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Characterization and Assessment of Irrigation Water Quality: A GIS Based Study of District Chakwal, Pakistan

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Abstract

Water quality is one of the most important criteria that not only affect crop growth but also its proper management can lead to sustainable yields and improved soil health. Hence, the current study was conducted to explain the quality of groundwater for irrigation. For this, random sampling of water was carried out in 5 tehsils of district Chakwal including Talagang, Chakwal, Lawa, Kallar Kahar, and Choa Sedan Shah for a period of five years. Three parameters including EC (µS/cm), RSC (meq/L), and SAR were considered for assessing the quality of groundwater of district Chakwal. About 343 water samples from tehsil Talagang, 86 from Lawa, 989 from Chakwal, 27 from Choa Sedan Shah, and 134 from Kallar Kahar were collected. Maximum range of EC (220-26500), SAR (0.00-75.57) and RSC (0.00-12.80) was observed in Tehsil Chakwal. According to water quality parameters, samples showed higher fitness in RSC in comparison to SAR and EC in all tehsils. For instance, in tehsil Choa Saidan Shah fit water samples were 97.87%, while in Kallar Kahar 86.56%, Talagang 90.08%, Lawa 90.69%, and Chakwal 82.40%. Finally classifying the water samples on the three quality parameters EC (µS/cm), RSC (meq/L), and SAR revealed that 54.28% of water samples were found unfit. Based on the presented data, it could be recommended that in tehsils where the quality parameters are poor, the water needs to be reclamation for sustained crop production and improved soil health.

Keywords: EC., SAR., RSC., Soil health., Chakwal., GIS mapping

Introduction

The total area of Chakwal district is 1.82 million hectares with undulating topography comprising of broken gullies and low hill ranges. The Potohar range climate varies from semi-arid to sub-humid and sub-tropical. The rainfall ranges from 250-750 mm in some northern hilly parts and is very erratic. About 75% of rainfall occurs during monsoon i.e., June to September, resulting in flash floods and causing erosion and soil loss. The total area of Chakwal district is approx. 6600 square kilometers with a population of approx 1.4 million. Chakwal is subdivided into five tehsils namely Chakwal, Talagang, Lawa, Choa Saidan Shah, and Kallar Kahar. The annual growth rate of Chakwal is 1.99% and the population density is 210 persons per square kilometer. The majority of the population (86%) is residing in rural areas while the remaining (18%) is settled down in urban areas. The per capita income of Chakwal is $ 890 which is considerably lower than national average of $ 1386; literacy rate is 69% and the average household size is 6 people. The Chakwal district is predominantly an agricultural land with no specific industry and a large number of people depend on their livelihood through agriculture production. The erratic rainfall pattern, increases the risk and vulnerability due to long drought and crop failures. Underground water is one of the most precious sources of water widely used on this planet. It is mostly utilized in the form of domestic, industrial, and agricultural activities and is considered to be the purest water as compared to other sources due to various filtration phenomena in the underground soil (Jamshidzadeh *et al.*, 2018; Thompson *et al.*, 2018). In countries like Africa, Bangladesh, India, etc. which are mostly developing, their water quality is mostly poor due to natural and anthropogenic sources(Chabukdhara *et al.*, 2017; Li *et al.*, 2017). Pakistan is also an underdeveloped country, facing a scarcity of pure water due to its ever-exhausting water resources (Hussain *et al.*, 2017). Therefore, the evaluation of important chemical parameters of water quality covering the hydrochemistry of the different areas is being carried out extensively throughout the world. These quality parameters specially the physiochemical play an important role in groundwater management practices (Kattan, 2018). Different indices of water quality have been developed for assessing groundwater quality and they are not only of great significance but also widely used all across the globe (Rana *et al.*, 2018; Shooshtarian *et al.*, 2018; Singh *et al.*, 2018). All major water resources (freshwater) are becoming scarce day by day due to overpopulation, therefore the accessibility of fresh water is decreasing at an alarming rate for humans as well as agriculture (Iqbal *et al.*, 2018). The quality of groundwater is also deteriorating due to developmental processes that contaminate the subsoil water reservoirs ultimately affecting human health and the entire ecosystem (Iqbal *et al.*, 2019). The deterioration of water quality is of great concern to public health at the world level (Rahman *et al.*, 2020). Moreover, the human-induced actions, like improper disposal of municipal and industrial effluents and unbalanced use of chemicals in agriculture are also playing a pivotal role in worsening the quality of subsoil water (Azizullah *et al.*, 2011; Iqbal *et al.*, 2020; Shirani *et al.*, 2018; Subedi *et al.*, 2019).The use of GIS-based indexes as assessment tools is common, with a focus on the spatial variations of all relevant physicochemical quality indicators. The degree of the restriction is used to evaluate the technique's results (i.e., fit, marginally fit and unfit on the use of irrigation water). The decision maker can produce parameter maps for simple visual interpretation by integrating the geographic information system (GIS) platform into the assessment process, which also improves the overall soundness, objectivity, and clarity of analysis (Rahman *et al.*, 2020). The current study was planned to understand the quality of groundwater in the Chakwal district using GIS-based technique and to chalk out an effective strategy to preserve this precious resource for sustained irrigated agriculture to ensure food security.

