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Spatial and Temporal Analyses of Water Quality in the Dhrabi Watershed of Pakistan: Issues and Options

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Abstract: Monitoring water quality is important for maintaining a healthy watershed, but it is mostly ignored in watershed planning and management. In the Dhrabi watershed of Pakistan, the quality of surface water was monitored at 16 locations to assess suitability for irrigation over regular intervals during the period 2007-2010. Similarly, groundwater quality was monitored at 10 locations for drinking and irrigation purposes. There was high spatial and temporal variability in surface water quality. Electrical conductivity (EC) and residual sodium carbonate (RSC) either exceeded or fluctuated around permissible limits at most of the locations throughout the monitoring period. Therefore, the use of such water for irrigation needs special care, otherwise its prolonged use may pose soil salinity and sodicity problems. The trend of EC and RSC for groundwater was similar to that for surface water. Exchangeable Mg^{2+} exceeded permissible limits for most of the surface water and groundwater samples. In addition, microbial analysis of groundwater revealed that only two out of eight monitoring points during August 2009, none out of eight points during February 2010, and one out of nine points during June 2010 provided water fit for drinking. Soil samples were collected from the catchment areas of the major contributing streams and from the beds of the Kallar Kahar Lake and the Dhrabi Reservoir. The soil samples from the catchments showed high salinity and sodicity that may be the cause of high salinity and sodicity in the streams. The highest EC, sodium adsorption ratio (SAR) and exchangeable sodium percentage (ESP) in the bed samples from the Kallar Kahar Lake were about 43 dS/m, 56, and 45, respectively. These high values were due to the saline water brought into the lake with the runoff.

Key words: Surface water quality, groundwater quality, drinking water quality, wastewater.

1. Introduction

With increasing population, urbanization, and industrialization, the quality of water is becoming a serious issue all over the world, and particularly in developing countries. Water quality is important for drinking, irrigation and for the maintenance of the ecosystem. A large proportion of the 900 million people living in rural areas, particularly the poorest, lack access to safe drinking water. This lack of access to safe drinking water and sanitation, along with poor personal hygiene, causes massive health problems; in particular, diarrheal diseases cost the lives of 2.18 million people every year, three-quarters of whom are children younger than five years old [1].

Water quality defines the usefulness of water and it is equal as important as water quantity. Water is required for several purposes, including domestic, industrial, municipal, and agricultural, where acceptable quality standards vary based on the intended use.

The quality of river water in Pakistan is generally good in terms of salinity. Rivers in the country, like other rivers in the world, contain soluble salts, the concentration of which varies from river to river depending on the type of catchment area, the sources of

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water, and the season. Generally, there is an increase in the salt content during low flows in winter, and a decrease in concentration during the high-flow (monsoon) period in summer.

Groundwater is another source of water for agricultural, domestic, and industrial uses. However, groundwater quality is far inferior to surface water with about 70% tubewells pumping sodic water [2]. The use of sodic water has in turn affected soil health and crop yields. This situation is being further aggravated by a reduction in rainfall as a consequence of climatic change.

The annual generation of wastewater from major cities of Pakistan is about 4.43 billion cubic meters (BCM), out of which 3.06 BCM is municipal and 1.37 BCM is from industries. On the one hand, this huge amount of water is a resource and can be reused after proper treatment. On the other hand, the wastewater is a nuisance as less than 1% is being treated and about 1.7 BCM is being disposed off directly into water bodies, resulting in serious consequences for aquatic life and downstream users. Because of improper disposal and unlined drains, the wastewater percolates and ultimately recharges groundwater, thereby contaminating drinking water, of which more than 90% comes from groundwater [3]. A study conducted by the Pakistan Council of Research in Water Resources (PCRWR) found four major contaminants in drinking water. These were bacterial (68%), arsenic (24%), nitrate (13%), and fluoride (5%). Overall, out of 357 drinking water samples only 45 (13%) were found to be safe, whereas the remaining 312 (87%) were found to be unsafe for drinking purpose [4]. These contaminants are responsible for most of the water-born and water-related diseases prevailing in the country.

A watershed is a land area which receives and transports rainwater to an outlet, commonly a reservoir. A proportion of the rainwater is either stored in the soil or percolates to recharge groundwater, thereby building a shallow aquifer of mostly perched water—a main source of drinking water for inhabitants. The remaining water moves to the outlet in the form of runoff. During this runoff process, the water also receives some point and non-point pollution, which transports to the water outlet. During transportation, some of these pollutants leach down and contaminate the groundwater. The monitoring of surface water and groundwater quality is therefore very important for assessing the health of any watershed. The main objective of this study was to monitor the surface water and groundwater quality of the Dhrabi watershed from irrigation, drinking and environmental viewpoints.

