (196)	21-366 (181)	26-368 (178)
CO_3 (mg/L)	25-325 (125)	32-386 (165)	12-203 (125)	15-286 (127)
Ca (mg/L)	10-76 (39)	16-88 (46)	9-90 (37)	12-93 (37)
Fe (mg/L)	1-215 (36)	2-211 (40)	1-693 (49)	0-687 (50)
K (mg/L)	3-26 (8)	4-36 (9)	2-10 (4)	3-10 (6)
Na (mg/L)	22-83 (48)	30-89 (52)	9-193 (42)	10-191 (46)
Mg (mg/L)	22-180 (56)	19-168 (59)	16-65 (36)	18-61 (40)

* data in paranthesis represent average content of n=3



2 (a)



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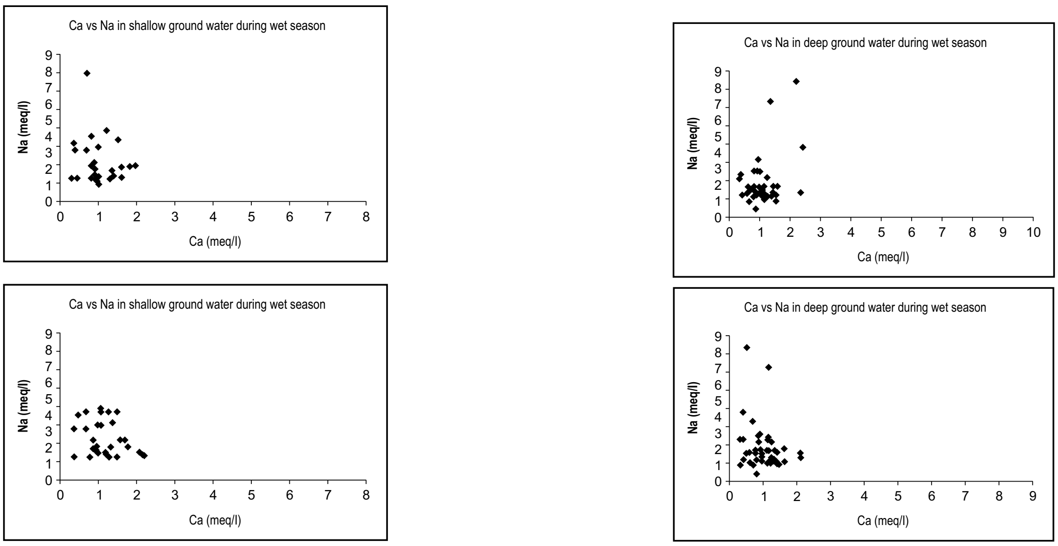

2 (c)

Figure 2: Ca+Mg vs SO_4+HCO_3, Na vs Cl and Ca vs Na scattered diagram showing silicate weathering and abundance of Ca, Mg and Na in deep groundwater during wet and dry seasons.

Potassium content in shallow and deep groundwater varies from 3 to 36 and 2 to 10 mg L^{-1}in both seasons. The greater content of K in shallow groundwater than deep groundwater in this study is most probably because of dissolution of K bearing mineral fertilizers added to soils. Potassium is found in feldspars, micas and clay minerals.

Iron content in shallow and deep groundwater ranged from 1 to 215 and 0 to 693 mg L^{-1}. The content of Fe in both groundwater remained less than 300 mg L^{-1} except for deep groundwater sample No 6 of Hayatabad[25]. The greater content of Fe in deep groundwater is most probably geochemical characteristics of the aquifers. There was no significant difference ($p<0.05$) in the mean content of Fe of shallow and deep groundwater samples during wet and dry seasons apart from a few exceptions.

WATER QUALITY FOR IRRIGATION PURPOSE

SODIUM ADSORPTION RATIO (SAR)

Sodium adsorption ration (SAR) is calculated using the formula[26].

$$SAR = \frac{Na}{\sqrt{\frac{(CA^{++})+(Mg^{--})}{2}}}$$

SAR is an estimate of salinity and alkalinity of groundwater and for suitability of irrigation. SAR for shallow and deep groundwater was less than 10 and suggests excellent water for irrigation purposes[27] (Table 2).