Materials and Methods

Site description and background of the study: The Chakwal district is situated in Potohar, in the northern Punjab of Pakistan (32.8322° N, 72.6151° E). The presence of hills, changes in slope, topography, and variation in rainfall pattern result in variation in water quality of district Chakwal. The Government of Punjab established different laboratories in all different districts to facilitate farmers. Soil and Water Testing Laboratory, Chakwal is also facilitating the farmers through analysis of soil and water samples. In this context, water samples (underground) were collected from five tehsils (Choa Saidan Shah, Kallar Kahar, Talagang, Lawa, and Chakwal) of district Chakwal and were analyzed for their fitness to evaluate their quality and then give recommendations based on the analysis. The map of Chakwal is presented in Fig. 1

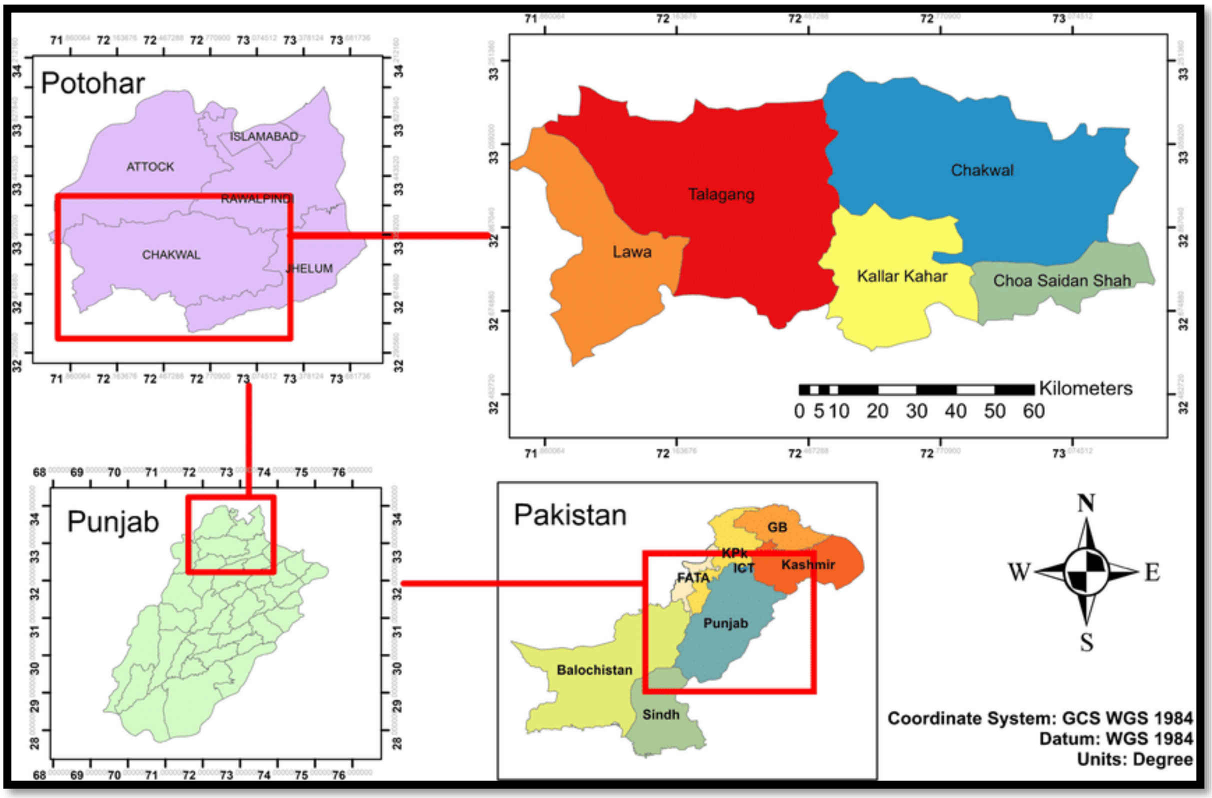

Fig. 1 Map of district Chakwal, Pakistan

Water sampling: To achieve the goal of this research, a study was carried out in the Soil and Water Testing Laboratory Chakwal having water samples collected from five Tehsils of Chakwal (Choa Saidan Shah, Kallar Kahar, Talagang, Lawa, and Chakwal). The water samples were collected from different tube wells with GPS (Geographical Positioning System) reading. The 0.5-1.0 liter water samples were collected at the depth of 80-250 feet after the 30 min operation of tube wells. The samples were stored in plastic bottles, properly labelled and closed with lids.

Water analysis: Approximately 1600 water samples were collected during 2016-2021 and were examined for electrical conductivity, cations (Ca^{+2}, Mg^{+2}, and Na^{+}), anions (CO_3^{-2}, HCO_3^{-1}, and Cl^{-1}) at the Soil and Water Testing Laboratory Chakwal using the procedures published by Page *et al.* (1982) Residual sodium carbonates (RSC) and sodium adsorption ratio (SAR) were computed using formulas outlined by the Thorne (1954).The obtained water samples were examined based on the following parameters (Table. 1) to determine their irrigation fitness.

$$SAR = \frac{\text{Na}}{\sqrt{Ca + Mg/2}}$$