2. Material and Methods

The study was conducted in the watershed area of the Dhrabi Reservoir (Fig. 1). This area is located between latitude $32^{\circ}42'36''$ to $32^{\circ}55'48''$ and longitude $72^{\circ}35'24''$ to $72^{\circ}48'36''$ in the Chakwal District, Pakistan. The total area is 196 km^2 including one lake, two small dams and 12 mini dams. Rainfall is the main source of freshwater in the watershed. A number of perennial and non-perennial streams flow to the Dhrabi Reservoir, and small springs originate from the hills. Topography varies from shallow to deep gullies, small to large terraces and mounds to hillocks. The soil is predominantly of a sandy loam type and is low in organic matter (less than 1%).

2.1 Water Quality Monitoring

A preliminary survey was conducted on 35 water sources to monitor the surface water quality. The surface water quality was monitored regularly at 16 representative locations (Fig. 1, Table 1) and assessed for the purpose of irrigation only. Groundwater was also assessed, as it is a major source of drinking water and is used by some farmers for irrigation. The groundwater quality of 10 open wells/dug wells, hand pumps and water turbine pumps were monitored for both irrigation and drinking purposes (Fig. 1).

2.2 Water Table Monitoring

The depth of the water table is an important factor in

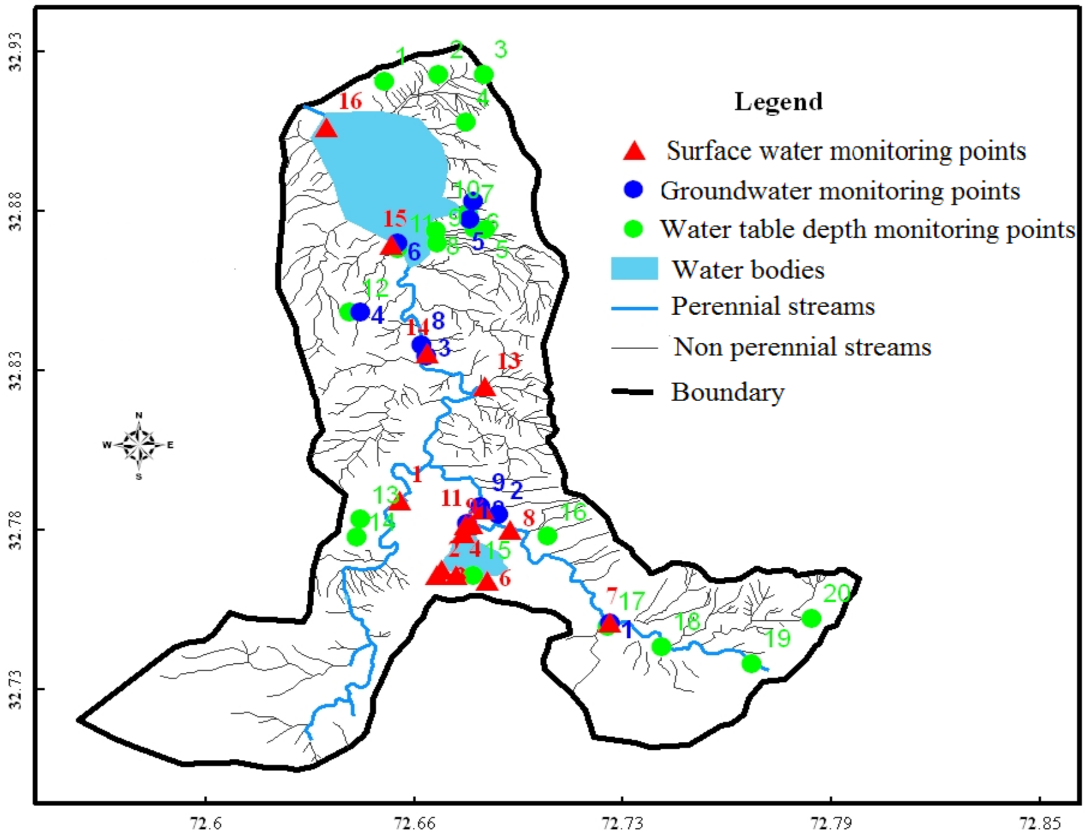

Fig. 1 Map of the watershed area of the Dhrabi Reservoir showing the water monitoring points.

Table 1 Locations of monitoring points for surface water quality.

Location	Description	Location	Description
1	Nikka Dam stream on Bhurpur Road	9	Outflow from KK Lake weir (exit)
2	Inflow to Kallar Kahar (KK) Lake near Khushab Road	10	Outflow from KK city drain
3	Inflow to KK Lake near police rest house	11	Outflow from KK Lake plus city drain through box pipe
4	Inflow to KK Lake, right side of tourist point	12	Outflow after the junction of four points: 8, 9, 10 and 11
5	Inflow to KK Lake, left side of tourist point (chocked now)	13	Outflow near Baba Totanwali Tomb
6	Inflow to KK Lake, behind KK motorway rest area	14	Outflow at Ratta Bridge
7	Outflow at Chak Khushi drain bridge	15	Near Dhoke Choi main inlet to Dhrabi Dam
8	Outflow at KK Chakwal Road Bridge	16	Dhrabi Reservoir exit

the design, installation, and operation of a tubewell and has a profound impact on the quality of groundwater. The depth of the water table was regularly monitored at 20 different locations (Fig. 1) and was measured using a water table level detector.

