SEASONAL VARIATION OF GROUNDWATER QUALITY ASSESSMENT FOR IRRIGATION AND DRINKING PURPOSE IN PHULELI CANAL COMMAND AREA (SINDH), PAKISTAN

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ABSTRACT

Assessing the water quality is an important measure for the appropriateness of water for irrigation and drinking purpose. Human health problems due to waterborne diseases are generally reported in newspapers in Phuleli canal command area (Sindh), Pakistan. The study was conducted during the year 2008-2009 to observe seasonal variation at different location (reduced distance, RD = 1000 ft.) of Phuleli command area. Water samples were collected during four seasons (summer, autumn, spring and winter) with three replications each from seven locations (RD-0, RD-30, RD-50, RD-70, RD-90, RD-110 and RD-130). The groundwater samples collected were analyzed for their EC, pH and ions concentration viz. HCO_3^-, CO_3^-, Cl^-, Ca^{2+}+Mg^{2+}, Na^+, SO_4^2, *and SAR. Results showed that the higher EC,* Cl^-, Ca^{2+}+Mg^{2+}, Na^+ *and SAR were observed near down reach (RD-130) during winter season as compared to upper reach (RD-O). As the season changed the values of these parameters showed decreasing trend (autumn>spring>summer), while,* SO_4^{2-} *was higher during autumn season. Same was true with RDs which had higher values of these traits at RD-130>110>90>70>50>30 and 0 except of sulphate (*SO_4^2*). The pH and* K^+ *content in groundwater showed opposite results. Higher pH and* K^+ *content was found at starting point (RD-0) during summer season and lower at down reach (RD-130) during autumn season. At most of the locations, EC of groundwater was higher than the FAO permissible limits and groundwater pH was within recommended values of FAO/WHO. The* SO_4^{2-}, Ca^{2+}+Mg^{2+}, Na^+ *and* K^+ *concentrations in groundwater were higher than the permissible limits of WHO (for drinking purpose), but were within recommended range of FAO for agriculture use. Statistically inter-ions correlation coefficients in groundwater of Phuleli command area showed strong positive correlation (*$p<0.01$*) for EC-HCO, EC-Cl, EC-*SO_4*, EC-Ca+Mg, EC-Na EC-SAR; Na-*HCO_3*, Na -Cl, Na -*SO_4*, Na -Ca+Mg, Na-SAR; Cl-HCO, Cl-*SO_4*, Cl-Ca+Mg, Cl-Na, Cl-SAR and K-pH and theses results divulged that ions found in the groundwater under Phuleli canal command area were mainly produced from various pollution sources viz, industrial and municipal liquid effluents Hence, people living at downstream reach of Phuleli canal command area using groundwater, directly or indirectly at health risk.*

Keywords: Groundwater, ions concentration, water quality, reduced distance (RD), correlation, regression.
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1. INTRODUCTION

Suitability of groundwater for drinking, irrigation and industrial purposes depends upon its quality [1]. Groundwater pollution is usually traced back to four main origins *viz*. industrial, domestic, agricultural and over exploitation of groundwater which creates health problems [2]. The quality of groundwater deteriorates because the widespread pollution of surface water. Besides, discharge of untreated waste water through bores and leachate from unscientific disposal of solid wastes which are likely to be polluting groundwater [3]. Almost all the big cities of the country are facing of safe disposal of wastewater. There is no any treatment plant where the sewerage could be treated and safely disposed off. The city Hyderabad, the second largest city of Sindh province, is also facing this problem, where the wastewater is being disposed off by means of pumping into Phuleli or Pinyari canals without any treatment [4]. Various newspapers also reported hazardous toxic effects on humans, animals, soil and plants, Daily Dawn [5-6] reported that highly toxic run-off from plastic factories, illegal cattle pens and slaughter houses was being released in Phuleli canal and the people of Badin and Tando Mohammad Khan districts are compelled to use it for drinking purpose. Thus the use of polluted canal water of Phuleli canal has put lives of millions of people at risk. Groundwater contamination can be associated with different sources, such as seepage of agrochemicals, sewage and industrial wastewater. Seepage from unlined sewage and industrial wastewater channel causes a great threat to groundwater quality [7]. Groundwater is in nature replenished by surface water from precipitation, streams and rivers. Groundwater is not as prone to pollution as surface water but once polluted restoration is difficult and long term [8]. In Punjab and Sindh, groundwater salinity is interconnected roughly to the river morphology [9].

Quality of groundwater may vary from place to place and from stratum to stratum. It also varies from season to season. The determination of appropriateness of groundwater would, therefore involve a description of the occurrence of the various constituents and their relation to the use to which water would be put [10]. For successful crops production on sustainable basis without deteriorating soils, the quality of groundwater is of main concern. Common quality characteristics considered are electrical conductivity (EC), sodium adsorption ratio (SAR) and residual sodium carbonate (RSC) reported by [11]. Study was attempted to determine groundwater quality for ions concentration in various seasons of Phuleli command area and compare the values with permissible limits of WHO and FAO for human consumption and for agriculture use.

2. MATERIALS AND METHODS

Study was carried out to determine the groundwater quality of Phuleli canal command area during the year 2008-2009. Phuleli canal was constructed during the year 1955, and draws water from Kotri Barrage/Ghulam Muhammad Barrage, Hyderabad Sindh Pakistan to meet the requirement of irrigation and daily consumption purpose. The length of Phuleli canal is about 153 km with discharge capacity of 14859 cusecs. Its command area is about 0.93 million acres.

In Pakistan, monsoon season start in summer from July to September which contributes about 70% of the total annual rainfall. About 30% of total rain fall occur in winter while spring and autumn are dry seasons. Sindh province has arid climate hence agriculture is not possible without supplemental irrigation [12]. In this situation, usually contaminant concentration in canal becomes low during rainy season which might be due to the dilution effect of rainfall whereas the higher concentration of ions are found during winter when canal flow is low as reported by [13], this patterns of rains and climatic condition that ultimately influencing on the groundwater flow and quality.