$$\text{RSC (Me/L)} = (CO_3^{--} + HCO_3^{-}) - (Ca^{++} + Mg^{++})$$

Table 1. Water analysis parameters criteria for irrigation purpose

Parameters	Fit	Marginally fit	Unfit
EC (µS/cm)	0-1000	1000-1250	>1250
SAR	0-6	6-10	>10
RSC (meq/L)	0-1.25	1.25-2.50	>2.50

GIS mapping: ArcGIS 10.3 was used to display the spatial distribution of fit, unfit and marginally fit water samples according to EC, SAR and RSC of water samples in the study area.

Statistical analysis: Statistical data were analyzed for mean and percentage using MS-Excel 2016.

Results

Quality parameters of tube well water: Quality parameters (EC, SAR and RSC) were determined for Choa Saidan Shah, Kallar Kahar, Talagang, Lawa and Chakwal. The highest value of EC ranging from 220 to 26500 µS/cm was noted in tehsil Chakwal while minimum ranged from 470 to 7888 µS/cm was recorded in Choa Saidan Shah. Same trend was observed for SAR and RSC (Table 2).

Table 2. Minimum and maximum values of EC, SAR and RSC of tube well water in district Chakwal

Tehsil	EC (µS/cm)	SAR	RSC (meq/L)
Choa Saidan Shah	470-7888	0.06-18.82	0.00-4.05
Kallar kahar	150-8750	0.00-55.72	0.00-4.70
Talagang	160-12220	0.00-33.76	0.00-4.50
Lawa	0.270-8500	0.00-27.89	0.00-3.70
Chakwal	220-26500	0.00-75.57	0.00-12.80

Categorization of tube well water based on EC, RSC and SAR parameters

Electrical conductivity (µS/cm) status: The categorization of water samples for fit, marginally fit and unfit based on EC (µS/cm) is presented in Table 3. It can be observed that in tehsil Choa Saidan Shah, 44.6% of samples were fit, 17.02% marginally fit and just 38.29% were found unfit. In Kallar Kahar, 46.26% of water samples were fit, 11.19% marginally fit and 42.53% were unfit. Similarly, in Talagang, 46.93% of water samples were fit, 21.86% marginally fit and 31.19% were unfit. In Lawa, it was noted that 30.23% of water samples were fit, 18.60% marginally fit and 51.16% were unfit. In Chakwal, 22.86% of water samples were fit, 14.35% were marginally fit and 62.79% were unfit. Figure 3 shows the spatial distribution of fit, marginally fit and unfit samples according to the EC.