2.3 Wastewater Monitoring

Wastewater is of major environmental concern and affects both surface water and groundwater quality, and the ecosystem. The major source of wastewater in the study area is from the town of Kallar Kahar's drainage outlet, which joins the stream system at point 11 (Table 1). Wastewater samples were collected from point 11, and 2 km downstream of this point, and were analyzed for biological oxygen demand (BOD) and chemical oxygen demand (COD). The wastewater generated from the villages was almost negligible. The exception was generated in the village of Khandua, where wastewater was stored outside the village and used for animal drinking and the small-scale growing of vegetables. The wastewater in this pond was also analyzed for BOD, COD and chemical parameters.

2.4 Soil Samples

To understand the parent material and its impact on surface water and groundwater quality, soil samples were collected from different catchments of up to 15 cm depth, and also from the beds of the Kallar Kahar Lake and the Dhrabi Reservoir. The samples were analyzed in the Soil and Water Conservation Research Institute laboratory using the standard procedures.

Residual sodium carbonate (RSC) and the sodium adsorption ratio (SAR) were determined using Eqs. (1) and (2) [5] where chemical concentrations are expressed in meq/L:

$$\text{RSC (meq/L)} = (CO_3 + HCO_3) - (Ca + Mg) \quad (1)$$

$$\text{SAR} = Na/((Ca + Mg)/2)^{1/2} \quad (2)$$

For drinking water, the parameters analyzed were Cl, Mg, SO_4, NO_3, NO_2, As, Mn, total coliforms, fecal coliforms and *E. coli*. These parameters were analyzed at the laboratories of PCRWR and the National University of Science and Technology, Islamabad.

2.5 Water Quality Standards

Water quality standards vary according to the use. For irrigation, there are no unified water quality standards in Pakistan and different agencies have proposed and used different standards. This paper uses the water quality standards for irrigation set by the Water and Power Development Authority (WAPDA).

The irrigation standards are based on the calcium and magnesium contents of soils. It has now been established that calcium and magnesium behave differently in soil systems, particularly excess magnesium leads to the deterioration in the soil structure. In irrigated soil, high levels of Mg^{2+} usually promote a higher development of exchangeable Na^+. Similarly to irrigation water, there are no unified standards available for drinking water quality. In this paper, National Environment Quality Standards and World Health Organization guidelines are mostly used to define the drinking water quality.

3. Results and Discussion

3.1 Surface Water Quality

Water quality at some important locations (head middle and tail) is presented in Table 2. These results show high spatial and temporal variation in surface water quality. Electrical conductivity (EC) was very high at point 10 (downstream from the city of Kallar Kahar): about four times higher than the threshold. However, after entering into the Dhrabi Reservoir (Point 16), the water improved in quality, most probably because salts were leached during conveyance and dilution in the reservoir.

The sodium adsorption ratio was also higher at Point 10 compared to other locations and was about 1.5 times higher than permissible limits during November 2007, August 2008, and August 2009. However, in the reservoir, SAR remained below the threshold. Residual sodium carbonate at point 10 was the highest during November 2007 and June 2008 (> 20 meq/L) and fluctuated during the rest of the period. In the reservoir, for most of the time, RSC was either higher than or remained close to the threshold limit.

The water quality in the streams depends on rainfall and the type of flow (perennial or intermittent) at the time of sampling. From an irrigation point of view, SAR and RSC (along with EC) are very important considerations. The management of high EC in soil is relatively easy because the salts can be leached downwards. However, the management of sodic water (water with high SAR and RSC values) is rather more difficult. The continuous use of such water may result in deterioration in the soil structure and reduce crop yields. Under such conditions, care should be taken to manage root-zone salinity so that it remains at or below a level that can be tolerated by the crop. For farmers and agronomists using low-quality irrigation

Table 2 Surface water quality at certain critical locations in the Dhrabi watershed.

	EC (dS/m)			SAR			RSC (meq/L)		
Monitoring points	1	10	16	1	10	16	1	10	16
Nov. 07	1.3	4.8	NA	7.95	15.11	NA	6.6	23.4	NA
Mar. 08	1.5	1.8	1	5.11	6.4	4.17	0.2	0.5	2
Jun. 08	0.8	4.8	1.1	5.32	0	7.99	3.5	23.4	11.8
Aug. 08	1.3	3.5	1.1	4.7	14.2	6.3	0	0.4	1.4
Oct. 08	1.2	2.7	1.1	7.6	7.6	7.7	2.3	0	2.6
Dec. 08	1.6	3.4	0.9	8.9	12.0	7.5	2.5	3.3	1.1
Feb. 09	1.8	1.7	1.2	6.5	6.1	5.7	5.3	3.7	2.7
Apr. 09	2.3	2.0	1.0	8.8	7.1	7.4	4.2	3.3	3.0
Jun. 09	1.6	1.3	1.1	7.5	1.7	7.7	8.3	3.7	3.9
Aug. 09	1.1	4.1	1.0	5.2	13.5	8.3	6.3	2.6	2.6
Oct. 09	1.4	3.5	1.0	5.3	5.1	5.7	1.8	5.6	0.0
Dec. 09	1.6	4.0	1.0	4.9	6.7	6.3	1.4	3.9	1.7
Feb. 10	1.8	4.9	1.0	5.7	9.0	6.0	1.7	0.0	0.9
Apr. 10	1.9	2.0	1.12	7.6	NA	5.8	2.7	0.0	0
Jun. 10	1.7	3.9	1.1	5.3	5.9	5.4	6.7	7.3	2.6
Sep. 10	0.8	1.5	0.9	3.5	2.7	4.5	1.7	1.9	2.3

