Pak. J. Biotechnol. Vol. 20(2), 376-384, ***2023*** http://doi.org/10.34016/pjbt.2023.20.02.863

Research Article

OPEN ACCESS

Available on http://www.pjbt.org
Pakistan Journal of Biotechnology
(PJBT)
(P-ISSN: 1812-1837 and E-ISSN: 2312-7791)

GEOSPATIAL ASSESSMENT OF IRRIGATION WATER QUALITY IN MULTAN TEHSIL: A COMPREHENSIVE ANALYSIS

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Article Received 08-11-2023, Article Revised 11-12-2023, Article Accepted 12-12-2023.

ABSTRACT

Water pollution and scarcity threaten sustenance and quality of life. The water usage for irrigation necessitates its content evaluation to ensure safe application and to meet high productivity goals. Drawing upon prior reports addressing salinity concerns in diverse agricultural regions of Pakistan, our study focused on assessing the risks in the Multan Tehsil of Punjab. To accomplish this, well water samples (*n=383*) were examined for parameters such as electrical conductivity (EC), sodium absorption ratio (SAR), and Residual Sodium Carbonates (RSC). Laboratory analyses indicated elevated levels of selected parameters in water samples from southwestern sites, with 21.4% exceeding SAR limits, 28.7% surpassing RSC thresholds, and 66.1% crossing permissible EC limits. The underlying anthropogenic causes of groundwater pollution include an increased rate of run-off, leachate percolation, reduced infiltration, inadequate recharge of well water, and urban land expansion. Rather than relying on end-of-pipe management strategies, it is recommended to prioritize source water treatment.

Key words: Climate change, irrigation, salinity, water quality, water table

Introduction

Water is an integral component of all physio-chemical reactions that sustain ecosystems and the survival of living beings. It is the basic medium to support the sectors necessary to meet human needs such as food, medicines, cloth, and hydro-energy. The sources of water are categorized as surface water (rivers, streams, canals, freshwater lakes, oceans) and ground water (borehole, well water) sources. As water acquires the instinctive traits of hydrogen bonding and polarity, it potentially dissolves the ionic substances while based on density, nonpolar substances suspend into it (Nadeem *et al.*, 2021). Thus, it develops a reaction matrix in which complex components disintegrate into simpler components that are visually undistinguishable (Shmeis, 2018). These are the compelling causes which make the availability of pristine water quite impossible. Surface water sources are exposed to the surrounding natural and man-made environment, and especially anthropogenic events put these sources at serious risk of contamination, overexploitation, and modification (Faraz *et al.*, 2023). These sources are equally shared between animals, birds and poisonous insects and serve as a niche for phytoplankton and zoo plankton (Kosemani & Oyelami, 2017). Therefore, groundwater is majorly used for drinking, industrial and agriculture purposes. But, the rising trends in population and urbanization have led to abrasive water withdrawals particularly in those regions where strategic lags exist. Furthermore, inappropriate management practices for liquid and solid wastes have further deteriorated the groundwater quality. In context of Pakistan, various studies have reported the water quality issues which are raised in absence of sound implementation of regulatory laws regarding the effluent and solid waste clearance (Batool & Shahzad 2021; Fida *et al.*, 2022). Pakistan ranks as fourth prevalent groundwater user following India, China and USA countries. Here, the agriculture is the major water reliant sector of which over 50% of cultivation requirements are met with the ground water sources (Qureshi *et al.*, 2020). The irrigation water sources in the vicinity of urban areas of Lahore, Faisalabad, Multan, Peshawar, Sheikhupura and Bahawalpur have been reported to have elevated levels of heavy metal loads (Batool & Shahzad 2021). The reasons behind deteriorating water quality are related to municipal wastewater release to water sources, and unrestricted pesticides/insecticides and excessive fertilizers application to crops (Daud *et al*., 2017). The unchecked withdrawal of water further concentrates the pollutants in the limited water supply. Over the time since 1990, there has been an ample increase in privately owned tube-wells installations in Pakistan (Abbas *et al*., 2022). To meet the agricultural production goals, the number of private tube wells has raised from 20,000 (in 1960) to over 6 million according to the latest estimates (Qureshi *et al*., 2020). The Province of Punjab has the 83% share of installed tube wells across the country. Data revealed that the aquifer recharge rate is 15% lower than groundwater discharge in the country (Prathapar *et al*., 2021). Multan is the fifth largest city of Pakistan; it comprises four tehsils namely Multan Saddar, Multan City, Jalalpur Pirwalaand Shujabad. Multan experiences an average annual rainfall of approximately 186 mm (7.3 inches), with the Chenab River serving as the primary source of groundwater recharge. Unfortunately, untreated municipal waste often contaminates surface water, and during the monsoon season, the land near the Chenab River becomes flooded. Mineral content in certain sections of the Chenab River has been observed to exceed permissible levels. Moreover, the escalating pace of urbanization has contributed to a heightened runoff and a diminished infiltration rate, essential for effective groundwater recharge. The urbanization trend, coupled with population growth (1.87 million as per the Population Census Report 2017), exerts increased pressure on limited water sources. This has led to water shortages, compelling the application of untreated municipal wastewater to agricultural fields to fulfill the water requirements of crops. The poor quality water supplies directly impact the crops biomass, fruit quality and yields (Seleiman *et al*., 2021). The metal salts bio-accumulation into fruits and vegetables has been mentioned in multiple studies (Aziz *et al*., 2021; Atta *et al*., 2023). Presently, the irrigation water contents are not monitored and open irrigation has given rise to soil salinity/acidity, weeds growth, metal(oid)s retention and declined crop productivity problems. Therefore, the analyses of water quality parameters is necessary to maintain the requisite nutrient and minerals balance in soil. Furthermore, the contaminated and saline water driven agriculture needs to be regulated in order to maintain the sustainable sectoral growth and healthy productivity. In view of the increasing wastewater irrigation trend and monitoring and regulatory gaps, the current research study has been designed to investigate water quality and irrigation risks to crop productivity to put forth solution oriented prospects. For this purpose, the study objectives are 1) to assess the suitability of groundwater sources for irrigation, considering factors such as salinity, alkalinity, pH, and mineral content; 2) to delineate spatial trends and variations in irrigation water quality, this study seeks to provide valuable insights for recommending targeted irrigation management strategies. The ultimate goal is to enhance water use efficiency and mitigate adverse impacts, fostering sustainable agricultural practices.