Table 3. Classification of water samples based on EC (µS/cm) in different Tehsils of Chakwal

Sites	**Total samples**	**Fit**		**Marginally fit**		**Unfit**	
		Samples	% age	Sample	% age	Samples	% age
Choa Saidan Shah	47	21	44.6%	8	17.02%	18	38.29%
Kallar kahar	134	62	46.26%	15	11.19%	57	42.53%
Talagang	343	161	46.93%	75	21.86%	107	31.19%
Lawa	86	26	30.23%	16	18.60%	44	51.16%
Chakwal	989	226	22.86%	142	14.35%	621	62.79%

Sodium adsorption ratio (SAR) status: The categorization of water samples based on SAR is presented in Table 4. The data revealed that in tehsil Choa Saidan Shah, 97.87% of samples were fit, 0% marginally fit and just 2.17% were found unfit. The data regarding Kallar Kahar showed that 86.56% of water samples were fit, 9.70% marginally fit and 3.73% were unfit. In Talagang, 90.08% of water samples were fit, 9.03% were marginally fit and 0.87% were unfit. The same result was observed in Lawa, showing 90.69% of water samples fit, 4.65% marginally fit, and 4.65% unfit. In Chakwal, 82.40% of water samples were fit, 8.39% were marginally fit and 9.20% were unfit. Figure 4 shows the spatial distribution of fit, marginally fit and unfit samples according to the SAR.

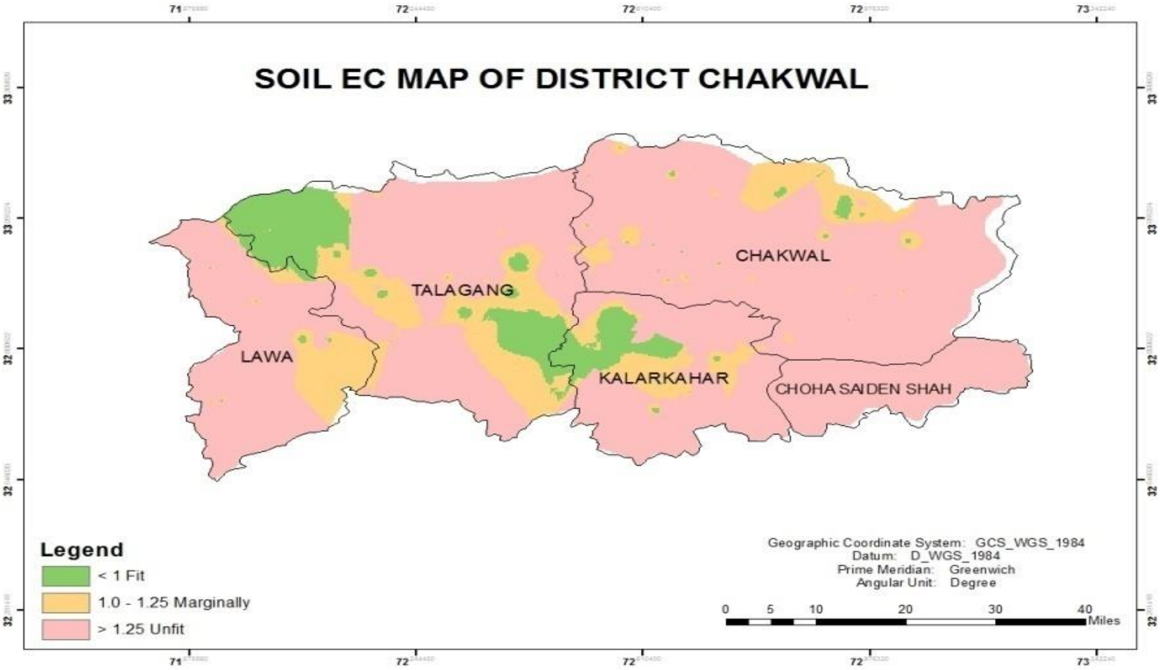

Fig 3: Quality status of EC of water samples in district Chakwal

Table 4. Classification of water sample on the basis of SAR in different Tehsils of Chakwal