NA: samples not available.

water, sufficient information is available in the literature on the importance of changes in land configuration, exchange phenomenon and salt leaching, gypsum usage and water requirements, irrigation scheduling, salinity/sodicity tolerance of crop cultivars at various phonological stages, and agro-techniques, etc.. However, physical, chemical, and biological methods alone may not be sufficient for the safe use of low-quality water. A combination of appropriate methods and cultural practices could nevertheless help make sure that low-quality water is used without the risk of salinity building up in the root zone [6-10].

Table 3 shows the overall quality of surface water samples at different points in time. If looking at the number of marginally fit and unfit samples, it is clear that most of the samples were unfit because of high EC and RSC. As discussed earlier, the long-term use of water with high RSC may pose serious problems to the soil. The following strategy may be useful to handle this issue: (1) Reducing the entry of high RSC water into the reservoir. Since Kallar Kahar Lake and its catchment are the main contributors of EC and RSC water, no water should be allowed to spill over from the lake. This may be done by raising the dikes of the Kallar Kahar Lake and storing as much water as possible from the catchment; (2) Using chemical amendments, such as gypsum in the field, to reduce the negative impacts of the sodic water; (3) Adopting an appropriate cropping pattern. Ashraf and Saeed [9] found that dhaincha (*Sesbania aculeate*) is a good short-duration crop for incorporating into the cropping pattern, particularly where low-quality sodic water was used for irrigation. Although dhaincha is not a salt-tolerant crop, it is used as fodder and green manure for reclaiming land and adding organic matter to the soil; adding organic matter such as this in a saline environment reduces the loss of ammonia through volatilization, improves the efficiency of nitrogen use, and retains nutrients that might otherwise be leached out from the soil [6].

Table 4 shows that most of the samples exceeded the permissible limits [11] for Ca^{2+} and Mg^{2+}. However, all the samples were within the permissible limit with respect to the Mg^{2+}/Ca^{2+} ratio. Magnesium ions, when present in excess levels on the cation exchange complex in combination with Na^{+} or alone, may result in soil degradation through their impact on physical properties in the soil [12, 13]. And a high Mg^{2+} level in

Table 3 Number of water samples suitable for irrigation (based on standards set by the Water and Power Development Authority).

Month	EC (dS/m)			SAR			RSC (meq/L)		
	Fit	Marginal	Unfit	Fit	Marginal	Unfit	Fit	Marginal	Unfit
Nov. 07	26	10	1	29	8	0	21	10	6
Feb. 08	13	1	1	15	0	0	10	4	1
Mar. 08	11	5	0	15	1	0	2	13	1
Jun. 08	0	1	15	4	0	12	6	5	5
Aug. 08	0	0	16	13	3	0	15	1	0
Oct. 08	8	7	1	15	1	0	4	12	0
Dec. 08	0	0	14	11	3	0	10	4	0
Feb. 09	0	0	16	15	1	0	5	9	2
Mar. 09	0	0	16	14	2	0	4	11	1
Apr. 09	0	0	16	15	1	0	6	10	0
May 09	0	0	16	15	1	0	8	6	2
Jun. 09	0	0	13	10	3	0	6	5	2
Jul. 09	5	6	4	11	3	1	6	8	1
Aug. 09	8	1	4	10	3	0	5	6	2
Sep. 09	11	3	1	14	0	1	4	0	11
Oct. 09	7	2	4	12	0	1	11	1	1
Nov. 09	5	4	4	12	0	1	13	0	0
Dec. 09	7	6	2	14	0	1	14	0	1
Jan. 10	6	6	0	12	0	0	12	0	0
Feb. 10	14	0	0	14	0	0	14	0	0
Mar. 10	7	7	1	14	0	1	13	0	2
Apr. 10	4	4	3	10	0	1	10	1	0
May 10	4	4	4	11	0	1	9	1	2
Jun. 10	5	2	4	11	0	0	8	1	2
Jul. 10	7	7	0	14	0	0	6	8	0
Aug. 10	9	5	1	1 4	0	1	11	4	0
Sep. 10	11	3	1	14	0	1	11	4	0
Oct. 10	4	10	1	14	0	1	11	3	1
Nov. 10	9	4	2	14	0	1	12	3	0
Dec. 10	10	4	1	14	0	1	13	2	0
Total	191	102	162	400	30	25	280	132	43

Table 4 Mg^{2+}, Ca^{2+} concentrations (mg/L) and Mg^{2+}/Ca^{2+} ratios in surface water samples in the Dhrabi watershed.

