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Divergent effect of Rainfall, Temperature and Surface water bodies on Groundwater Quality in Haveli Canal Circle of Multan Irrigation Zone, Southern Punjab, Pakistan

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Abstract: Agricultural lands of Southern Punjab, Pakistan are characterized by fertile lands and historically rich for crop production. Water resource including both underground and surface is affecting the quality of water for irrigation. In this study, meteorological parameters (precipitation and temperature) and canal discharge were studied from 2014 to 2017. Results indicated that meteorological parameters and canal discharge had a strong influence on groundwater quality, however, different trends were observed. EC, SAR & RSC were affected by temperature, rainfall and canal discharge, due to salt accumulation. More than half area (51%) of the Shorkot was affected due to the presence of waterlogged and salt affected soil with brackish groundwater. Perennials canals also exist in this area. But 34% of the study area was affected by meteorological parameters (more temperature, rainfall) and surface waterbodies (due to mixing of detergents and solid waste coming from nearby colonies and towns).

Keywords: Groundwater, meteorological parameters, correlation, pre & post-monsoon.

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1. Introduction

Water exists in form of surface water, rainfall and underground used for irrigation that also plays vital role in the hydrological cycle (Cui et al., 2019; Sprenger et al., 2019). Globally, groundwater is the largest storehouse of unfrozen freshwater for human's generation to come. It is essential to the economic viability and livability of the community with diversified utilization, including irrigation, drinking, domestic and industrial purposes municipal water supplies (Bierkens and Wada. 2019; Wu et al., 2013; Allen et al., 2002; Jia et al. 2019). Groundwater serves as the source of water supply for the majority of residents in the urban areas. It is heterogeneously linked with various processes at spatiotemporal scales (Afonso et al., 2020; Dawood et al., 2020; Gleeson et al., 2020). Sustainability of global ecosystem is highly linked with the sustainable groundwater management, as it assists humans to adapt climate change and variability (Elshall et al., 2020; Khatri and Tyagi, 2015). Although, groundwater is pooled water reservoir, shared by humans, critical to meet requirements of both humans and ecosystem, however, often exploited and depleted without considering its sustainability (Rodell et al., 2018). Groundwater supplies the drinking water needs of nearly all the population in the area. Good quality groundwater is important for domestic, industrial and agricultural uses (Rosa et al., 2019; Mangalekar and Samant 2012). Long-term and stable storage maintenance of good quality water encompasses the sustainability of groundwater (Gleeson et al., 2020).

Freshwater resources are facing unprecedented pressure due to population growth and climate change-induced anomalies in the hydrological cycle (Sapkota, 2019). Increasing crisis, of freshwater

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availability and quality issues, is compromising, public health and food security by aggravating agricultural water shortage. Adequate protection of groundwater requires periodic monitoring of groundwater quality (Kacaroglu, 1999; Talabi and Kayode. 2019). Groundwater management is an important natural resource issue to underpin the socio-economic sustainability of the region (Castilla-Rho et al., 2017; Sampson and Perry. 2019). The aquifer vulnerability caused by landfill operations, disposal of pollutants, industrial and agricultural activities (Aslam et al., 2018; Barbulescu, 2020; Machiwal et al., 2018; Nema et al. 2017).

Excessive water Excessive water extraction affects the groundwater quality and level. In Pakistan, around 1.20 million tube wells were installed, more than 90% of these were used to extract water for agriculture purpose (Qureshi et al., 2008; Arshad et al., 2013; Qureshi, 2012). The research was conducted to evaluate the effect of temperature, rainfall and discharge on groundwater quality. Furthermore, it was designed to discover the potential linkage between groundwater quality, meteorological conditions (rainfall and temperature) and field area (six tehsils) covered by three main canal discharge (cumecs).

2. Materials and Methods

2.1. Study area

The study area consists of six tehsils (Shorkot, Toba Tek Singh, Kabir Wala, Multan, Shujabad and Jalalpur Pirwala) of Punjab having same starting point of canal division that starts from the Trimmu Headworks end on Shujabad canal division as shown in Fig. 1. It also exists under three canal division such as Trimmu Barrage division, Multan canal division and Shujabad canal division. Three main canals off-take from Trimmu Headworks (H/W) on the right-side Rangpur canal (Non-perennial) and on the left side Haveli Main Line (HML) (Perennial) & Trimmu Sidhnai link (TSL) Canal are existing. Haveli Main Line and TS Link Canal fall into River Ravi and become part of Sidhnai Handworks. Rangpur Canal and HML irrigate the Trimmu Canal Division. The agricultural land of Multan canal division is under the command of Sidhnai canal (Perennial) which off-takes from Sidhnai (H/W) and cover the area of tehsil Khanewal and Multan. The canal command area of Shujabad canal division is throughout in vicinity and along with the River Chenab and irrigated by Shujabad canal (Non-perennial) which off-takes from Sidhnai canal.