Sites	Total samples	Fit		Marginally fit		Unfit	
		Sample	% age	Samples	% age	Samples	% age
Choa Saidan Shah	47	46	97.87%	0	0%	1	2.17%
Kallar kahar	134	116	86.56%	13	9.70%	5	3.73%
Talagang	343	309	90.08%	31	9.03%	3	0.87%
Lawa	86	78	90.69%	4	4.65%	4	4.65%
Chakwal	989	815	82.40%	83	8.39%	91	9.20%

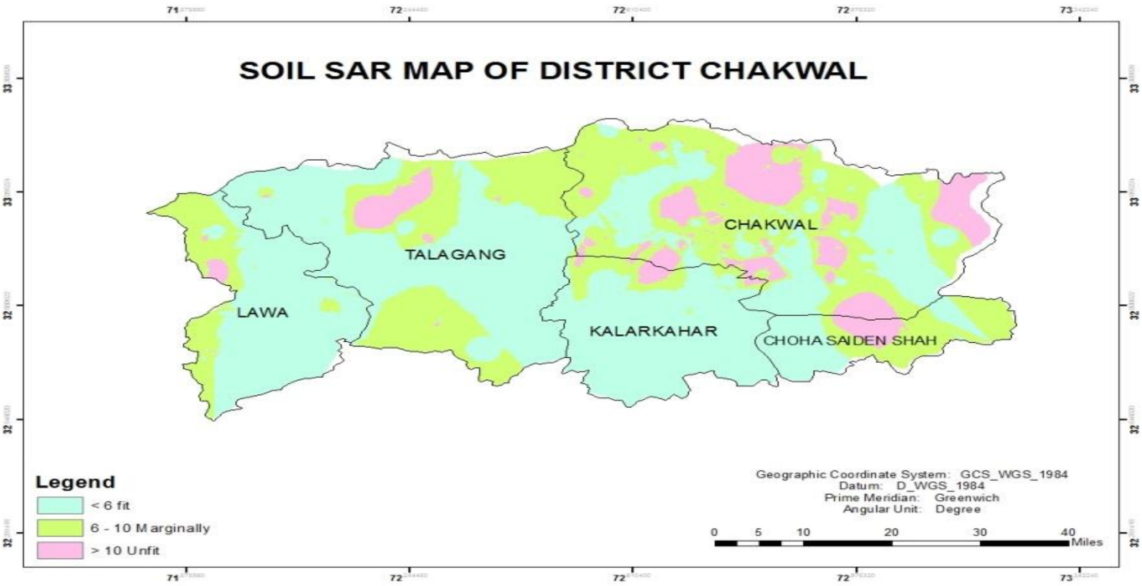

Fig 4: Quality status of SAR of water samples in district Chakwal

Residual sodium carbonates (RSC) status: The categorization of water samples based on SAR is presented in Table 5. It was noticed that in tehsil Choa Saidan Shah, 91.48% of samples were fit, 4.65%

marginally fit and just 4.65% were found unfit. In Kallar Kahar, 70.14% of water samples were fit, 10.44% were marginally fit and 19.40% were unfit. In Talagang 76.67% of water samples were fit, 11.95% were marginally fit and 11.37% were unfit. In the case of Lawa, 82.55% of water samples were fit, 6.97% were marginally fit and 12.67% were unfit. In Chakwal, 55.81% of water samples were fit, 16.58% were marginally fit and 27.60% were unfit. Figure 5 shows the spatial distribution of fit, marginally fit and unfit samples according to the RSC.