MATERIAL AND METHODS

Study area: Multan is the sixth biggest city of the country which covers a 3,721 km² area and has 1.8 million population. The research area was Multan tehsil (Latitude: 30° 9'26.85"N; Longitude: 71°31'29.70"E) in Southern Punjab, Pakistan. Multan has arid environmental conditions with intense cold winters (minimum 4.5 °C temperature) and warm summers (maximum 46 °C temperature) (Sajid *et al*., 2020). Multan location at bend of five rivers in central Pakistan (the river Chenab flows on its Western side) and the canal system across the Multan agri-fields are supportive of irrigated cropping system and land fertility. The major crops are wheat, rice, maize, cotton, sugarcane, fodder, sunflower, rapeseed, mustard, and pulses. The hot climate ideally suits mangoes, citrus, date-palm, pomegranate, guava, falsa, banana, strawberry, jujube and grapes production (Hussain *et al*., 2019).

Water samples collection: Water sampling locations were selected based on their nearness to agricultural fields; the selected points have been presented over the map (Figure 1). The samples (n=383) were collected from the outlets of the tube wells rather than the reservoir. Before sampling, the tube wells were run for half an hour. After cleansing the bottles with distilled water, they were filled with flowing water from running tube wells manually, leaving two inches at the top. Then, the lids were tightly closed, and all sample bottles were labelled denoting sampling locations, time, and date. The sample bottles (kept in ice boxes for preservation) were shipped to the Soil and Water Testing Laboratory for Research, Multan, for further analyses. Information was also acquired on tube well depth, pipe diameter, irrigated area, farmer details (name, address and area owned), and area (GPS (*Geographical Positioning System*)) location.