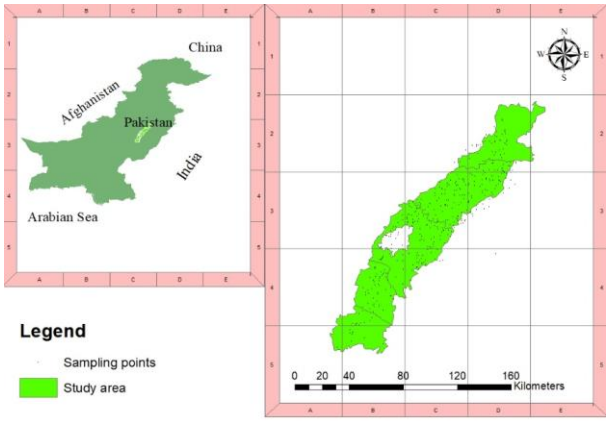

Fig. 1. Map of the study area

The area of the Shorkot is bound by River Chenab on the right side, while on the left side there are HML and TSL Canal. The latter is unlined and is the source of seepage and waterlogging in the adjacent area and on the south side there is River Ravi. The Agricultural land of Tehsil Shorkot is under the command of channels that directly off-take from the right side of HML. The soils of the area are salt-affected and waterlogged. Moreover, groundwater is mostly brackish. The agricultural land of this canal division is under the command of Sidhnai canal (perennial) which off-takes from Sidhnai (H/W) and covers the area of Tehsil Khanewal and Multan. This area is best for agricultural crops with the greatest utilization of canal/ tube wells water. The main crops of this area are Wheat, Cotton, Gardens, fodder etc. The main canal of tehsil Shujabad and Jalalpur Pirwala is Shujabad Canal (Non-perennial) from which different distributaries instigated and irrigate the land in vicinity of the area. The main field crops grown here are wheat, cotton, rice, mango & citrus orchard, and fodder. The Climate of study area is arid and semi-arid with hot summer and mild-cold winter (Farid, et al., 2019). With respect to climate changes, the highest and lowest temperature recorded in the study area was 54 °C and −1 °C respectively (Abbas and Abbas 2013). The rainfall varies across two seasons that are pre-monsoon and post-monsoon season, but the average rainfall in the study area varies from 100 mm to 300 mm, but 60% of the total annual rainfall occurs including pre-monsoon and post-monsoon (Faisal et al., 2013).

2.2 Datasets Collection and Methodology

The meteorological data of rainfall and temperature was collected from Pakistan Meteorological Department, Multan, Punjab, Pakistan and groundwater quality data was collected from Multan Irrigation Zone (Land Reclamation

Department), Irrigation Department Punjab, Pakistan. The groundwater quality data of electrical conductivity (EC), sodium adsorption ratio (SAR), and residual sodium carbonate (RSC) of different samples were analyzed by the Punjab Irrigation Department, using standard protocol from monitoring sites in pre-monsoon and post-monsoon throughout the year.

Rainfall and temperature are the important parameter to evaluate its overall effect on groundwater quality, environment and water resources. These parameters also effect the transpiration as well as evaporation of plants and land surface (Mohammed and Scholz 2017). Trend analysis groundwater quality parameters (EC, SAR and RSC) with respect to meteorological parameter and canal discharge were evaluated through graphical analysis and comparison of all parameters used in this study.