Groundwater quality at seven locations viz. Reduced distance (RD = 304.8 m) 0, 30, 50, 70, 90, 110 and 130) of Phuleli command area was studied. These locations start from Kotri Barrage of regulator point (RD-0) in Jamshoro towards RD-30, RD-50, RD70, RD-90 situated in Hyderabad district while RD-110, RD130 fall in Tando Muhammad Khan district, Sindh, Pakistan (Fig. 1). The water samples were collected in four seasons (summer, autumn, winter and spring) to monitor the EC, pH and ions concentration of groundwater of Phuleli canal command area at different locations and water quality status was compared with WHO/FAO standards for human consumption and agriculture purpose.

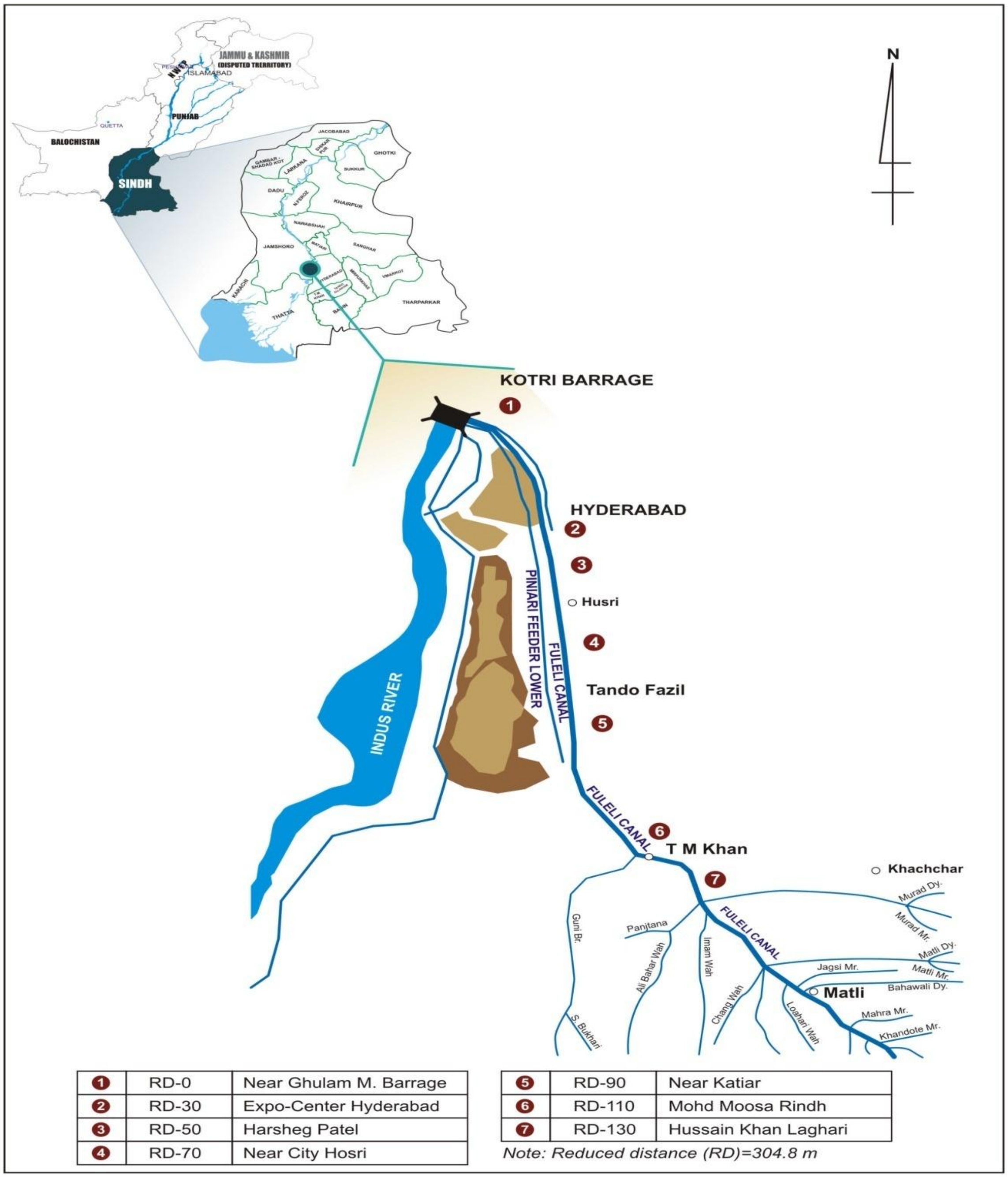

Fig. 1: Map showing locations along Phuleli canal command area from where groundwater samples were taken.

2.1 Collection of water samples

Groundwater samples were collected from seven locations of Phuleli canal command area (RD-0, RD-30, RD-50, RD-70, RD-90, RD-110 and RD-130) with three replications during four seasons (summer, autumn, winter and spring). For determination of EC, pH and ions concentration samples were collected directly from the hand pump installed located at about 100-110 m away from Phuleli canal (Fig. 1). The purging was carried out by making one stroke for every foot of water depth [14]. After purging, the polyethylene bottles and their caps were washed with same water. Collected samples were sent to the laboratories of Land and Water Management, Faculty of Agricultural Engineering, Sindh Agriculture University Tandojam and Drainage Research Center Tandojam for analysis. The canal water samples for determination of EC, pH, ions concentration were collected in properly washed 1.5 liter polyethylene containers.

2.2 Chemical Analysis

The analysis of water samples were carried out according to the methods described [15]. The pH of water samples was measured using portable pH meter (Orion-ISE Model-SA-720 USA) calibrated with buffers of pH 4.0 and pH 9.0, Electrical conductivity (EC) was measured using conductivity meter (Hana Model-8733, Germany) after calibration with standard KCl solution. Soluble cations and anions were determined by titrations as described in Hand Book 60 except sodium and potassium that was determined using flame photometer (Jenway UK Model No. PFP-7) Sulphate, Sodium adsorption ration (SAR) and residual sodium carbonate (RSC) were calculated by using following relations [16].

$$\text{Sulphate}(So_4^{2-}) = (Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}) - (CO_3^{2-} + HCO_3^{2-} + Cl^{-}) \quad (1)$$

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \quad (2)$$

$$\text{Residual Sodium Carbonate (RSC)} = (CO_3^{2-} + HCO_3^{-}) - (`Ca^{2+} + Mg^{2+}) \quad (3)$$

1.3 Statistical analysis

The data collected were subjected to statistical analysis using analysis of variance technique. The LSD (Least Significant Differences) test was applied to compare the individual treatment means as per the statistical methods developed by [17]. The above statistical analyses were performed by using MSTAT-C Computer Software.