Physical and chemical parameters analysis: The selected parameters for well water analyses include electrical conductivity (EC), and minerals (Magnesium (Mg^{2+}), Calcium (Ca^{2+}), Carbonates (CO_3^{2-}), Bi-carbonates (HCO_3^-), Sodium (Na^+) and Chloride (Cl^-)) analyses (Table 1) which were measured via standard procedures at Soil and Water Testing Laboratory for Research, Multan. Salinity hazard of irrigation water is measured via electrical conductivity (EC) which refers to dissolved "salts" (Ca^{2+}, Na^+, Cl^-) in water. Sodicity of water is determined by Sodium Adsorption Ratio (SAR) by calculating sodium (Na) relative abundance in relation to magnesium (Mg^{2+}) and calcium (Ca^{2+}) ions as milliequivalents per liter (meq L^{-1}). Likewise, Residual Sodium Carbonate (RSC) is a water quality parameter used to assess the suitability of water for irrigation. It is a measure of the potential of sodium-related problems in soil caused by polluted water irrigation. RSC is calculated based on the concentrations of carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) ions in water. High HCO_3^- and CO_3^{2-} ions in water precipitate with Ca^{2+} and Mg^{2+} ions and the resulting excess of $NaHCO_3$ and $CaCO_3$ poses a threat to soil structure. RSC and SAR were calculated by Richard's (1954) formulas. Based on RSC, SAR and EC values and international standards, water samples were classified accordingly.

To calculate the SAR (cations concentration = milliequivalents per liter (meq L^{-1}) value, the following formula was applied.

$$SAR = Na^{+}/[(Ca^{2+} + Mg^{2+})/2]^{1/2}$$

To calculate the RSC (cations/anions concentration = milliequivalents per liter (meq L^{-1}) value, the following formula was applied.