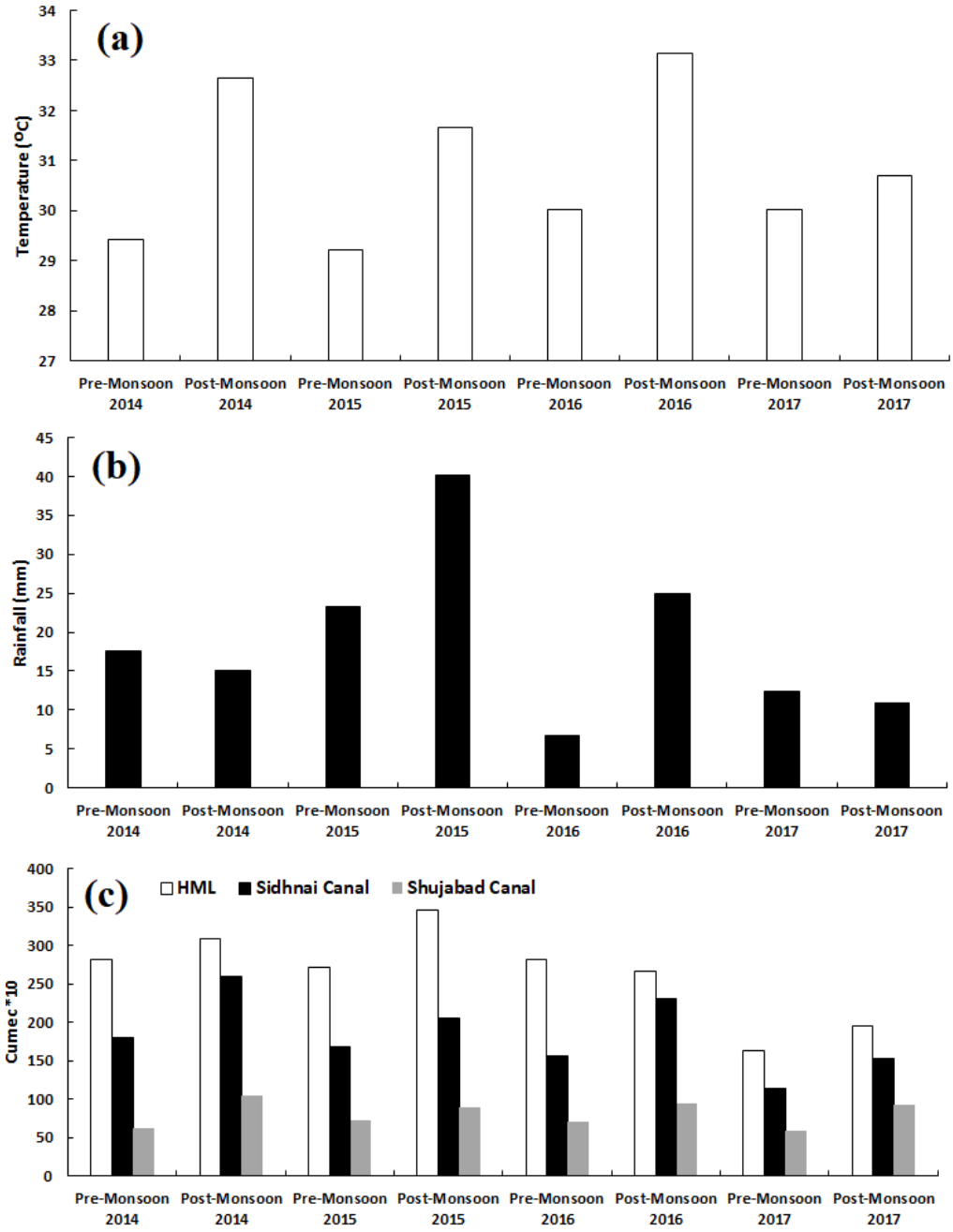

Fig. 2. Mean maximum temperature (a) and rainfall (b) over study area and seasonal water discharge at different at Haveli Main Line (HML), Sidhnai and Shujabad Canal (c).

3. Results and Discussion

The trend analysis and correlation of meteorological parameters and main three canals with respect to groundwater quality parameters are shown in Fig. 2. HML canal passes through tehsil Shorkot and Toba Tek Singh, Sidhnai canal passes through Kabirwala and Multan and Shujabad canal used to irrigate Shujabad and Jalalpur Pirwala.

The groundwater quality parameters data was analyzed with average value due to vicinity of river and canal passing through its command area of every tehsil and So, the trend analysis is shown of Haveli Main Canal for the command area of Shorkot and Toba Tek Singh.

3.1. Shorkot and Toba Tek Singh Region

The main canal of Shorkot tehsil is Haveli Canal Main Line from which different distributaries instigated and irrigate the land in the vicinity of the area. Its estimated terrain elevation above sea level is 146 meters. The main field crops grown here are sugarcane, rice, wheat and fodder.