3. RESULTS AND DISCUSSION

Seasonal variability of groundwater quality revealed that electrical conductivity during winter season was relatively higher (3.304 dS m^{-1}) as compared to autumn (3.20 dS m^{-1}), spring (3.09 dS m^{-1}) and summer seasons (3.04 dS m^{-1}). The pH (7.38) and K^+ (0.52 meq l^{-1}) were relatively higher during summer, however, HCO_3^-, (3.55 meq l^{-1}), Cl^-, (17.00 meq l^{-1}), Ca^{2+}+Mg^{2+} (10.87 meq l^{-1}), Na^+, (21.8 meq l^{-1}) and SAR (9.318) were more during winter. With regard to SO_4^{2-} (1.90 meq l^{-1}), it was significantly higher during autumn seasons (Table 1). Overall results of the study revealed that all the chemical properties of groundwater increased significantly in the Phuleli canal command area during winter and decreased in summer, with the exception of pH and K^+. The EC of groundwater samples was slightly higher than the FAO permissible limits for human consumption and agriculture use, while pH was within the permissible limits. The determined values for HCO_3^-, Cl^-, SO_4^{2-}, $Ca^{2+}+Mg^{2+}$, Na^+ and SAR of groundwater samples were well comparable and within the recommended range of WHO and FAO, while values of K^+ were slightly higher than the permissible limits of WHO and FAO for human consumption and agriculture use.

Similarly, EC, pH ions concentration of groundwater were different at various locations (Table 2). The groundwater concentrations for EC (4.707 dS m^{-1}) HCO_3^{2-} (4.851 meq l^{-1}), Cl^- (22.67 meq l^{-1}), SO_4^{2-} (19.45 meq l^{-1}), $Ca^{2+}+Mg^{2+}$ (2.61 meq l^{-1}), Na^+ (4.45 meq l^{-1}) and SAR (3.89) significantly increased at down reach RD-130 and decreased at upper reach RD-0 (Table 2). However, pH and K^+ ranged between 7.16-7.46 and 0.38-0.65 meq l^{-1}, having decreasing trend towards down reach (RD-130>110>90>70>50>30>0). The EC in groundwater samples was higher than the permissible limits FAO for irrigation purpose, while pH was within the recommendation of FAO and WHO for multipurpose consumption. The K^+, Cl^-, SO_4^{2-} and Na^+ concentrations were higher than WHO recommendations for drinking water and within permissible limits of FAO for agriculture use.

Table. 1 Ions concentration of groundwater in various seasons under Phuleli canal command area

Parameters	SE	LSD (5%)	Seasons				*WHO	**FAO
			Summer	Autumn	Winter	Spring		
EC (dS m^{-1})	0.0120	0.0540	3.004 d	3.200 b	3.304 a	3.09 c	-	0-3
pH	0.0020	0.0099	7.38 a	7.296 c	7.261 d	7.340 b	6.5-8.5	6.5-8.4
CO_3^- (meq l^{-1})	-	-	-Nil-				--	0-1
HCO_3^- (meq l^{-1})	0.024	0.110	3.228 c	3.47a	3.55 a	3.34 b	--	0-10
Cl^- (meq l^{-1})	0.0022	0.010	15.07 d	16.25 b	17.00 a	15.67 c	7.0	0-30
SO_4^{2-} (meq l^{-1})	0.0069	0.0310	11.81 d	12.71 a	12.59 b	12.19 c	5.2	0-20
$Ca^{2+}+Mg^{2+}$ (meq l^{-1})	0.0023	0.0098	9.702 d	10.63 b	10.87 a	10.11c	--	--
Na^+ (meq l^{-1})	0.0019	0.0097	19.88 d	21.27 b	21.80 a	20.58 c	8.7	0-40
K^+ (meq l^{-1})	0.0021	0.0096	0.5248 a	0.4805c	0.471 c	0.506b	0.26	-
SAR	0.0020	0.0097	8.986 d	9.189 b	9.318 a	9.115c	--	0-15
RSC	--	--	-Nil-				--	--

Table. 2 Ions concentration of groundwater at various locations under Phuleli canal command area

Parameters	SE	LSD (5%)	Locations							*WHO	**FAO
			Regulator (RD-0)	RD-30	RD-50	RD-70	RD-90	RD-110	RD-130		
EC (dS m^{-1})	0.0158	0.0547	2.286 g	2.443f	2.63 e	2.815d	3.382 c	3.786 b	4.707 a	-	0-3
pH	0.0027	0.010	7.469 a	7.40b	7.36c	7.343d	7.28e	7.23 f	7.16 g	6.5-8.5	6.5-8.4
CO_3^- (meq l^{-1})	--	--	-Nil-							--	0-1
HCO_3^- (meq l^{-1})	0.0320	0.110	2.25 g	2.503f	2.722e	3.653d	3.796 c	3.994 b	4.851 a	--	0-10
Cl^- (meq l^{-1})	0.0029	0.0098	11.33 g	11.80f	13.75e	16.94c	16.77 d	18.71 b	22.67 a	7.0	0-30
SO_4^{2-} (meq l^{-1})	0.0091	0.0316	11.04d	10.72 e	10.47 f	7.41 g	12.65 c	14. 54 b	19.45 a	5.2	0-20
Ca^{2+}+Mg^{2+} (meq l^{-1})	0.0027	0.0097	7.739 f	7.505g	8.363e	9.455 d	11.21 c	12.82 b	15.20 a	--	--
Na^+ (meq l^{-1})	0.0028	0.0098	16.16 f	16.92 e	18.04 d	18.04 d	21.58 c	24.03 b	31.39 a	8.7	0-40
K^+ (meq l^{-1})	0.0026	0.0096	0.6467a	0.5975b	0.55 c	0.50d	0.413e	0.38 f	0.386 7 f	0.26	-
SAR	0.0028	0.0099	8.217 g	8.735e	8.82d	8.297f	9.116c	9.493 b	11.39 a	--	0-15
RSC	-Nil-										--

In each column, means followed by common letter are not significantly different at 5% probability level.