$$RSC(me\ L^{-1}) = (CO_3^{2-} + HCO_3^{-}) - (Ca^{++} + Mg^{++})$$

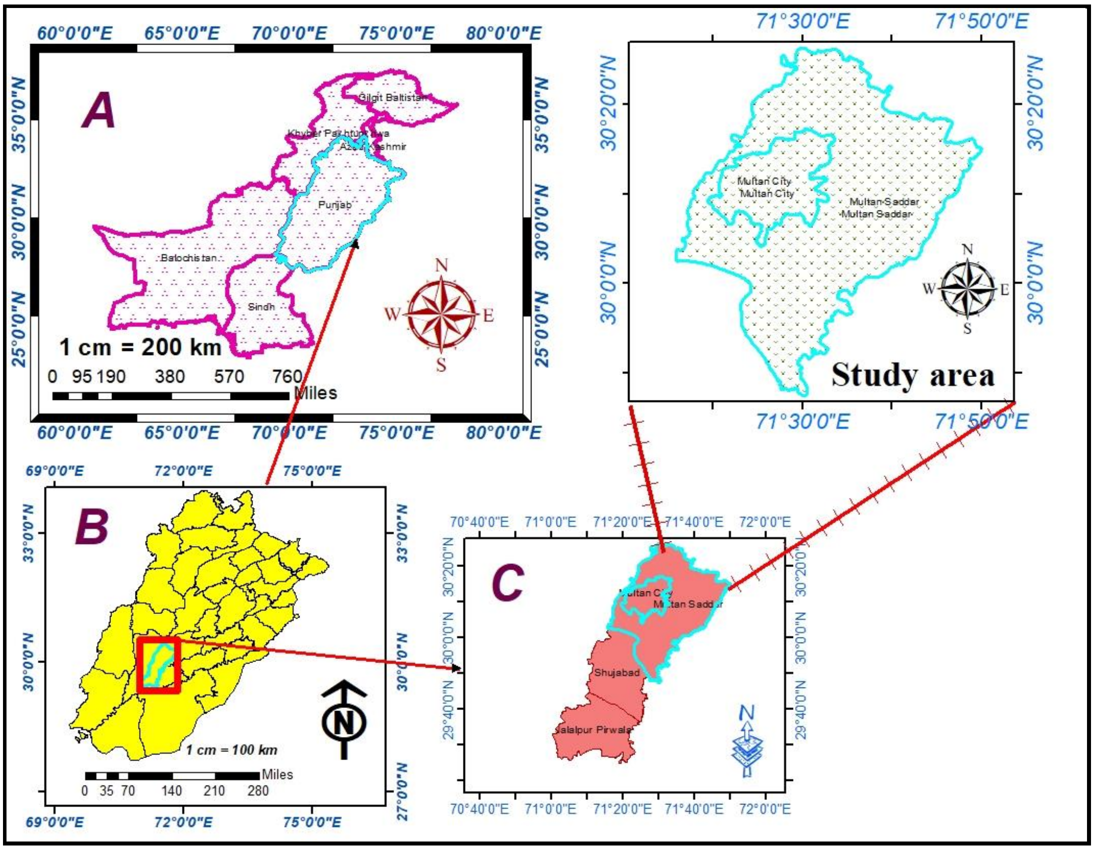

Figure 1. Study area and sampling sites

GIS Mapping: Through GIS, water quality and other supporting maps were generated. To present the spatial allocation of healthy, unhealthy, and marginally healthy water samples based on water quality data, GIS mapping was performed via the ArcGIS (version 10.3) tool. The sampling locations were integrated with the water data for the generation of spatial distribution maps of selected water quality parameters. Data used for mapping water quality was acquired from the analyses of samples that were collected from predetermined locations of existing water wells.

Statistical analysis: Statistical analysis was performed on the dataset to get descriptive values. Descriptive statistics, including calculations of the mean, standard deviation, and percentage, were carried out following the methodology outlined by Steel *et al*. (1997).

RESULTS

Figure 2 illustrates the fitness levels of water extracted from various tube wells in Tehsil Multan. The comprehensive dataset reveals that 59% of the samples were deemed unsuitable for use, while 33% met the criteria for irrigation. Notably, approximately 8% of the samples fall into the classification of marginally suitable water for irrigation, based on the criteria established by Malik *et al*. (1984). These criteria have been adopted by the Department of Agriculture in Punjab, as outlined in Table 2.

Ground (Tube-well) Water Quality Parameters

Electrical conductivity (EC) (µS cm^{-1}) and pH: The status of samples in terms of their EC is presented in Figure 3. The EC values ranged from 82 to 40031 µS cm^{-1}. Approximately 22% of the water samples fell within the safe range (<1000 µS cm^{-1}), while 66.1% of the samples were considered unsuitable (>1250 µS cm^{-1}). Additionally, 11.9% of the samples were deemed marginally suitable (1000-1250 µS cm^{-1}) for irrigation. Water having pH between 6.5-8.4 is suitable for irrigation, otherwise it affects plant growth and development; in the present study, the pH ranges from 0 to 14.

Minerals: The calcium-magnesium range was 0–163 meq L^{-1}, sodium ranged from 0 to 237 meq L^{-1}, chlorides varied from 0 to 361 meq L^{-1}, carbonates ranged from 0 to 3.52 meq L^{-1}, and bicarbonates varied from 0 to 28.6 meq L^{-1}. The values were utilized to calculate the SAR and RSC values.

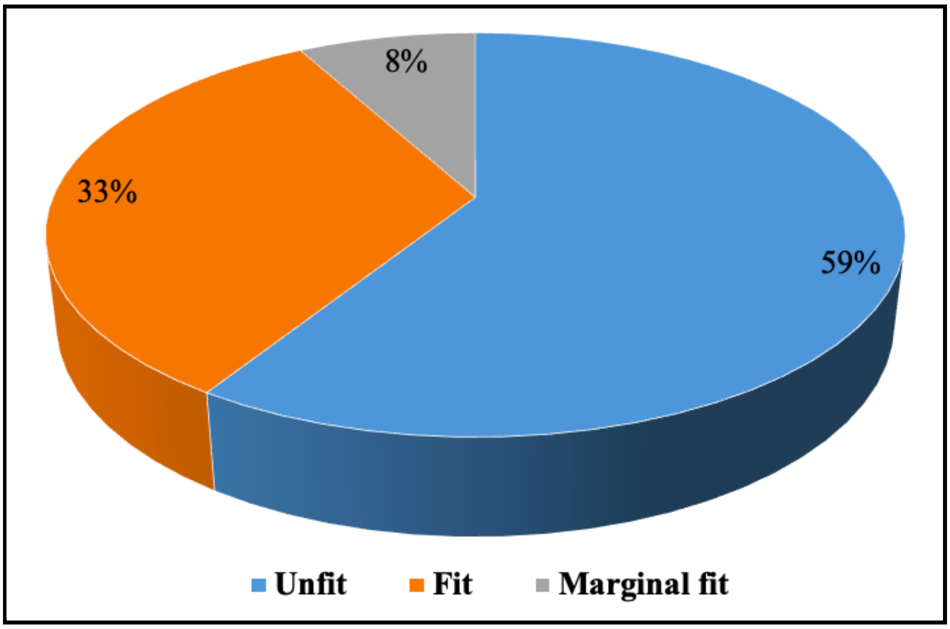

Figure 2: Percentage (%) distribution of ground water quality status of tehsil Multan