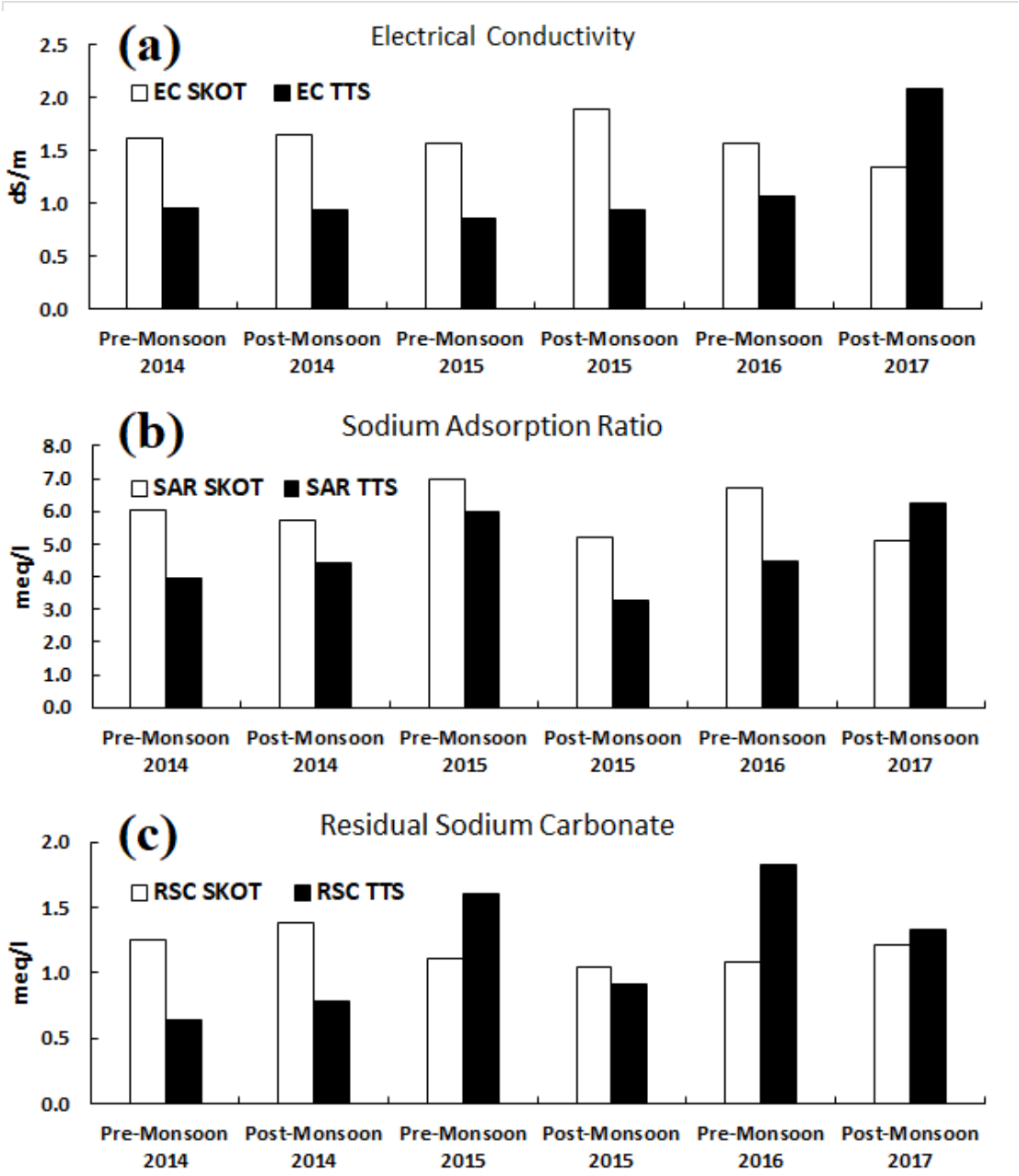

Fig. 3. Groundwater quality parameters (a) electrical conductivity (EC, dS/m), (b) sodium adsorption ration (SAR, meq/l) and (c) residual sodium carbonate (RSC, meq/l) of tehsil Shorkot and Toba Tek Singh.

The area around roots of these field crops including rhizosphere and rhizoplane have immense variable effects on water in soil solution, that have a greater effect on groundwater quality parameters due to water chemistry (Etesami, et al., 2018). Metals and different heavy materials that decomposed as solid waste are dissolved during infiltration and seepage, to create an adverse effect on groundwater quality (Abedinzadeh, et al., 2019). Uptake and discharge of different anions and cations through plant roots may ameliorate the groundwater composition through seepage if internal soil drainage is good and the groundwater table is not too deep. A wide spatial variation has been recorded on cultivated land and uncultivated land as plantation affect soil physical, chemical and biological processes which ultimately give sharp effect on groundwater.

There were 43 numbers of groundwater quality points in tehsil Shorkot under study area jurisdiction out of which 48.8% were fit according to parameters (EC, SAR & RSC) analyzed and 51% went unfit. Maximum unfit points were due to the electrical conductivity, residual sodium carbonate and sodium adsorption ratio. The ratio amongst unfit points due to studied parameters i.e., EC: SAR wise were 18:5. The results demonstrate absolute dissolution mechanisms involved in the groundwater chemistry of the study area.

Similar relations can be perceived in Fig. 2, highlighted that maximum precipitation and discharge of HML (Haveli Main Line) were observed in post-monsoon 2015. These factors advocate the leaching effect in the soil which stimulates the ionic and non-ionic particles mineral dissolution chemistry (Sadegh-Zadeh et al., 2017; Zerrouqi et al., 2020). Thus, water that leaves the soil to the underlying groundwater is enriched with salts. Thereat might be the reason of maximum electrical conductivity during the post-monsoon 2015 and later seasons as depicted in Fig. 3 (a). However, the least value of electrical conductivity was recorded during the post-monsoon season of 2017, potentially due to the low canal discharge and rainfall.

Nonlinear correlation was observed in pre- and post-monsoon of each year for SAR as showed in Fig. 3 (b). Maximum SAR values were recorded during pre-monsoon as compared to post-monsoon. The inconsistency between SAR values of pre- and post-monsoon might be attributed due to the canal flow and precipitation. Canal flow and rainfall intensity remained higher after monsoon season and the same residual effect can cause the high Na ratios in groundwater chemistry during monsoon due to the forerunning season. Pedochemical processes may be invoked in such zig-zag variation of SAR in the study period. The dissolution of halite, ion exchange reactions on the surfaces of some clay minerals whereby sodium is released to the water in exchange for calcium or magnesium (Yokozeki., 2004). After the dissolution and reaction of silicate minerals and different metals like feldspar minerals, sodium is formed. These were possible ways of such result that can be viewed as above. Water chemistry is dependent upon water resources and their duration of interaction with the reactive minerals (Chiogna et al., 2016; Lane et al., 2018; Maher and Navarre-Sitchler, 2019; Singh et al., 2016).

All these factors that were discussed above from different literature are also dependent to annual precipitation, temperature of the area and surrounding canals flow. There was no significant relation could be established amongst recorded environmental conditions and variations in RSC values (Fig. 3 c). The high values of RSC were recorded in the year 2014 as compared to lateral years. So, there must be some sort of link with preceding meteorological circumstances as their residual possessions might be likely the way of such variations. Therefore, the existing chronicled data is inadequate to elucidate the current conditions of RSC based relation with precipitation, temperature and canal flow. It may be some hydrological chemistry involved in such variation of RSC value.