* Max: permissible limit for drinking purpose/human consumption [23]
**Recommended Maximum concentration for irrigation/crop production [24]

The interactive effect of seasons x locations on EC, pH and ions concentration in groundwater results (Table 3) indicated that the higher EC (4.88 dS m^{-1}), HCO_3^- (5.11 meq l^{-1}), Cl^- (23.66 meq l^{-1}), Ca^{2+}+Mg^{2+} (15.9 meq l^{-1}), Na^+ (32.38 meq l^{-1}) and SAR (11.48) in groundwater water were observed near RD-130 during winter season, while, (SO_4^{2-}) was higher during autumn season. The values of the parameters were decreased in autumn > spring > summer. However, groundwater concentrations for EC, HCO_3^-, Cl^-, Ca^{2+}+Mg^{2+}, Na^+ and SAR were found higher at RD-130>110>90>70>50>30>0 showing higher values at down reach (Table 3) except of pH and K. At most of the locations, EC of groundwater was higher than the FAO permissible limits and groundwater pH was within the recommended values of FAO/WHO. The SO_4^{2-}, Ca^{2+}+Mg^{2+}, Na^+ and K^+ concentrations in groundwater were higher than the permissible limits of WHO (for drinking purpose), but were in the recommended range of FAO for agriculture use.

Correlation coefficient (r) between groundwater ions concentration of Phuleli canal command area Ions concentration

The correlation of ions concentrations of groundwater across various locations and various season showed that EC was positively associated with HCO_3^-, Cl^-, SO_4^{2-}, Ca^{2+} + Mg^{2+}, Na^+ and SAR with r value of 0.94, 0.95, 0.86, 0.99, 0.99 0.93 respectively. However, EC was negatively associated with pH (r= -0.91) and K^+ (r = -0.88). Statistical results showed that EC was significantly different at 1% probability level with these ions parameters (Table 4).

Na was positively associated with EC, Cl^-, HCO_3^-, SO_4^{2-}, Ca^{2+} + Mg^{2+} and SAR with r value of 0.99, 0.91, 0.92, 0.91, 0.97 and 0.97 respectively. However, Na^+ was negatively associated with pH (r= -0.89).

Statistical results showed that Na^+ was significantly different at 1% probability level with these ions parameters. Cl^- was positively associated with HCO_3^-, SO_4^{2-}, $Ca^{2+} + Mg^{2+}$ and SAR with r value of 0.98, 0.68, 0.96 and 0.83 respectively. However, Cl was negatively associated with pH (r= -0.91) and K (r = -0.89). Statistical results showed that Cl was significantly different at 1% probability level with these ions parameters. K was negatively associated with HCO_3^-, SO_4^{2-}, $Ca^{2+} + Mg^{2+}$, Na^+ and SAR with r value of -0.92, -0.61, -0.90, -0.82 and -0.69 respectively. Whereas, K^+ was positively associated with pH (r= 0.91). Statistical results showed that K^+ was significantly different at 1% probability level with these ions parameters.

Table. 3 Interactive effect of seasons x locations of groundwater on ions concentrations under Phuleli canal

Season	Locations	Parameters									SAR	RSC
		EC ($dS\,m^{-1}$)	pH	$meq\,l^{-1}$								
				CO_3^-	HCO_3^-	CL^-	SO_4^{2-}	$Ca^{2+}+Mg^{2+}$	Na^{2+}	K^+		
Summer	RD-0 (Regulator)	2.14	7.59a	-Nil-	2.02	10.98z	10.27r	7.23z	15.37z	0.68a	8.09u	-Nil-
	RD-30	2.29	7.47c		2.34	11.57x	9.74t	7.04z	15.98z	0.63cd	8.52q	
	RD-50	2.46	7.41ef		2.57	12.95t	10.20s	7.93w	17.23u	0.56fg	8.66p	
	RD70	2.68	7.40fg		3.51	14.22q	9.027u	8.98p	17.25t	0.53hi	8.14t	
	RD-90	3.27	7.34i		3.63	15.96o	11.16m	10.22l	20.09l	0.44k	8.88l	
	RD-110	3.64	7.28l		3.870	17.91i	13.88g	12.22h	23.02h	0.42l	9.31h	
	RD-130	4.54	7.21n		4.65	21.88d	18.40d	14.30d	30.21d	0.42l	11.30d	
Autumn	RD-0 (Regulator)	2.35	7.39e-g		2.55	11.34y	11.6k	7.99u	16.54y	0.64bc	8.27r	
	RD-30	2.48	7.39e-g		2.54	11.93v	10.97n	7.67x	17.19v	0.58f	8.78n	
	RD-50	2.71	7.38g		2.77	13.98r	10.72o	8.69r	18.26o	0.52hi	8.76n	
	RD70	2.85	7.32ij		3.67	17.78k	6.72w	9.580n	18.11p	0.48j	8.28r	
	RD-90	3.42	7.28l		3.85	16.97l	13.78h	11.78j	22.43j	0.38mn	9.25i	
	RD-110	3.83	7.21n		4.02	18.83g	14.86e	12.98f	24.36f	0.37mn	9.56e	
	RD-130	4.76	7.10q		4.86	22.92b	20.27a	15.69b	31.98b	0.38mn	11.42b	
Winter	RD-0 (Regulator)	2.43	7.41de		2.33	11.94v	11.32l	8.210s	16.77w	0.61e	8.28r	
	RD-30	2.59	7.32ij		2.67	12.02u	11.66k	7.96v	17.83r	0.56fg	8.94k	
	RD-50	2.78	7.31jk		2.89	14.85p	10.42q	8.75q	18.87n	0.54h	9.02j	
	RD70	2.96	7.28l		3.77	18.86f	6.67w	9.88m	18.95m	0.47j	8.53q	
	RD-90	3.52	7.20no		3.98	17.88j	13.49i	11.96i	22.99i	0.41l	9.40g	
	RD-110	3.97	7.18o		4.11	19.78e	14.72f	13.44e	24.81e	0.34o	9.58e	
	RD-130	4.88	7.12p		5.11	23.66a	19.88b	15.90a	32.38a	0.37n	11.48a	
Spring	RD-0 (Regulator)	2.23	7.49b		2.11	11.09z	10.97n	7.53y	15.97z	0.66ab	8.22s	
	RD-30	2.40	7.423d		2.46	11.68w	10.51n	7.35z	16.68x	0.62de	8.70o	
	RD-50	2.56	7.38g		2.65	13.23s	10.55p	8.08t	17.79s	0.56g	8.85m	
	RD70	2.76	7.36h		3.66	16.89m	7.23p	9.38o	17.86q	0.52i	8.24s	
	RD-90	3.31	7.30kl		3.72	16.25n	12.15j	10.87k	20.83k	0.42l	8.93k	
	RD-110	3.71	7.24m		3.98	18.31h	14.68f	12.65g	23.94g	0.39m	9.52f	
	RD-130	4.65	7.19o		4.79	22.23c	19.25c	14.90c	30.98c	0.39m	11.34c	
SE		0.0316	0.0058		0.0633	0.0058	0.018	0.0058	0.0058	0.0058	0.0058	
LSD (5%)		0.094	0.0172		0.1879	0.0172	0.054	0.0172	0.0172	0.0172	0.0172	
*WHO		–	6.5-8.5		–	7.0	5.2	–	8.7	0.26	–	–
**FAO		0-3	6.5-8.4		0-10	0-30	0-20	25	0.40	–	0-15	