RESIDUAL SODIUM CARBONATE

Residual Sodium Carbonate (RSC) was determined using the formula[28].

$$RSC\ (meq\ L^{-1}) = [\ (HCO_3+CO_3) - (Ca + Mg)\ ]$$

Residual sodium carbonate ratio for shallow and deep groundwater during wet and dry season ranged from -0.51 to 15.86 (Table 2). Most of the deep groundwater samples and some of the shallow groundwater samples has RSC more than 2.5 meq L^{-1}. Therefore such groundwater is considered to be unsuitable for irrigation[29].

WATER QUALITY FOR DRINKING PURPOSE

WATER QUALITY INDEX (WQI)

Standards[15] for groundwater quality suitability for drinking purpose was used to calculate WQI. Prior to calculate[30,31] WQI for drinking purpose, quality rating was calculated using the formula as below:

Quality rating (Q_i) = 100 [(Vn-Vi)/(Vs-Vi)]

Vn= Actual amount of the n^{th} parameter

Vi= the ideal value of this parameter, vi is zero for all parameters except for pH which is 7.0.

Vs= recommended WHO value for this parameter

Relative weight (Wi) was calculated using the following formula[32]

Wi = 1/Si

Si = WHO standard value for the respective parameter

Total water quality index was calculated using the following formula[33]

WQI= Σ (Qi) Wi / Σ Wi (WQI)

WQI for shallow groundwater in wet season = ΣWiQi/ΣWi = 95.03

WQI for shallow groundwater in dry season = ΣWiQi/ΣWi = 56.83

WQI for deep groundwater in wet season = ΣWiQi/ΣWi = 89.55

WQI for deep groundwater in dry season = ΣWiQi/ΣWi = 86.78

Mean values of various parameters used to calculate WOI of shallow and deep groundwater during set and day reasons are presented in Table 3.

When water quality index of shallow and deep groundwater was compared with the water quality classification it was observed that WQI of shallow and deep groundwater in both seasons were placed in the good water class (50-100) (Table 4). The result of this study is in agreement with the findings of vasanthaniam et al 24 and Tendel et al 33 who reported that lake water is classified into good water category according to water quality classification and is best suitable for drinking purposes in winter and summer seasons.

Table 2. Water quality index for shallow and deep groundwater during wet and dry seasons.

parameters	%SAR				RSC (meq L-1)				% Na				TH (mg L-1)			
groundwater	Shallow		Deep		Shallow		Deep		Shallow		Deep		Shallow		Deep	
seasons	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
Range	0.85-4.3	0.54-4.95	0.11-5.25	0.33-5.26	-0.736-15.86	-5.19-12.92	-2.91-12.19	-3.73-9.89	12.81-56.99	9.97-44.65	14.53-51.52	14.53-39.20	129-795	128-793	149-411	168-422
average	2.52*	2.15	2.09**	2.91	2.90	2.40	2.13	2.12	29.70	27.72	25.60	25.85	344	355	263	270

Table 3. Mean value of various parameters used to calculate WQI of shallow and deep groundwater during wet and dry seasons.

	Shallow groundwater		Deep groundwater		Standard value (Si)	Relative Weight (Wi)	Quality rating (Qi) shallow groundwater		Quality rating (Qi) Deep groundwater		Weighed Qi value = quality rating / standard value shallow groundwater		Weighed Qi value = quality rating / standard value Deep groundwater	
Parameters	Wet season	Dry season		Dry season										
pH	6.9	7.7		7.2	8.5	0.1176		53.3	93.33	86.66	10.98	6.27	10.98	10.19
EC (mS/cm)	598	564		545	300	0.0033		188	146	181.66	0.66	0.63	0.28	0.60
TDS (mg/L)	370	376		270	500	0.0020		75.20	55.20	54.0	0.142	0.014	0.114	0.108
Cl (mg/L)	119	122		66.31	250	0.0040		48.80	26.11	26.52	0.190	0.195	0.104	0.106
Total Hardness (mg/L)	344	356		270	300	0.0033		118.66	87.66	90.0	0.4	0.40	0.29	0.30
						∑0.1302					∑WiQi =12.372	7.40	11.66	11.30

Table 4. Water Quality Classification derived from Water Quality Index (WHO, 1996).