HML also exists in Toba Tek Singh (T.T. Singh). There were 08 numbers of groundwater points in tehsil T.T Singh under study area jurisdiction out of which 75% are fit according to parameters (EC, SAR and RSC) analyzed and 25% went unfit. Maximum unfit points were due to the EC, SAR and RSC, throughout the period under study. The ratio amongst unfit points due to studied parameters i.e., EC: RSC wise were 2:1. The results reveal dissolution processes involved in the groundwater chemistry of the area under study (Fig. 3). The similar corresponding relations can be perceived in Fig. 2, disclosed that maximum precipitation and discharge of HML were observed during post-monsoon 2015. Threat of maximum electrical conductivity during the post-monsoon 2015 and later season as depicted in Fig. 2. But maximum EC was recorded in post-monsoon 2017 which may be the reason due to the residual effects of climatic change and the presence of plagioclase feldspar minerals. Further the initial increase in EC may be due to the forerunning

meteorological conditions and canal discharge or others.

Nonlinear relationship was detected in pre- and post-monsoon of each year for SAR as showed in Fig. 3 b. Maximum SAR values were recorded at post-monsoon 2017. The reason behind the maximum value of SAR at pre-monsoon might be due to highest temperature recorded during the span of time. Thermal energy is a key source to trigger internal soil processes that may leads to accelerated geochemical processes (Karroum et al., 2017; Shyartsev et al., 2018). That may be the reason of maximum SAR value of sodium as highest value of temperature may disintegrate the sodium minerals such as plagioclase feldspars and accelerate the release of sodium ions into groundwater. The canal flow has a little effect as a residual effect in its increase through seepage.

In Fig. 3 c, there was maximum values of RSC were noted during the pre-monsoon season than after monsoon seasons. The maximum value (1.83) was noted in pre-monsoon 2016. The inconsistency between RSC values of pre-monsoon and post monsoon might be attributed due to the canal flow and precipitation. Canal flow and rainfall intensity remained higher after monsoon season and the same residual effect can cause the high Na ratios in groundwater chemistry during pre-monsoon due to the forerunning season. Pedochemical processes may be entreated in such alternative variation of RSC values in the study period.

3.2. Multan and Kabirwala Region

The trend analysis is shown of Sidhnai Canal for the command area of Kabir Wala and Multan. There were 142 numbers of groundwater points in tehsil Kabir Wala under study area jurisdiction out of which 76.7% were fit according to parameters (EC, SAR and RSC) analyzed and 23.3% went unfit. The ratio amongst unfit points due to studied parameters i.e., EC: RSC wise were 8:1. Maximum EC values were recorded as 20 and minimum were 18 in unfit points. RSC values were higher in unfit points as its maximum recorded values were 19 during pre-monsoon season. The results reveal dissolution processes involved for higher EC values of the area under study as shown in Fig. 4. During post-monsoon season the recorded values of EC were higher as compared to pre-monsoon season. The similar corresponding relations can be perceived in the above Fig 3. Fig. 2-c, disclosed that maximum discharge of Sidhnai Canal was observed in after monsoon 2014 and 2016. The EC of same seasons remained higher as is shown in Fig. 4 (a), and maximum value was recorded in post-2017. These factors advocate the leaching effect in the soil which stimulates the ionic and non-ionic particles mineral dissolution. Thus, water that leaves soil to become a part of groundwater is enriched with salts.

The Fig. 4 (b), indicates the relationship of SAR values among different periods under study. Maximum values of SAR were recorded during post-monsoon 2017. The reason behind the maximum value of SAR at pre-monsoon seasons may be some hydrological chemistry involved in such variation of RSC value or may be groundwater samples were not properly analyzed during the said period. Highest values of precipitation and canal flow make the release of Na as a residual effect from exchange sites and desorption from adsorbed sites through random thermal motion and other physical forces involved through these factors.

Maximum values of RSC were noted during pre-monsoon season than after monsoon seasons (Fig. 4 c). The inconsistency between RSC values of pre- and post-monsoon might be attributed due to the canal flow and precipitation. There were 106 numbers of groundwater points in tehsil Multan under study area jurisdiction out of which 67.9% were fit according to parameters (EC, SAR and RSC) analyzed and 32% went unfit. The ratio amongst unfit points due to studied parameters i.e., EC: RSC wise were 28:9. Maximum EC values were recorded as 28 and minimum were 26 in unfit points. SAR values were higher in unfit points as its maximum recorded values were 22 during pre-monsoon season. The results reveal dissolution processes involved for higher EC values of the area under study as shown in Fig. 4 a. During post-monsoon season the recorded values of EC were higher as compared to pre-monsoon season except for post-monsoon-2017. The similar corresponding relations can be perceived in Fig. 2. The maximum precipitation and discharge of Sidhnai Canal were observed in after monsoon 2014-16. The EC of same seasons remained higher as is shown in Fig. 4 (a), The higher values of EC during pre-monsoon 2016 were recorded as 1.92. It may be due to the residual effects of high canal flow (2591 Cumecs) and high rainfall (40.10 mm) that affects high salts.