In each column, means followed by common letter are not significantly different at 5% probability level.

Table. 4Correlation coefficient between groundwater ions concentration parameters of Phuleli canal command area

Parameters	Intercept	Slope	r value
EC ($dS\ m^{-1}$) v/s			
Ph	7.72	-0.13	-0.91**
HCO_3^- ($meq\ l^{-1}$)	0.17	1.03	0.94**
Cl^- ($meq\ l^{-1}$)	1.85	4.49	0.95**
SO_4^{2-} ($meq\ l^{-1}$)	0.24	3.84	0.86**
Ca^{2+} Mg^{2+} ($meq\ l^{-1}$)	-0.11	3.31	0.99**
Na^+ ($meq\ l^{-1}$)	1.47	6.16	0.99**
K^+ ($meq\ l^{-1}$)	0.84	-0.11	-0.88**
SAR	5.5	1.16	0.93**
Na^+ ($meq\ l^{-1}$) v/s			
EC ($dS\ m^{-1}$)	-0.17	0.16	0.99**
pH	7.73	-0.02	-0.89**
HCO_3^- ($meq\ l^{-1}$)	0.10	0.16	0.91**
Cl^- ($meq\ l^{-1}$)	1.4	0.70	0.92**
SO_4^{2-} ($meq\ l^{-1}$)	-1.2	0.65	0.91**
Ca^{2+} Mg^{2+} ($meq\ l^{-1}$)	-0.59	0.52	0.97**
SAR	5.11	0.19	0.97**
Cl ($meq\ l^{-1}$) vs			
pH	7.75	-0.027	-0.91**
HCO_3^- ($meq\ l^{-1}$)	-0.19	0.22	0.98**
SO_4^{2-} ($meq\ l^{-1}$)	2.07	0.64	0.68**
Ca^{2+} Mg^{2+} ($meq\ l^{-1}$)	-0.5	0.68	0.96**
K^+ ($meq\ l^{-1}$)	0.87	-0.024	-0.89**
SAR	5.66	0.22	0.83**
K^+ v/s			
pH	6.82	1.00	0.91**
HCO_3^- ($meq\ l^{-1}$)	7.36	-7.99	-0.92**
SO_4^{2-}($meq\ l^{-1}$)	23.16	-21.83	-0.61**
Ca^{2+} Mg^{2+} ($meq\ l^{-1}$)	22.32	-24.18	-0.90**
Na^+ ($meq\ l^{-1}$)	41.11	-40.77	-0.82**
SAR	12.58	-6.91	-0.69**

*ns = non significant, * and ** significant at 5% and 1% probability level respectively*

Linear regression of seasons and locations for groundwater ions concentration of Phuleli canal command area Coefficient of determination (R^2)

The coefficient of determination (R^2) showed that total variation in ions concentration of groundwater *viz.* EC (50, 0.90, 0.91 and 0.89%) , pH, (97, 98, 88 and 96%), Cl^- (94, 91, 90 and 93%), Na^+ (80, 81, 84 and 82%), Ca^{2+} + Mg^{2+} (91, 90, 88 and 92%) and K^+ (95, 93, 94 and 96%) in various locations due to its association with Summer, Autumn, Winter and Spring seasons respectively (Fig. 2-7).

Regression coefficient (b)

The regression coefficient indicated that a unit increase in locations resulted in correspondingly increase of ions concentration of groundwater *viz.* EC (0.47, 0.38, 0.39 and 0.38 dS m^{-1}), Cl^- (1.73, 1.84, 1.92 and 1.78 meq l^{-1}), Na^+ (80, 81, 84 and 82 meq l^{-1}) and Ca^{2+} + Mg^{2+} (91, 90, 88 and 92 meq l^{-1}) by Summer, Autumn, Winter and Spring seasons respectively (Fig. 2 & 4-6). However, the regression coefficient indicates a unit increase in locations resulted in correspondingly decrease of ions concentrations *viz.* pH (0.97, 0.99, 088 and 0.96) and K^+ (0.05, 0.05, 0.05 and 0.05 meq l^{-1}) in Summer, Autumn, Winter and Spring seasons respectively (Fig. 3 & 7).