Table 5. Classification of water sample on the basis of RSC (meq/L) in different Tehsils of Chakwal

Sites	Total samples	Fit		Marginally fit		Unfit	
		Samples	% age	Samples	% age	Samples	% age
Choa Saidan Shah	47	46	97.87%	0	0%	1	2.17%
Kallar kahar	134	116	86.56%	13	9.70%	5	3.73%
Talagang	343	309	90.08%	31	9.03%	3	0.87%
Lawa	86	78	90.69%	4	4.65%	4	4.65%
Chakwal	989	815	82.40%	83	8.39%	91	9.20%

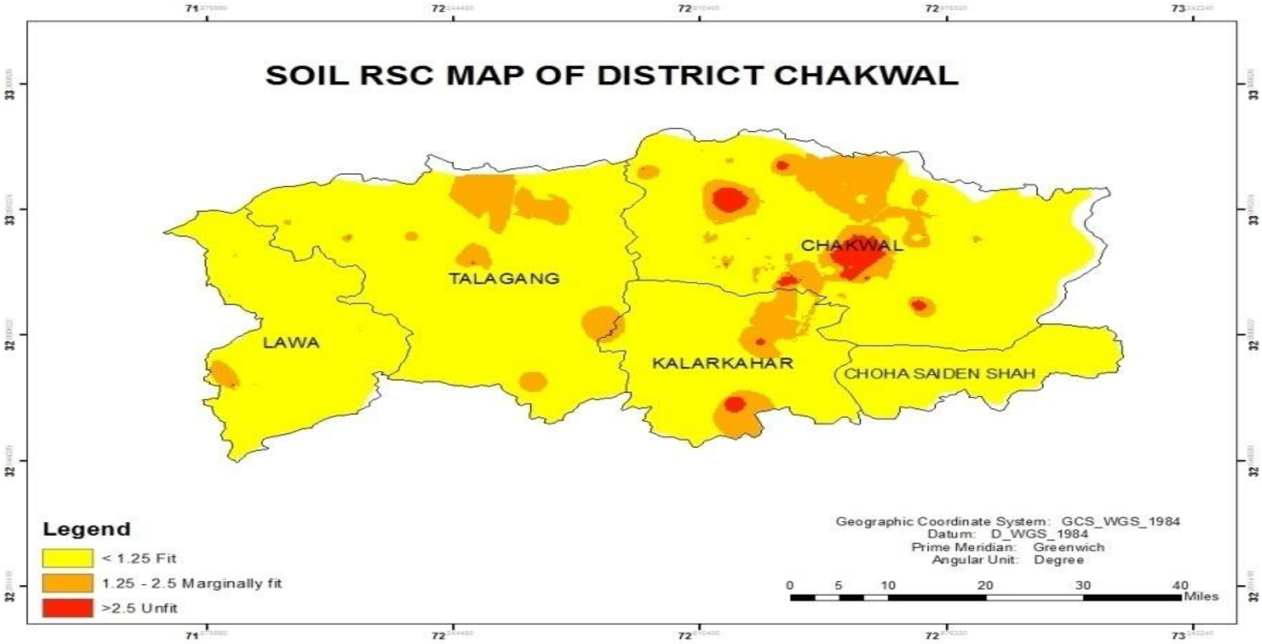

Fig 5: Quality status of RSC of water samples in in district Chakwal

Cumulative effect of EC, RSC, SAR on water quality: Finally classifying the water samples on the three quality parameters EC (µS/cm), RSC (meq/L), and SAR in district Chakwal, the following results were set up in Table 6. It points out that based on EC (µS/cm), 31.01% of water samples were fit, 16.20% marginally fit, and 52.79% unfit. Similarly, based on RSC (meq/L), 85.30% of samples were fit, 8.20% were marginally fit and 6.50%% checked unfit. In the case of SAR, 63.98% of samples were fit, 14.20% were marginally unfit and 21.82% were unfit. Figure 6 shows the spatial distribution of fit, marginally fit and unfit samples according to the EC, SAR and RSC.