The Fig. 4 (b), indicates the relationship of SAR values among different periods under study. The maximum values of SAR were recorded during pre-monsoon especially during pre-monsoon 2016 (6.85). The reason behind the maximum value of SAR at pre-

monsoon seasons might be due to high precipitation recorded during the post-monsoon season as shown in Fig. 4 (b). The highest values of precipitation make the release of Na as a residual effect from exchange sites and desorption from adsorbed sites through random thermal motion and other physical forces involved through these factors. Similarly, high temperature also accelerates the different chemical processes in soil especially pedoturbation which encounters different ions in soil water and addition to groundwater chemistry. In Fig. 4 (c), there was not any corresponding relation could be established amongst recorded environmental conditions and variations in RSC values. The maximum value (0.91) was noted in pre-monsoon 2015.

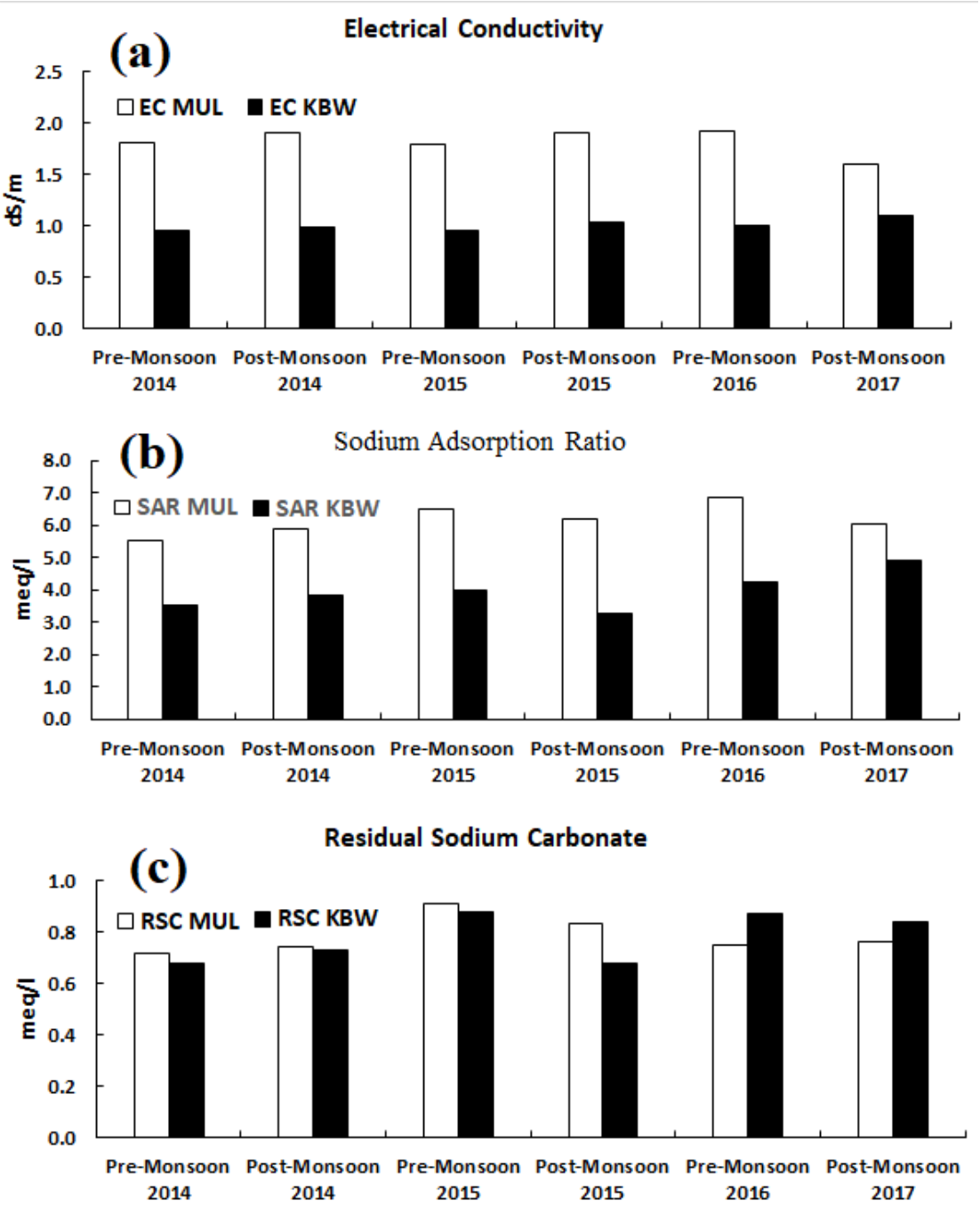

Fig. 4. Groundwater quality parameters (a) electrical conductivity (EC, dS/m), (b) sodium adsorption ration (SAR, meq/l) and (c) residual sodium carbonate (RSC, meq/l) of tehsil Multan and Kabirwala.