Location	July 2010			Aug. 2010			Sept. 2010			Oct. 2010		
	Mg^{2+}	Ca^{2+}	Mg^{2+}/Ca^{2+}	Mg^{2+}	Ca^{2+}	Mg^{2+}/Ca^{2+}	Mg^{2+}	Ca^{2+}	Mg^{2+}/Ca^{2+}	Mg^{2+}	Ca^{2+}	Mg^{2+}/Ca^{2+}
1	40.8	19.2	2.1	48.0	56	0.9	8.4	56	0.2	28.8	64	0.5
2	96	98.4	1.0	54.0	104	0.5	40.8	100	0.4	36.0	120	0.3
3	136.8	74.4	1.8	36.0	126	0.3	51.6	108	0.5	46.8	112	0.4
4	103.2	110.4	0.9	32.4	106	0.3	37.2	110	0.3	33.6	110	0.3
6*	136.8	103.2	1.3	28.8	90	0.3	21.6	110	0.2	39.6	90	0.4
7	76.8	60	1.3	39.6	76	0.5	30.0	90	0.3	39.6	78	0.5
8	60	48	1.3	26.4	100	0.3	42.0	80	0.5	37.2	78	0.5
9	**	**	**	15.6	110	0.1	84.0	210	0.4	198.0	410	0.5
10	120	72	1.7	42.0	100	0.4	46.8	112	0.4	51.6	120	0.4
11	81.6	112.8	0.7	44.4	116	0.4	40.8	82	0.5	50.4	116	0.4
12	96	108	0.9	38.4	110	0.3	42.0	110	0.4	60.0	120	0.5
13	60	19.2	3.1	31.2	80	0.4	21.6	56	0.4	30.0	60	0.5
14	60	2.4	25.0	30.0	80	0.4	24.0	60	0.4	28.8	56	0.5
15	52.8	21.6	2.4	34.8	86	0.4	24.0	50	0.5	34.8	70	0.5
16	60	4.8	12.5	6.0	40	0.2	14.4	36	0.4	14.4	44	0.3

*Source No. 5 was completely chocked; ** No flow of water.

soil tends to increase surface sealing and erosion during rainfall events [14]. It has also been shown that Mg^{2+} enhances the effect of Na^{+} on dispersing clay particles, thereby lowering the infiltration rate and hydraulic conductivity, and increasing compaction in the topsoil, which ultimately affects crop growth and yield. The process is insidious and takes years for its effects to manifest in structural decline [15, 16].

The productivity of soils affected by magnesium ions can be enhanced by increasing Ca^{2+} cation exchange to mitigate the effects of excessive exchangeable Mg^{2+} [17]. This can be accomplished by applying sufficient amounts of Ca^{2+} to soil [18]. Phosphogypsum, the main by-product of phosphate fertilizer from phosphate rock, can be used as a source of Ca^{2+} as it is mainly composed of gypsum ($CaSO_4{\cdot}2H_2O$).

Rashid et al. [19] reported that applying gypsum at a rate of 2.5 t/ha before the monsoon in a rainfed environment increased moisture in the soil profile at the time of sowing, thereby helping to increase wheat yield by up to 46%. This application of gypsum increased Ca^{2+} cation exchange in the soil and reduced the effect of Mg^{2+}, helping to increase the infiltration rate of the soil and hence conserve moisture.

3.2 Groundwater Quality

The water table is very deep in the study area, and groundwater (mostly perched) has developed in the vicinity of the recharging sources. The groundwater is used for both drinking and irrigation purposes and was monitored at 10 different locations in the watershed. The groundwater quality for various locations is shown in Table 5. Trends in groundwater quality are very similar to those for surface water and show high spatial and temporal variability. At points 1, 3, 5, 7 and 8, the EC was within the permissible limit, at point 6 it was slightly higher, and at points 2, 4, 9 and 10, it was about 1.5 times higher than the threshold. Therefore, four out of ten samples exceeded the permissible limit for EC. Similarly, three out of ten samples exceeded the permissible limits for SAR, and six out of ten exceeded those for RSC, reflecting sodicity in the groundwater. As discussed previously, the use of such water may lead to a deterioration in the soil structure and ultimately affect crop yields.

Table 6 shows that most of the groundwater samples exceeded the permissible limit of Mg^{2+} during the months of October and November 2010, whereas Ca^{2+} and the Mg^{2+}/Ca^{2+} ratio were within permissible limits for the monitored period.

The quality of drinking water can be judged from aesthetic, chemical, and microbiological points of view. The chemical quality of the monitored sources of groundwater was within the permissible limit at all except two locations (Table 7) where the Cl content

Table 5 Groundwater quality at certain critical locations in the Dhrabi watershed.