Table 1: Groundwater Quality Analysis Methods and Instrumentation

Parameters	**Technique**	**Instrument make**	**Model**	**Range**
pH	Potentiometry	EDT direct Ion Limited	RE357Tx-Kit	0-14 pH
Electrical Conductivity	Conductance	Orion Star	A212 Conductivity Benchtop Meter	0.001 µS/cm to 3000 mS/cm
Ca^{+2}, Mg^{+2}, CO_3^-, Cl^- and HCO_3^-	Titrimetric method			
Na^+ and K^+	Flame photometry	BWB XP Flame Photometer	XP-2006	Na 0.1 – 60 ppm K 0.05 – 100 ppm

(Richards, 1954)

Table 2: Statistical analysis (descriptive) of water analysis results

Parameters	**EC** (µS cm^{-1})	**Ca^{+2} + Mg^{+2}** (meq L^{-1})	**Na^+** (meq L^{-1})	**HCO_3^-** (meq L^{-1})	**Cl^{-1}** (meq L^{-1})
Mean	2697	12.01	15.01	8.00	13
Median	1613	7.02	10.03	7.02	4
Mode	1413	6.84	13.15	6.21	2
SD	3342	15.01	22.09	3.11	32
Max	40032	163	237.01	28.12	361
MIN	82	0.00	0.00	1.01	-24

Sodium Adsorption Ratio (SAR): In this current investigation, the SAR values spanned from 0.11 to 141. When classifying the water samples based on SAR (Sodium Adsorption Ratio), it was found that approximately 57.9% of the samples fell within the safe range (<6). Conversely, 21.4% of the samples were considered unsuitable (>10), while 20.7% were marginally suitable (6-10) for irrigation. The SAR values for all water samples ranged from 0.02 to 52.66.

Residual Sodium Carbonates (RSC): The RSC levels varied between 0 and 15.7 meq L^{-1}. Around 46% of the water samples fell within the safe range (<1.25 meq L^{-1}). Only 28.7% were deemed unsuitable (>2.50 meq L^{-1}), and an additional 10.1% were considered marginally suitable (1.25-2.50 meq L^{-1}) due to elevated RSC levels as presented in table 3.

Table 3: Criteria for irrigation water quality

Parameters	**Fit**	**Marginally fit**	**Unfit**
EC (µScm^{-1})	<1000	1000 – 1250	> 1250
RSC (meq L^{-1})	<1.25 - 1.25	– 2.25	> 2.25
SAR (meq L^{-1})	<6	6 – 10	>10

(Malik *et al*., 1984)

Risk mapping (spatial distribution of fit/unfit water points): In the southern region of Punjab province of Pakistan, lies Multan city which is characterized by an arid climate featuring intense summers and winters. The water samples' unsuitability, attributed to elevated levels of EC and SAR, is graphically depicted in Figures 2 and 3. The southwestern site of Multan tehsil exhibits a higher prevalence of pollution, particularly concerning elevated EC levels. Moving eastward from the southern sites, water samples demonstrate suitability. However, from west to north, sampling points exhibit varying degrees of suitability, gradually improving towards the northern region of the district. In certain areas, elevated EC levels render the samples unfit for crop irrigation. Regarding SAR ratios, overall city water samples meet suitability criteria. Nevertheless, suitability for irrigation diminishes when transitioning from western to northern sites. The border areas in the north and west, as well as the southern sites joining Tehsil Shuja bad (particularly those located towards the north), and Tehsil Multan Sadar (especially areas towards the west), exhibit water unsuitability for irrigation purposes due to the cumulative impact of EC, SAR, and RSC elevations. The western regions of the district, particularly those near the Chenab River, are of significant concern in terms of water quality