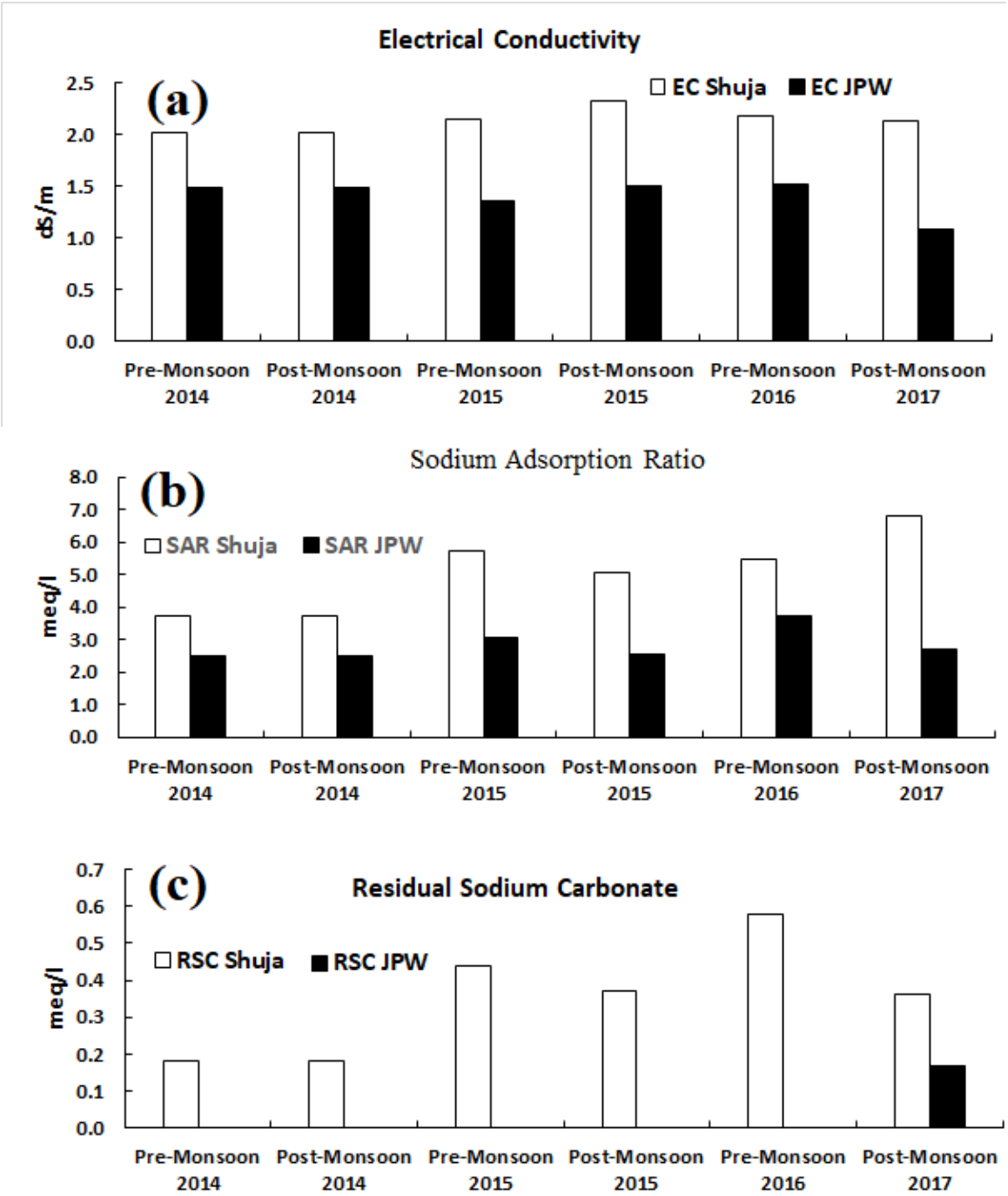

Fig. 5. Groundwater quality parameters (a) electrical conductivity (EC, dS/m), (b) sodium adsorption ration (SAR, meq/l) and (c) residual sodium carbonate (RSC, meq/l) of tehsil Shujabad and Jalalpur Pirwala

3.3. Shujabad and Jalalpur Pirwala Region

The trend analysis is shown of Shujabad Canal for the command area of Shujabad and Jalalpur Pirwala. There were 31 numbers of groundwater sampling points in tehsil Shujabad under study area jurisdiction out of which 61.2% were fit according to parameters (EC, SAR and RSC) analyzed and 38% went unfit. The ratio amongst unfit points due to studied parameters i.e., EC: SAR wise were 6:1. SAR values were also higher in unfit points as its maximum recorded values were 05 during pre-monsoon season and only one point was observed unfit due to RSC criteria. The results revealed dissolution processes involved for higher EC values of the area under study as shown in Fig. 5. During post-monsoon 2015

season, the recorded value of EC (2.33) was higher as compared to pre-monsoons or another season. The similar corresponding relations can be perceived in the above figures especially for canal flow, temperature and rainfall. Fig. 2, disclosed that maximum precipitation, temperature and discharge of Shujabad Canal were observed after monsoon 2015. The EC of same season remained higher as shown in Fig. 5 (a). These factors support the leaching effect in soil. The higher value of EC during post-monsoon 2015 were recorded as 2.33**.**