WQI value	Water Quality
<50	Excellent water
50-100	Good Water
100-200	Poor water
200-300	Very poor water
Above 300	Unsuitable for drinking purposes

CONCLUSIONS

- The pH, EC and TDS of both shallow and deep groundwater are within the WHO reported values for groundwater apart from a few exceptions.
- Sodium Adsorption Ratio of both groundwater was less than 10 irrespective of the season classifying groundwater as excellent. However, some shallow groundwater is alkaline during dry season with SAR greater than 10. This revealed the contention that evaporation and precipitation and geochemical characteristics of the area cannot be ignored when considering the groundwater quality.
- Shallow and deep groundwater is enriched with Ca, Mg, K, CO_3 and HCO_3. In contrast to that Cl was found to be more concentrated in some of the deep groundwater. The greater content of Cl during wet season is because of rainfall recharge process.
- There is no contamination from natural or anthropogenic sources in any of the groundwater apart from some deep groundwater samples where TDS was more than 1500 mg L^{-1}. Thus generally groundwater is of good quality and suitable for drinking and irrigation purposes apart from some of the deep groundwater.

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REFERENCES

1. Alley, *W.M.,(*1993). *Regional Ground*Water Quality*, Van Nostrand Reinhold, New York, NY. 635 p.*
2. *Bartarya, S. K and Bahukhandi, D. L., (2012). Impact assessment of urbanization and industrialization on surface and groundwater quality. G J Eng. Design. Tech. vol, 1 (1): 11-22.*
3. *Siddiqui S, Khattak R.A. (2010). Trace elements fractionation in calcareous soils of Peshawar-Pakistan. Soil Environ, 29 (2), 148-158.*
4. *Vijay R, Khobragade P, Mohapatra PK. (2010). Assessment of groundwater quality in Puri City, India: an impact of anthropogenic activities. Environ Monit Assess, 177 (1-4), 409-418.*
5. *Appelyard S. (2010). The impact of urban development on recharge and groundwater quality in a coastal aquifer near Perth, Western Australia. Hydrogeol, 3 (2), 65-75.*
6. *Lakshmanan E, Kannan R., Senthil Kumar M. (2003). Major ion chemistry and identification of hydrogeochemical processes of groundwater in a part of Kancheepuram district, Tamil Nadu, India. Environ Geosci, 10 (4), 157-166.*
7. *Shanyengana E.S, Seely M.K, Sanderson R.D. (2003). Major-ion chemistry and groundwater salinization in ephemeral floodplains in some arid regions of Namibia. Arid Environ, 57 (2), 211-223.*
8. *Zahoorullah, Akhtar, T., and Zai, S., (2003). Quality of drinking water in rural Peshawar. Pak J Med Res, vol: 42; 85-93.*
9. *Nasrullah, R. N., Hamida, B and Mudassar, I., 2006. Pollution load in industrial effluent and groundwater of Gadoon Amazai Estate Industrial (GAEI) Swabi, NWFP. Agri. Biol.Sci. vol 1 (3): 18-24.*
10. *Hussain, M., S. A. Rasool, M. T., Khan and A. Wajid., 2012. Enter-ococci vs coliforms as a possible fecal contamination indicator. Baseline data for Karachi. Pak. J. Pharm. Sci., vol 20(2):107-111.*
11. *APHA. (1998).* Standard methods for the examinations of water and wastewater, *19th Edn, APHA, Washington, D.C., USASS.*
12. *Shahida N. (2006). Monitoring of surface water groundwater, air and soil in Peshawar Basin against time the 3rd Dimension. Ph.D thesis submitted to University of Peshawar, 238p.*
13. *Soil Survey Report, 2004. Detailed Soil survey Report of Peshawar by Soil Survey of Pakistan.*

14. Armstrong, T., Bauman, A., and Davis, J., (2000). Physical activity patterns of Australian adults. AIHW catalogue CVD 10. Australian Institute of health and Welfare, Canberra.