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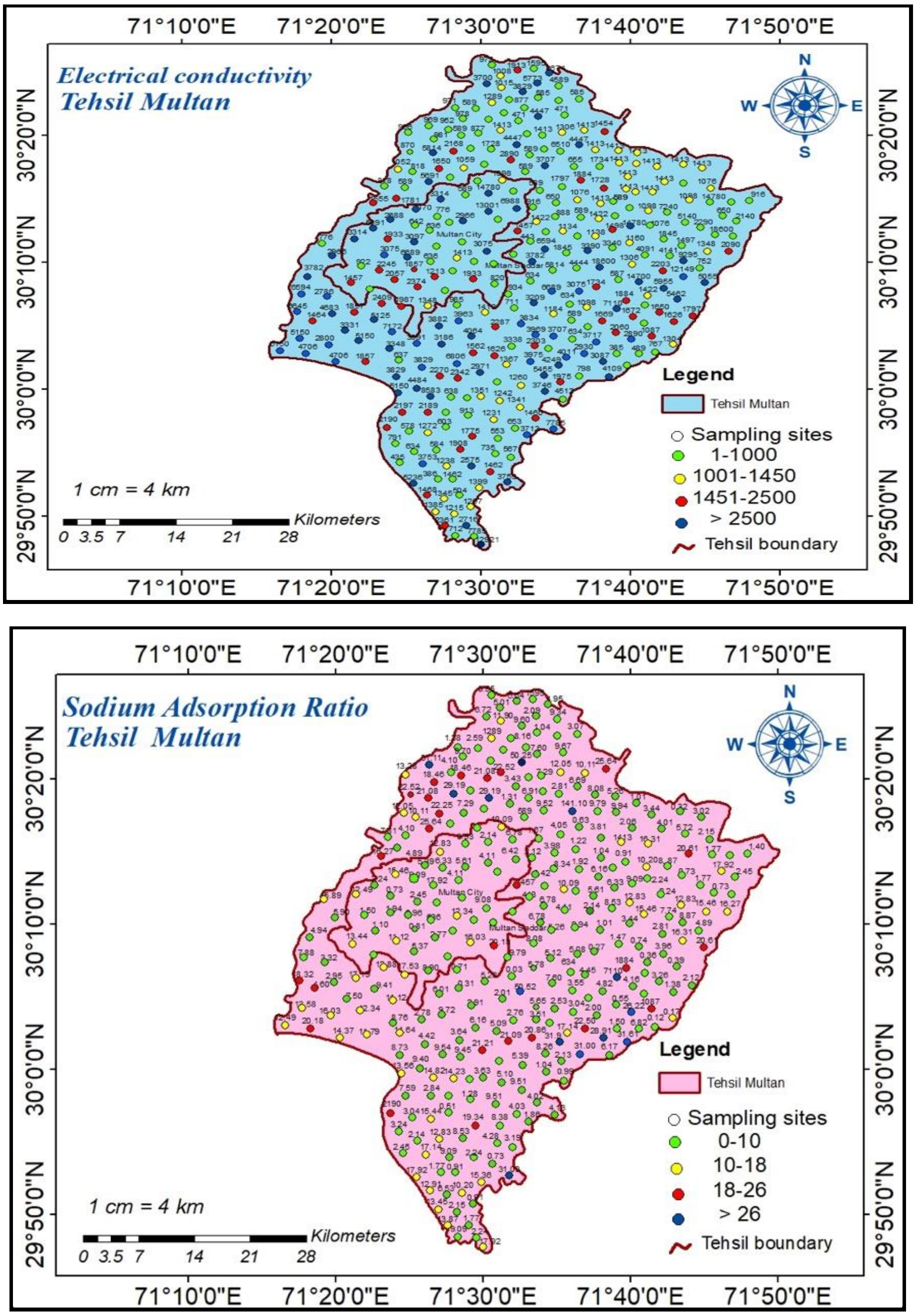

Figure 2: Electrical Conductivity (EC) status and Sodium Adsorption Ratio (SAR) of water samples in tehsil Multan