Table 6. Classification of water sample on the basis of EC (µS/cm), SAR and RSC (meq/L) of District Chakwal

Sites	Total samples	Fit		Marginally fit		Unfit	
		Samples	% age	Samples	% age	Samples	% age
EC (µS/cm)	1599	496	31.01	259	16.20%	2	52.79%
RSC (meq/L)	1599	1364	85.30%	131	8.20%	104	6.50%
SAR	1599	1023	63.98%	227	14.20%	349	21.82%

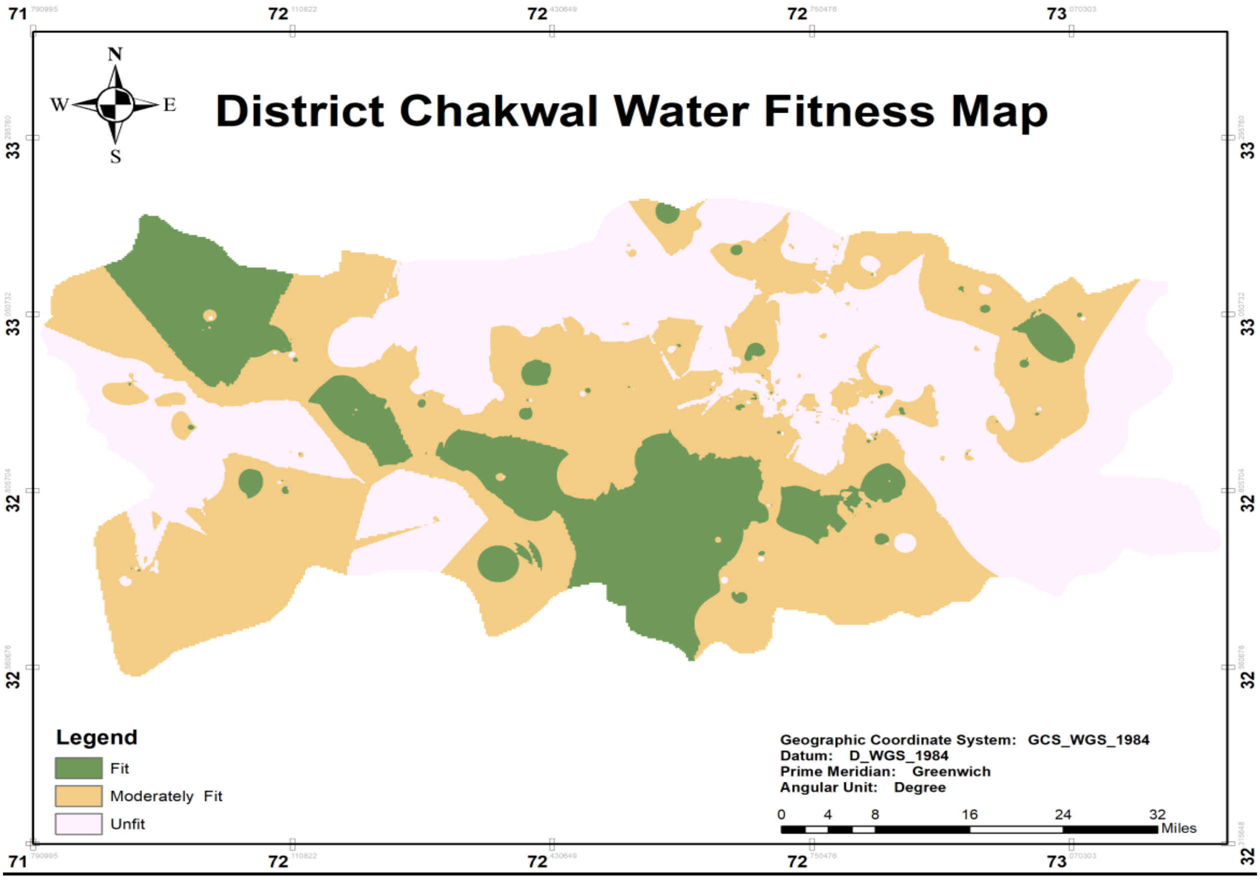

Fig 5: Quality status of water samples in district Chakwal

Discussion

Dissolved salts determine irrigation water quality. The amount and kind of salts in water determine its irrigation appropriateness. Long-term use problems determine water quality. Soil, climate, crop, and water user skill affect the type and severity of the difficulties. Salinity, water infiltration rate, specific ion toxicity, and other soil issues are most often utilized to assess water quality (Rahman *et al.*, 2020). The quality of groundwater for agricultural use was the main concern of this study. Based on the classification, the analytical data shows that 38.29%, 42.53%, 31.19%, 51.16%, and 62.79% of water samples were found to be unfit due to EC in Tehsil Choa Saidan Shah, Kallar Kahar, Talagang, Lawa, and Chakwal, respectively containing high content of soluble salts. According to Shakir *et al.* (2016), groundwater generally contains high levels of total soluble salts as well as cations and anions. Groundwater quality analysis by different researchers, for instance, Rasool *et al.* (2015) and Rasool *et al.* (2016) also reported the high pH and EC in different districts of Punjab. Based on the classification, the analytical data shows that 4.65%, 19.40%, 11.37%, 12.67%, and 27.60% of water samples were found to be unfit due to SAR in Tehsil Choa Saidan Shah, Kallar Kahar, Talagang, Lawa, and Chakwal, respectively. Actually, in the Pothwar area, a higher ratio of sodium to chloride remained at the surface of the soil in the arid and semi-arid regions due to low rainfall, high temperature, and high evaporation rate (Rasool *et al.*, 2016). Dissolution of calcite and other silicate clay minerals results in the accumulation of different cations and anions which results in poor quality of water (Jiang *et al.*, 2011). Different researchers ((Niazi *et al.*, 2018; Podgorski *et al.*, 2017; Shahid *et al.*, 2018) also reported similar findings mixing behavior of calcium and sodium is dominant in groundwater as compared to other cations which result due to minerals and rocks composition, chemical reaction, and dissolution of those minerals which are enriched with Na^{+} and Ca^{2+}. In addition to Na^{+}, Ca^{2+}, and Mg^{2+} cations and SO_4^{2-} and Cl^{-} anions were also dominant anions. Nutrient imbalance in the root zone is mainly due to high sodium adsorption which creates due to an imbalance of cationic ratio especially the dominance of sodium and calcium which results in lower availability of essential nutrients (Vasanthavigar *et al.