Fig. 5(b), indicates the relationship of SAR values among different periods under study. Maximum values of SAR were recorded during pre-monsoon 2015 and post-monsoon 2017 (6.80). The reason behind the maximum value of SAR at pre-monsoon seasons might be due to the involvement of underground water chemistry. Residual effects of high canal flow and precipitation recorded during the post-monsoon season as shown in Fig. 2. Highest values of precipitation and canal flow make the release of Na. In Fig. 5(c), maximum values of RSC were noted during pre-monsoon season than after monsoon seasons as shown in the above figure. The maximum value (0.58) was noted in pre-monsoon 2016. There were 12 numbers of groundwater points in tehsil Jalalpur Pirwala under study area jurisdiction out of which 66.6% were fit according to parameters (EC, SAR and RSC) analyzed and 33.3% went unfit. The ratio amongst unfit points due to studied parameters i.e., EC: SAR: RSC wise were 4:0:0. Maximum EC values were recorded as 04 and no point was observed unfit due to SAR or RSC criteria. The results revealed dissolution processes involved for higher EC values except for pre-monsoon 2015 and post-monsoon 2017 season of the area under study as shown in Fig. 5(a). During post-monsoon 2017 season the recorded value of EC (1.09) was least as compared to all other season. The reasons behind this can be due to the multifactorial issues including wrong sample collection, handling, and management or may be analyzing. Geology or hydrology science matters to understand such a sudden fall of EC. But in other seasons, the corresponding relations can be perceived in the above figures especially for canal flow and rainfall. The Fig. 2, disclosed that maximum precipitation, temperature and discharge of Shujabad Canal were observed in after monsoon 2015. The EC of same season was remained higher (1.52) as it shown in Fig. 5(a). The higher value of EC during pre-monsoon 2016 were recorded as 1.52. The reason behind the maximum value of EC might be due to the maximum canal flow and precipitation recorded during the post-monsoon 2015 season as shown in Fig. 2. Highest values of precipitation and canal flow make the release of soluble salts as a residual effect from surrounding minerals.

Relationship of SAR values among different periods under study is presented in Fig. 5(b). Maximum values of SAR were recorded during pre-monsoon especially during pre-monsoon 2016 (3.73). The reason behind the maximum value of SAR at pre-monsoon seasons might be due to highest canal flow and precipitation recorded during the post-monsoon 2015 season as shown in Fig. 2. There was a linear relationship observed amongst recorded RSC values, similar values were also visible in Shujabad canal division (Fig. 5 c).

Table 1. Water sample fitness percentage across the regions.

Study area tehsil-wise	Sample Fitness (%)	
	Fit	Unfit
Shorkot	48.8	51.2
Toba Tek Singh	75.0	25.0
Kabir Wala	76.7	23.3
Multan	67.9	32.1
Shujabad	61.2	38.8
Jalalpur Pirwala	66.6	33.3

The overall results of adverse effected area are presented in Table 1, in which half of the tehsil Shorkot area having adverse effect on groundwater quality due to moorland presence with salinity issues.

4. Conclusion

Effect of meteorological parameter and canal discharge on groundwater quality was investigated. Maximum precipitation and discharge were observed during post-monsoon season and residual effect can cause the high sodium (Na) ratios in groundwater chemistry during monsoon due to the forerunning season. High precipitation leaches down the maximum salts but high canal discharge dissolves the salts through high temperature and seepage which may cause a high rate of reaction in soil that affects salts accumulation in groundwater with time. Thus, water that leaves the soil to the underlying groundwater is enriched with salts. EC remained higher during maximum precipitation, temperature and canal discharge. But least value of electrical conductivity was recorded during post-monsoon 2017, due to the low canal discharge and rainfall. Due to extended rainfall (pre-monsoon) season, canal discharge and temperature, it was observed that SAR

and RSC were affected as like EC due to salt accumulation. Frequently, maximum values of groundwater quality parameters were recorded in pre-monsoon season with low values of canal discharge and rainfall and having more temperature. The inconsistency between SAR values of pre-monsoon and post-monsoon might be attributed due to the canal flow and precipitation. Maximum values of RSC were noted during the pre-monsoon season than after monsoon seasons. There was not any corresponding relation could be established amongst recorded environmental conditions and variations in RSC values. The maximum value was noted in pre-monsoon 2015. The existing chronicled data is inadequate to elucidate the current conditions of RSC based relation with precipitation, temperature and canal flow. It may be some hydrological chemistry involved in such variation of RSC value. The result indicating increasing trend with 65.05 monitoring sites were fit. However, 33.95 of the studied area was affected by rainfall, temperature and canal discharge distribution. More than half area was affected from Shorkot. Farmers were more dependent on surface water of perennials canal discharge. The soils of the Shorkot area was salt-affected and waterlogged. Moreover, its groundwater was mostly brackish. Following recommendations are given to avoid adverse effects:

The Rain harvesting, aquifer storage or artificial recovery wells techniques should be applicable in area having degraded quality to control disaster events like rural flooding through rivers. Surface water bodies such as perennials canal should be flow in poor groundwater quality area to decrease the water extraction rate. Construction of mini dam is necessary to control intense rainfall events, later these dams will be helpful to manage water quantity. To control the temperature, first control the emission of hazardous gases and HFCs (hydrofluorocarbons) from different vehicles and refrigeration systems, that effect the global warming and cause increase in temperature that occurs changes in hydrological cycles.

This research will be crucial for the policy makers to make amendments for installation of tubewells at proper distance and depth to extract recommended quantity of water to maintain its quality.

Competing Interest Statement: All the authors declare that they have no competing interests.

Author's Contribution: Ali planned and conducted study, collected data, wrote and revised manuscript under supervision of Hafiz Umar Farid and internship trainer Mehboob Hassan. The authors are agreed with the content of paper.

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