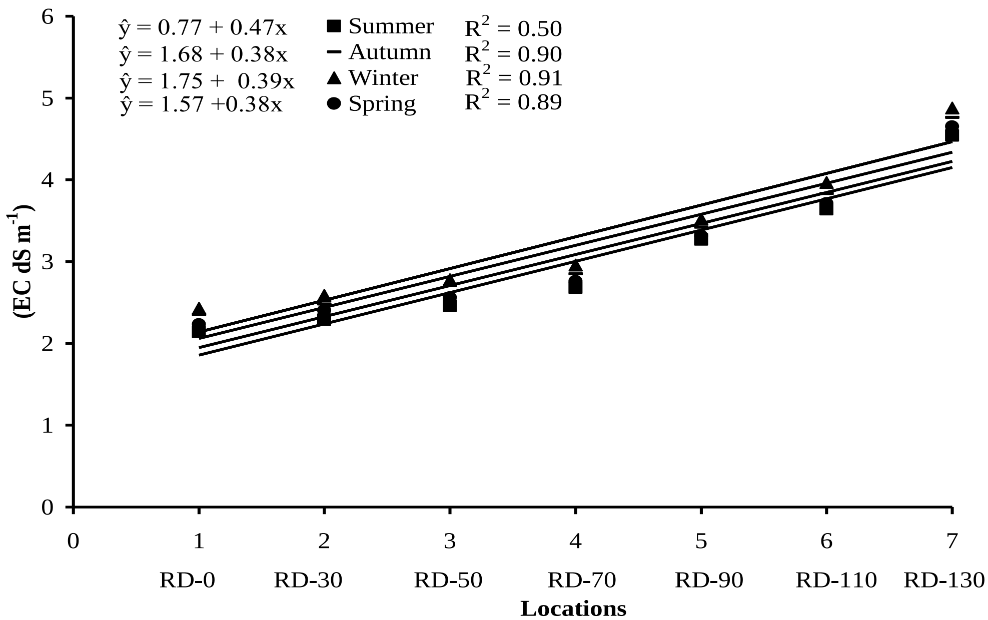

Fig. 2 Linear regression of groundwater EC (dS m^{-1}) between seasons and locations of Phuleli canal command area

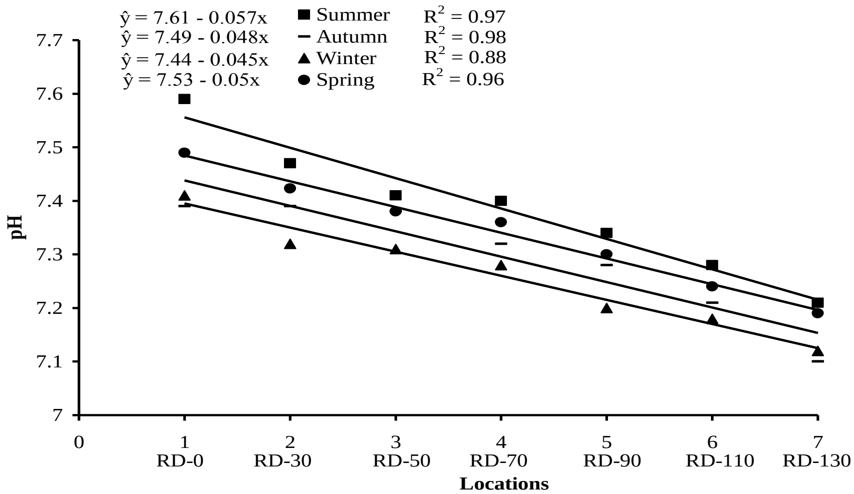

Fig 3. Linear regression of groundwater pH between seasons and locations of Phuleli canal command area

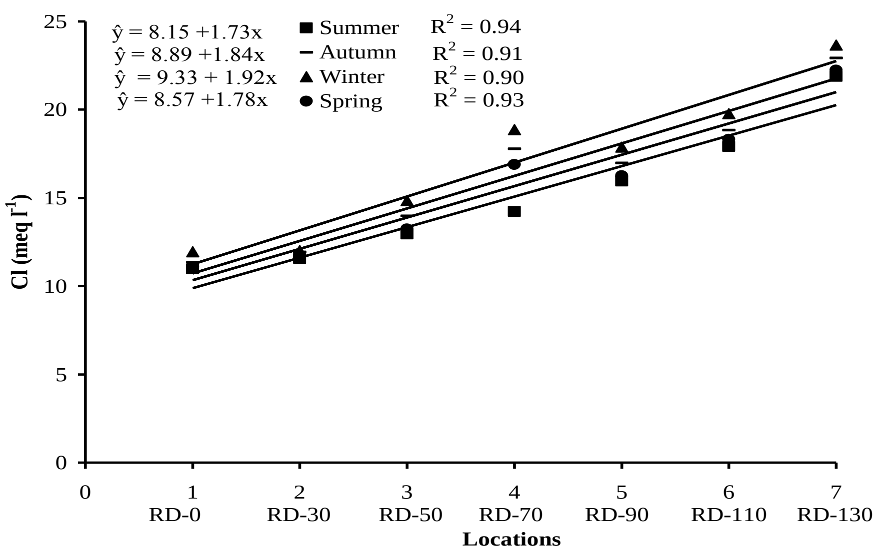

Fig. 4: Linear regression of groundwater Cl^- (meq l^{-1}) between seasons and locations of Phuleli canal command area

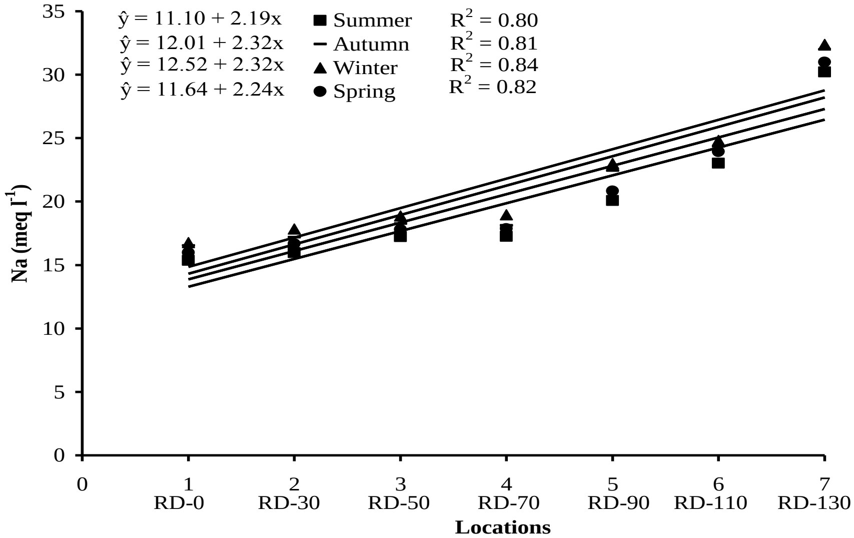

Fig. 5Linear regression of groundwater Na^+ (meq l^{-1}) between seasons and locations of Phuleli canal command area