*, 2010). Based on the classification, the analytical data shows that 2.17%, 3.73%, 0.87%, 4.65%, and 9.20% of water samples were found to be unfit due to RSC in Tehsil Choa Saidan Shah, Kallar kahar, Talagang, Lawa, and Chakwal, respectively. According to Vasanthavigar *et al.* (2010), the sodication process follows the salinization as sodium in the form of sodium chloride and sodium sulphate leach down below the root zone after that calcium precipitated and leaving the sodium as dominant cations. This sodium reacts with carbonate and bicarbonate and results into higher RSC. These carbonate react with alkaline earth cations especially calcium and magnesium to form calcium carbonate and bicarbonate which are all preponderance to enhancing the RSC of groundwater (Chitsazan *et al.*, 2019). On an overall basis, it was observed that all three parameters are considered to see the fitness of the quality status of underground water. In all of the Tehsils, it was observed that 54.28% of tube wells were delivering poor quality water and ultimately causing a gradual increase of deposition of salts and deteriorating the soil health. Some investigations revealed that poor quality of water exerted hazardous effects on soil quality, soil fertility, and ultimately plant health.

Recommendations

A valence dilution effect is an approach to reducing the groundwater brackish effect which is the mixing of good quality water with tube well water which will reduce the EC and SAR of groundwater and minimize the lethal effect and make it suitable water for a crop. The lining of water channels with gypsum stones releases calcium and sulphate and reduces SAR of irrigation water. To minimize RSC of groundwater use of canal water and different acids like sulfuric acid and elemental sulfur are beneficial to neutralize carbonate and bicarbonates. Other options like the use of gypsum, press-mud, and farm yard manure should be applied to reduce the effect of groundwater on the soil. Preference for low delta water crops over the high delta of the crop is a need to manage the water demand of a crop. Other water harvesting techniques for rainwater and the use of efficient irrigation methods for the recharge of groundwater are also beneficial.

Conflicts of Interest: A letter for conflict of Interest

Data availability statement: All relevant data are within the paper.

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