15. WHO. 2004. Guidelines for drinking water quality 3rd edn, Recommendations, Genneva, 1-515.

16. ISI. (1995). International standards specification for drinking water New Dehli, IS, 10500.

17. Singh, A. K., Mondal, G. C., Singh, P. K., Singh, S., Singh, T. B., Tewary, B. K., 2005. Hydrochemistry of reservoirs of Dawodan River Basin, India weathering processes and water quality assessment. Environ. Geol. Vol, 48: 1014-1028.

18. Cerling, T. E., Pederson, B.L., Damm, K.L.V., 1989. Sodium calcium ion exchange in the weathering shales. Implications for global weathering budgets. Geol. Vol 17: 552-554.

19. Ettazarin, S., 2005. Process of water rock interaction in the Turonian aquifer of Oum E Rabia Basin, Morocco. Environ. Geol. Vol. 49: 293-299.

20. Karmegam U, Chidamabram S, Sasisdhar P, Manivannan R, (2010). Geochemical characteristics of groundwater of shallow coastal aquifer in and around Kalpakkam, South India. Res J Environ Earth Sci, 2(4), 170-177.

21. Khatib M, (2010). Hydrogeochemical characteristics and evaluations of drinking water quality in Ghaza Strip. M.Sc thesis submitted to the Al Azhar University Ghaza.

22. Ekwere, A. S., Edet, A. E., Ekwee, S.J., 2012. Groundwater chemistry of the Oban Massif, South Eastern Nigeria. Appl. Sci. vol: 7(1): 51-66.

23. Levitt, N., Acworth, RI., Jankowski, J. (1997). Verticle hydrogeochemical zonation in a coastal section of the Botany Sands aquifers, Sydney Australia: Hydrogeol, 5, 64-74.

24. Vasanthanigan M, Srinivasamoorthy K, Vijayarangavar K, Ganthi RR, Chidambaram S, Anandhan P, Manivannan R, Vasudevan S. (2010). Application of water quality index for groundwater quality assessment: Thirumanimuhar sub basin, Tamilnadu, India. Environ Monit Assess, 10661-009, 1302.

25. EPA. (1982). U. S. Environmental Protection Agency. Office of Water Regulations and Standards. PB85221711. EPA 440485005.1.1-4.68.

26. Llyod, J, W., Heathcoat, J. A., (1985). Natural hydrochemistry in relation to groundwater. Oxford Press, Oxford, 296p.

27. Richard L. A, ed. (1954). Diagnosis and improvement of saline and alkali soils. Agriculture Hand Book. vol. 60, U.S. Department of Agriculture, Washington, DC, 160 pp.

28. Siddiqui N.A, Zianddin A. (2006). Water quality index-A tool to determine quality of water. EPC , 10 (1),.60-63.

29. Gurugnanam B, Suvedha M, Vasudevan S, Murugaih M, Karthikeyan C. (2009). Groundwater quality investigation in Veerana catchment area, Tamil Nadu. Ind J Appl.Geochem, 11 (1), 76-83.

30. Horton, R. K., (1965). An index number system for rating water quality. Water Pollution Control Fed 37, 300-305.

31. House, M. A and Ellis, J. B., (1987). The development of water quality indices for operational management. Water Sci Tech, 19; 145-154.

32. Tandel BN, Macwan GEM, Soni CK. (1998). Assessment of water quality index of small lake in south Gujrat Region, India. http://isems.org/images/extraimages/10.pdf.

33. Subramani T, Elango L, Damodarasamy, S.R. (2005). Groundwater quality and its suitability for drinking and agricultural use in Chithar River Basin, Tamil Nadu, India. Environ Geol, 47 (8), 1099-1110.