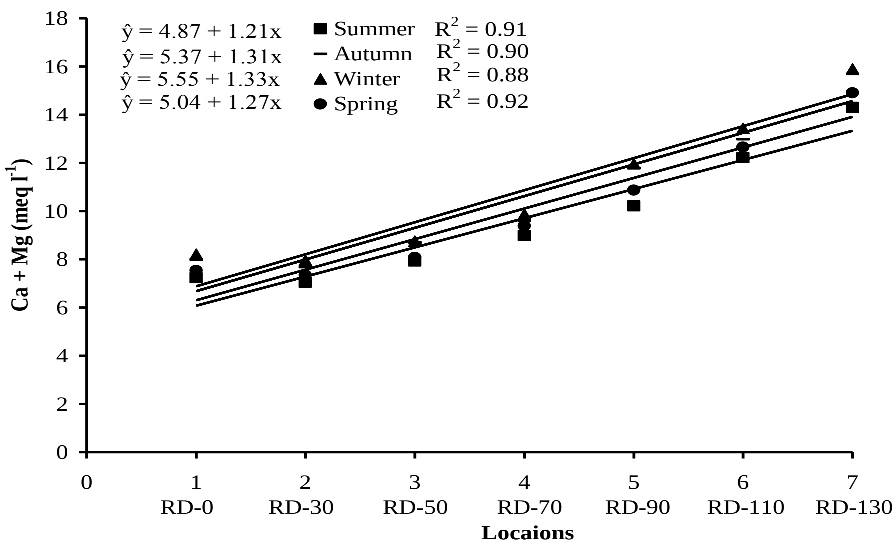

Fig. 6 Linear regression of groundwater $Ca^{2+} + Mg^{2+}$ (meq l^{-1}) between seasons and locations of Phuleli canal command area

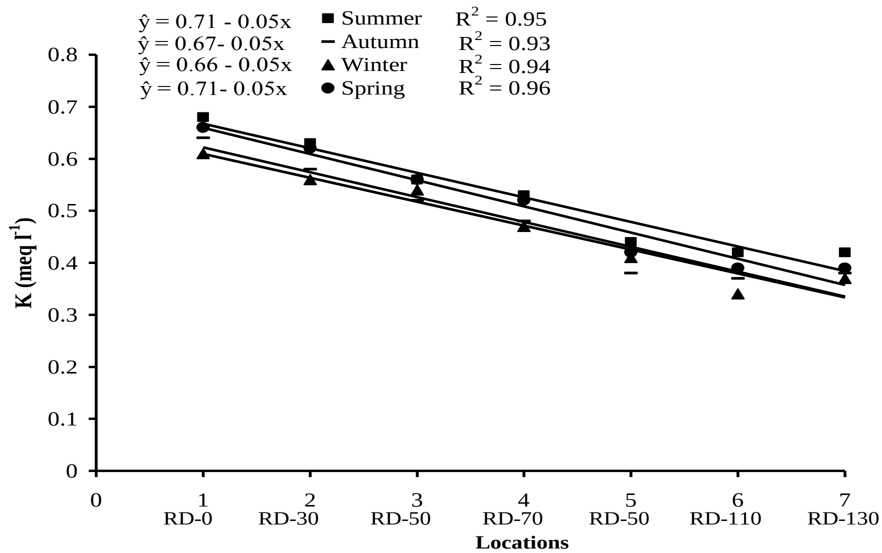

Fig. 7 :Linear regression of groundwater K^+ (meq l^{-1}) between seasons and locations of Phuleli canal command area

DISCUSSION

Electrical Conductivity is a measure of water capability to transmit electric current and also it is a tool to assess the purity of water [18]. Electrical Conductivity of water is mainly associated with the dissolved material [19]. The quality of groundwater is highly variable in various parts of the country both vertically and horizontally from fresh to extremely saline. In this study, groundwater EC was higher (4.88 dS m^{-1}) near down reach during winter and lower (2.14dS m^{-1}) at upper reach canal command area. The EC had decreasing trend *viz.* autumn>spring>summer. It was observed that EC of the groundwater increased when EC of surface water was also high. In Punjab and Sindh, groundwater salinity is related roughly to the river morphology [9]. One of the main problems with groundwater quality in Pakistan is high salinity which results from water logging of salinized soils due to irrigation, dissolution of salts in the sediments, evaporation under the arid conditions and industrial pollution and sewage irrigation. This problem affects the groundwater in large parts of various provinces of Pakistan [20]. This study shows that EC of ground water ranged from 2.14 to 4.88 dS m^{-1}. At most of the locations, EC of groundwater was higher than the FAO permissible limits, however exceed than the permissible limit of WHO.

Chloride usually occurs as NaCl, $CaCl_2$ and $MgCl_2$ and varies in concentrations, in all natural waters. Chloride concentration in water indicates presence of organic waste particularly of animal origin [21]. Increase in chloride concentration due to discharge of municipal and industrial waste has been reported [21]. Chlorides when reaches concentration above 250 mg l^{-1} (7 meq l^{-1}); imparts an unacceptable taste to waters although no adverse effect have been observed on human beings regularly consuming water with much higher concentrations of chloride. But it may affect to a person who already suffer from disease of heart and kidney [18]. In groundwater, the Cl^- were higher near down reach in winter and lower during summer at upper reach of Phuleli canal command area. [18] also observed that water with high electrical conductivity value is predominant in sodium and chloride ions. Application of water having high chloride concentrations makes the soil salty and unfit for agricultural purpose [22]. In the present study, the Cl^- concentrations in groundwater were higher than the permissible limits of WHO (for drinking purpose) [23], but were in the recommended range of FAO for agriculture use [24].