Location	EC (dS/m)					SAR					RSC (meq/L)				
	Oct. 09	Nov. 09	Feb. 10	May 10	Sep. 10	Oct. 09	Nov. 09	Feb. 10	May 10	Sep. 10	Oct. 09	Nov. 09	Feb. 10	May 10	Sep. 10
1	1.02	0.97	0.98	1.03	0.88	1.4	0.6	1.2	1.4	1.3	0.0	0.1	2.3	1.5	3.4
2	2.32	2.20	2.17	2.26	2.22	6.7	8.6	6.0	6.2	6.6	1.0	4.6	3.7	4.8	6.9
3	1.12	1.07	1.11	1.16	1.06	10.3	8.7	16.3	22.2	15.5	3.4	3.6	7.1	6.6	6.4
4	2.48	2.46	2.45	2.60	2.30	12.5	12.2	10.4	12.0	11.4	2.5	1.9	3.3	4.8	6.1
5	0.55	0.56	0.72	0.61	0.59	0.3	0.4	0.0	0.2	0.6	0.0	0	0.7	1.0	4.3
6	1.69	1.00	1.54	NA	1.09	9.9	6.9	4.8	NA	4.5	1.9	2.4	1.2	NA	2.1
7	0.66	0.62	0.64	0.71	0.64	1.0	1.3	0.7	1.3	1.4	0	0.4	1.4	3.0	3.5
8	0.89	0.86	1.52	1.06	0.95	6.9	6.6	5.3	20.2	12.0	1.9	0.9	2.2	7.0	5.8
9	3.08	2.44	1.95	1.90	1.02	6.8	4.70	5.7	7.8	2.1	0	0	3.0	5.9	2.1
10	NA	2.6	1.75	3.08	1.45	NA	4.76	2.8	6.1	2.8	NA	0	0	0	3.9

NA: samples not available.

Table 6 Values for Mg^{2+}, Ca^{2+} and Mg^{2+}/Ca^{2+} ratios in groundwater samples from various locations of the Dhrabi watershed.

Location	Mg^{2+} (mg/L)					Ca^{2+} (mg/L)					Mg^{2+}/Ca^{2+}				
	Jul. 10	Aug. 10	Sep. 10	Oct. 10	Nov. 10	Jul. 10	Aug. 10	Sep. 10	Oct. 10	Nov. 10	Jul. 10	Aug. 10	Sep. 10	Oct. 10	Nov. 10
1	25	20	36	38	32	90	76	70	90	80	0.3	0.3	0.5	0.4	0.4
2	6	20	41	48	47	40	60	104	116	110	0.2	0.3	0.4	0.4	0.4
3	2	2	2	8	5	6	10	12	36	28	0.4	0.2	0.2	0.2	0.2
4	5	22	22	24	30	44	64	64	74	76	0.1	0.3	0.3	0.3	0.4
5	19	11	24	20	29	56	76	60	70	60	0.3	0.1	0.4	0.3	0.5
6	11	14	16	30	42	52	48	60	60	80	0.2	0.3	0.3	0.5	0.5
7	24	10	18	20	24	50	70	56	66	60	0.5	0.1	0.3	0.3	0.4
8	26	6	2	6	20	40	20	16	30	64	0.7	0.3	0.2	0.2	0.3
9	12	32	34	42	48	70	60	74	130	160	0.2	0.5	0.5	0.3	0.3
10	40	53	48	37	68	100	112	92	140	120	0.4	0.5	0.5	0.3	0.6

Permissible limits: $Ca^{2+} < 75$ mg/L; $Mg^{2+} < 30$ mg/L; Ca/Mg ratio < 1.5. Source: Ref. [11].

Table 7 Groundwater contaminants in drinking water sources in the Dhrabi watershed (Nov. 04, 2009).

Site	Cl	Mg	SO_4	NO_3	NO_2	As (ppb)	Mn
Chak Khushi hand pump	35	58	50	5	0.052	4.67	BDL
Ghulam Haider hand pump	174	75	165	51	BDL	0.57	BDL
Ratta hand pump	95	6	48	0.2	BDL	4.9	BDL
Dhoke Mori dug well	418	50	124	17	0.259	0.71	BDL
Dhoke Zawar dug well	5	40	28	2	0.055	0.65	BDL
Dhoke Choie stream	122	29	60	1	0.066	7.08	BDL
Sadat Turbine	17	29	10	5	0.052	0.86	BDL
Shahid Abbasi Ratta	71	9	41	0.3	0.038	8.94	BDL
Downstream KK	456	46	229	2	BDL	2.82	BDL
Upstream KK	19	4	224	10	0.029	3.23	BDL

Permissible limit (mg/L): Cl (250), Mg (150), SO_4 (250), NO_3 (10), NO_2 (3) As (10 ppb) and Mn (0.1). BDL: below detection limit.

exceeded permissible limits. Chloride toxicity has not been observed in humans except in the special case of impaired sodium chloride metabolism, e.g. in congestive heart failure. Healthy individuals can tolerate the intake of large quantities of chloride provided that there is a concomitant intake of freshwater. However, little is known about the effect of a prolonged intake of large amounts of chloride in the diet. As in experimental animals, hypertension associated with the intake of sodium chloride appears to be related to the sodium rather than the chloride ion [20].

Microbiologically, two out of eight samples during August 2009, none out of eight samples during February 2010 and one out of nine samples during June 2010 were found fit for drinking (Table 8). Similarly, a study conducted by PCRWR in Chakwal showed that all the sampled drinking water sources in the Dhrabi watershed were microbiologically contaminated [21]. Microbiological contamination is therefore one of the major problems in the drinking water of Pakistan. It is responsible for directly or indirectly spreading major infections and parasitic diseases such as cholera, typhoid, dysentery, hepatitis, giardiasis, cryptosporidiosis and guinea-worm infections. The United Nations Conference on Environmental and Development estimated that about 80% of all diseases are water-borne, that 33% of the total deaths in developing countries are due to polluted water, and that 10% of each person's productive time is wasted due to water-related diseases. However, the chemical quality of the Dhrabi Reservoir was relatively good for drinking purposes (Table 9).

Table 8 Microbiological quality of drinking water sources in the Dhrabi watershed.

Site	28 Aug., 2009		22 Feb., 2010		22 June, 2010	
	Total coliforms	*Fecal coliforms*	*Total coliforms*	*Fecal coliforms*	*Total coliforms*	*Fecal coliforms*
Chak Khushi hand pump	350	280	3.6	3.6	20	4
Ghulam Haider hand pump	4	4	1.1	1.1	0	*0*
Ratta Hand pump	280	220	NA	NA	1100	1100
Dhoke Mori dug well	220	130	2.2	2.2	1100	1100
Dhoke Zawar dug well	1600	350	>23	>23	1100	1100
Dhoke Choi/Mori Stream	170	170	2.2	2.2	1100	1100
Sadat Turbine	0	0	12	12	93	43
Shahid Abbasi Ratta	0	0	23	23	1100	11
Dhrabi Reservoir	NA	NA	12	12	1100	23

NA: samples not available.

Table 9 Chemical water quality of the Dhrabi reservoir (with relevance for drinking purposes).

Parameter	Unit	Water quality	Permissible limit
pH	-	7.2	6-10
Conductivity	dS/m	1.1	ND
Turbidity	NTU	3	5
Total alkalinity	mg/L	280	ND
Total hardness	mg/L	228	ND
Total solids	mg/L	534	ND
Total suspended solids	mg/L	4	150
Chloride	mg/L	130	250
Fluoride	mg/L	0.75	20
Calcium hardness	mg/L	132	250
Total organic carbon	mg/L	11.2	ND
Total nitrogen	mg/L	1.5	15

ND: not detected.

3.3 Water Table Depth

The depth of the water table may have a significant impact on groundwater quality depending upon the extent and locations of the recharging sources. Fig. 2 shows water-table depth with respect to the soil surface. There was high spatial variation in water-table depths, mostly due to topography and proximity to the recharging sources. By contrast, there was a very small temporal variation, most probably due to the small degree of groundwater extraction in the area.

3.4 Wastewater

Wastewater is an important component of integrated watershed management. In the Dhrabi watershed, however, most villages do not generate much wastewater; local water availability is low and most farmers have to fetch water for their domestic uses. Only one village-Khandoa has a wastewater pond outside the village. This pond also stores rainwater and is used for animal drinking and small-scale agriculture. Most wastewater tested was within the permissible limits for BOD and COD. However, the Khandoa wastewater pond had high levels of BOD and COD, which may be due to stagnant water remaining in the pond for a relatively long period of time.

3.5 Sources of Salinity in the Water

There could be two sources that are contributing to salinity and sodicity in the surface water and groundwater: (1) perennial streams (rather than

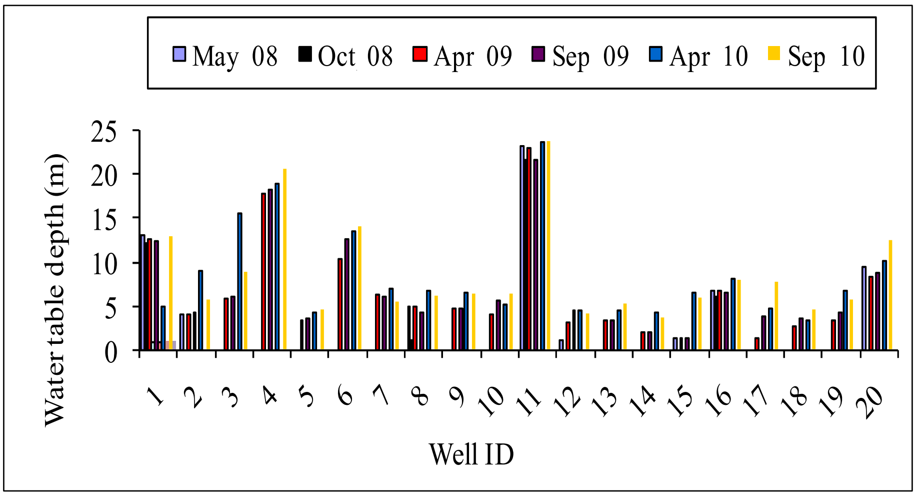

Fig. 2 Water table fluctuations in the Dhrabi watershed during some months of the years 2008, 2009 and 2010.

rainwater which is always free from such impurities); and (2) salts present in the soil profile that are detached and are transported to the water bodies with the runoff. To identify the sources of salinity in the surface water, samples were collected from two perennial streams during low-flow periods (November 2009). Table 10 shows that the water quality in the perennial streams was relatively good.