The waters high in calcium or magnesium are considered hard and are not suitable for domestic water supplies, but could be used for irrigation purpose. The highest desirable limit of total hardness is reported as 6.0 meq l^{-1} (300 mg l^{-1}) [25]. The hardness of the water is objectionable from the viewpoint of water use [25]. In this study greater Ca^{2+}+ Mg^{2+} concentrations in groundwater was found near down reach during winter and lower values were noted near upper reach of canal command area. Ca^{2+}+ Mg^{2+} concentrations in groundwater were higher than the permissible limits of WHO (for drinking purpose) [23], but were in the recommended range of FAO for agriculture use [24]. In this study, Ca^{+2} + Mg^{+2} increased with increasing electrical conductivity of the groundwater. Similar findings were also reported by [26].

Sodium contained water usually affect fresh water aquatic life. In this study higher Na was noted at down reach (RD-130) during winter and lower at upper reach (RD-0) during summer season. The increase of sodium may increase the percentage of salinity, which has serious effect on both human life and crop yield. Water with high electrical conductivity values were predominant in sodium and chloride ions as observed by [18]. The Na^+ concentrations in groundwater of Phuleli canal command area were higher than the permissible limits of WHO for drinking purpose [23], but were in the recommended range of FAO for agriculture use [24].

SO_4^{2-} was higher during autumn at down reach and lower at upper reach. In a study conducted by [27] at Tamil Nadu shows that sulfates deteriorated the groundwater quality. However, reported [14] by that SO_4^{2-} concentrations of water samples ranged from 0.09 to 0.45 mg l^{-1} were not problematic for irrigating agricultural crops. The SO_4^{2-} concentrations in groundwater of Phuleli command area were higher than the permissible limits of WHO for drinking purpose [23], but were in the recommended range of FAO for agriculture use [24].

Ions of groundwater of canal command area for HCO_3^- was higher near down reach during winter. The HCO_3^- in groundwater of canal command area decreased in autumn>spring>summer trend. The groundwater concentrations for HCO_3^- showed increasing trend towards down reach (RD-130>110>90>70>50>30>0). The result show that HCO_3^- are within permissible limit of FAO [24].

Potassium is an essential plant nutrient commonly found in good quality irrigation water. Potassium is an important element in irrigation waters and consequently its determination is no longer a routine part of irrigation water analysis [28]. With regard to K^+ content of groundwater, this study showed that K^+ increased near upper reach during summer and decreased towards down reach in autumn. The K^+ concentrations in groundwater were higher than the permissible limits of WHO for drinking purpose [23], but were in the recommended range of FAO for agriculture use [24].

RSC gives relation of calcium and magnesium in the water sample as compared to carbonate and bicarbonate ions [16]. In this study, RSC were nil in groundwater. Negative residual sodium carbonate (RSC) indicates that sodium buildup is unlikely sufficient due to excess calcium and magnesium.

Sodium adsorptive ratio (SAR) is used as one of the criteria for classifying irrigation water. Water having SAR ranged from 0 - 10 are classified as S_1, from 10 - 18 as S_2, from 18 - 26 as S_3 and above 26 as S_4 water [19]. In groundwater, SAR was higher towards down reach in winter as compared to upper reach. Regarding seasons, the values of this parameters decreased in autumn>spring>summer. The groundwater concentrations for SAR showed increasing trend towards down reach (RD-130>110>90>70>50>30>0). SAR of groundwater was within the range recommended by WHO [23] and FAO [24] for human consumption and agriculture use respectively.

Strong positive correlation for EC- HCO_3, EC-Cl, EC-SO_4, EC- Ca + Mg, EC-Na, EC-SAR; Na-HCO_3, Na -Cl, Na -SO_4, Na-Ca+Mg, Na-SAR; Cl- HCO_3, Cl-SO_4, Cl-Ca + Mg, Cl-Na, Cl-SAR and K-pH. These relations showed that ions found in the groundwater under Phuleli canal command area were mainly produced from various pollution sources *viz.* industrial and municipal liquid effluents.

CONCLUSIONS AND RECOMMENDATIONS

It is concluded from the study that mostly, water contamination is greater during winter season due to low water discharge from Kotri Barrage and reception of low rainfall which ultimately affects the groundwater quality. The concentrations of EC, HCO_3^-, Cl^- , Ca^{2+}+Mg^{2+}, Na^{2+} and SAR of groundwater increased considerably towards down-reach of Phuleli anal command area during winter season at RD-130 with the exception of pH and K^+ showing maximum at up-reach (RD-0) and decreasing trend towards down-reach. As the season changed the values of these parameters showed decreasing trend (autumn>spring>summer) Same was true with RD's which had higher values of these traits at RD-130>110>90>70>50>30 and 0. At most of the locations, EC of groundwater was higher than the FAO permissible limits and groundwater pH was within the recommended values of FAO/WHO. The SO_4^{2-}, Ca^{2+}+Mg^{2+}, Na^+ and K^+ concentrations in groundwater were higher than the permissible limits of WHO (for drinking purpose), but were in the recommended range of FAO for agriculture use.

Strong positive correlation for EC-HCO_3, EC-Cl, EC-SO_4, EC- Ca + Mg, EC-Na, EC-SAR; Na-HCO_3, Na -Cl, Na -SO_4, Na-Ca+Mg, Na-SAR; Cl- HCO_3, Cl-SO_4, Cl-Ca + Mg, Cl-Na, Cl-SAR and K-pH were observed. These relations showed that ions found in the groundwater under Phuleli canal command area were mainly produced from various pollution sources *viz,* industrial and and municipal liquid effluents. It is recommended that instead of releasing municipal sewage water directly into the canal and its command area, it should be partially treated and then utilized for the urban agriculture. Thus, industries must be bound lawfully to discontinue draining toxic effluents directly into the canal. Regular monitoring should be carried out for contamination of the canal water quality for healthy environment of command area. Awareness programs among local people should be started/initiated.

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