Soil samples were also collected from the catchment areas of the major polluting streams and from the beds of the Kallar Kahar Lake and Dhrabi Reservoir. The soil samples from the catchments show relatively high salinity and sodicity that might be the cause of high salinity and sodicity in the streams (Table 11). It is interesting to note that the highest EC, SAR and exchangeable sodium percentage (ESP) in the bed samples from the Kallar Kahar Lake were about 43 dS/m, 56 and 45, respectively. Similarly, the EC in the bed samples of the Dhrabi Reservoir was 5.1 dS/m and it was almost double than the threshold value. The high EC, SAR and ESP values in the bed of the Kallar Kahar Lake are due to the saline water brought into the lake with the runoff; evaporation from the lake results in increased salinity in the water, and the salts ultimately settle down at the lake bed increasing the salinity and sodicity. The Dhrabi Reservoir became operational during 2007. It is expected that salinity and sodicity in the bed of the Dhrabi Reservoir will also increase with time.

The small and mini dams and ponds are the main sources of groundwater recharge in the watershed area of the Dhrabi Reservoir. However, with such a high sodicity at the bed of the Dhrabi Reservoir, recharge to the groundwater will be substantially reduced. There is therefore a need to conduct a systemic study on the effect of saline-sodic water on groundwater recharge.

To ascertain how the catchments are contributing to salinity in water, soil samples were collected to a depth of 15 cm from both uncultivated and cultivated fields. Table 12 shows that there are substantial amount of salts present in the soil profile, particularly in the catchment areas of the Kallar Kahar Lake. Since the

Table 10 Water quality in perennial streams in the Dhrabi watershed.

Location	EC (dS/m)	SAR	RSC (meq/L)
Inflow to Kallar Kahar (KK) Lake (Point 1)	1.51	1.96	0
Inflow to KK Lake (Point 2)	1.56	1.4	0
Drain surrounding the KK Lake	1.64	1.75	0
Nikka Dam	0.68	2.61	1.6

Table 11 Soil analysis of samples in the Dhrabi watershed.

Site	Date of sampling	pH	EC (dS/m)	SAR	ESP
Right side of the Dhrabi Reservoir bed	4.11.09	7.9	2.4	1.0	0.2
Left side of the Dhrabi Reservoir bed	4.11.09	7.8	5.1	3.9	4.3
Right side of Kallar Kahar (KK) Lake bed	4.11.09	8.7	41.9	56.2	44.9
Left side of the KK Lake bed	4.11.09	8.6	32.8	44.6	39.2
Catchment of water point No. 1	15.11.09	9.7	2.4	12.6	14.7
Catchment of water point No. 1*	15.11.09	9.0	0.6	3.5	3.7
Catchment of KK Lake (right)	23.11.09	8.0	2.7	3.6	3.8
Catchment of KK Lake (middle)	23.11.09	8.4	0.3	0.2	0.0
Catchment of KK Lake (left)	23.11.09	8.3	2.7	7.7	9.1

*Two different samples from the same catchment.

Table 12 Soil salinity status in the Dhrabi watershed.

Site	Land use	pH	EC (dS/m)	SAR	ESP
Bhurpur Road near surface water sampling point No. 1	Uncultivated	7.89	1.36	1.94	4.05
	Cultivated	8.01	0.47	1.53	3.48
Chak Khushi near surface water sampling point No. 7	Uncultivated	7.69	0.93	0.68	2.27
	Cultivated	7.83	0.55	0.69	2.28
Kallar Kahar near surface water sampling point No. 8	Uncultivated	8.56	2.23	9.64	13.70
	Cultivated	8.10	0.43	3.36	5.99
Ratta Bridge near surface water sampling point No. 14	Uncultivated	7.90	1.22	3.55	6.25
	Cultivated	8.22	1.07	4.43	7.40

main source of water to the Kallar Kahar Lake and the Dhrabi Reservoir is runoff, large amounts of these soil-based salts are transported to the water bodies.

4. Conclusions

Monitoring of water quality has emerged as one of the most important components of watershed management. In the Dhrabi watershed of Pakistan, the surface water and groundwater quality was relatively poor, with high spatial and temporal variability. The prolonged use of such water for irrigation purposes may pose soil salinity and sodicity problems. The quality of drinking water in the study area was also poor; without proper treatment, its use may threaten the heath of local people. Since the Kallar Kahar Lake and its catchment are the main contributors of water with high levels of EC and RSC, no water from the lake should be allowed to spill over into the wider environment. This could be done by: (1) raising the dikes of the Kallar Kahar Lake and storing as much water as possible from the catchment; (2) using chemical amendments, such as gypsum in fields, to reduce the negative impacts of the sodic water; and (3) adopting an appropriate cropping pattern.

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