DISCUSSION

Multan, the fifth-largest city in Pakistan, comprises four tehsils: Multan Saddar, Multan tehsil, Jalalpur Pirwala, and Shujabad (Perveen & Haque, 2023). According to the findings of this study, pollution intensity was notably higher in the western sites of Multan tehsil. In this investigation, 66.1% of the water samples from the southwestern sites were deemed unsuitable, displaying EC values exceeding 1250 µS cm^{-1}. Corroborating these results, a field study indicated that the utilization of saline water for irrigation in Multan led to a reduction in crop yield by up to 17.3% compared to freshwater irrigation (Cheng *et al.*, 2021). Further, an experimental study demonstrated that plants (tomatoes and pumpkins) irrigated with a water measuring 2400 µS cm^{-1} EC experienced diminished biomass compared to drip-irrigated plants, emphasizing the negative impact of elevated electrical conductivity on plant growth (Cifuentes *et al*., 2023). The application of saline or sodic water significantly affects crop yield by inducing physiological stress. This stress influences the uptake capacity of essential ions (Ca, Mg, Fe) and water, leading to impaired root function due to the deregulation of Ca^{2+} and K^+ ions and osmotic balance (Malik *et al*., 2021). Additionally, irrigation with sodic water has been found to adversely affect soil permeability potential based on soil texture, further compromising water availability to crops and, consequently, reducing yields. Furthermore, sodicity induces soil pore plugging and soil hardening, resulting in increased water runoff and diminished water infiltration. Crops affected by high salinity display abnormalities in membrane permeability, stomatal conductance, and ion balance. Additionally, an imbalance of Cl^- ions heightens crop susceptibility to diseases and impedes the uptake of essential minerals such as calcium (Tekile, 2017). Analyses of mineral content in the current study revealed that Cl^- concentrations in collected water samples ranged from 0 to 361 meq L^{-1}, exceeding the FAO Cl^- standard limit of 10.19 meq L^{-1} (106.5 mg/L) at certain points, particularly in the western sampling sites. Similarly, Na^+ concentrations in groundwater wells ranged from 0 to 237 meq L^{-1} in the study area, surpassing the Na^+ standard limit of 8.69 meq L^{-1} (200 mg L^{-1}) recommended by WHO (2017). Furthermore, groundwater was identified as unsuitable due to elevated HCO^{3-} values, leading to a pH exceeding 8.5 and causing alkalinity. The carbonate content in water samples ranged from 0 to 3.52 meq L^{-1}, and bicarbonates ranged from 0 to 28.6 meq L^{-1}. These concentrations exceeded the FAO allowable limits, which specify 9.984 meq L^{-1} (610 mg L^{-1}) for bicarbonates and 0.0612 meq L^{-1} (6 mg L^{-1}) for carbonates. These findings suggest the presence of carbonate-containing minerals and degraded organic matter in the underground water. The binding of calcium and magnesium minerals with CO_3^{2-} and HCO_3^- causes water hardness, while an increase in sodium ions availability in solution results in a positive RSC value (Fallatah & Khattab, 2023). Calcium at 2.5 meq L^{-1} (100 mg L^{-1}) and magnesium at 1.25 meq L^{-1} (50 ppm) are considered suitable for irrigation purposes, as suggested by WHO. However, the high solubility of calcium-magnesium was evident in many groundwater samples, with concentrations ranging between 0 and 163 meq L^{-1}. Moreover, the higher concentration of carbonate and bicarbonate compared to magnesium and calcium in water contributes to a high RSC (Sarah *et al*., 2014). In the study area, RSC levels exhibited variations ranging from 0 to 15.7 meq L^{-1}, with 28.7% of the samples deemed unsuitable for irrigation (exceeding 2.50 meq L^{-1}), particularly in the western region. Evaluating the sodium adsorption ratio (SAR) is crucial, as sodium's tendency to replace other cations, particularly magnesium and calcium (as estimated by SAR), can impact the availability of these ions to plants. SAR values in the study area ranged from 0.11 to 141, with 21.4% of samples deemed unsuitable based on high SAR values (>10). In another study focused on Multan water wells, SAR values ranging from 1 to 19 meq L^{-1} highlighted the need for restrictions in certain locations due to the potential irreversible damage caused by prolonged high sodium application (Fallatah & Khattab, 2023). Furthermore, within Tehsil Multan, an analysis of 106 groundwater samples revealed the highest levels of SAR and EC values preceding the monsoon, attributed to intensified dissolution processes. In a specific focus on Jalalpur Pirwala and Shujabad, 31 groundwater samples were collected, with 61% deemed appropriate and 38% considered unfit based on criteria such as SAR, EC, and RSC (Asif *et al*., 2021). In a study spanning from 2001 to 2010, 2686 groundwater samples were collected from Multan (1877), Shuja Abad (549), and Jabalpur Pirwala (260) tehsils to assess irrigation water quality. Analyses involving EC, mineral content, and SAR revealed that 32.4% of samples from Multan, 11.6% from Shuja Abad, and 27.3% from Jalalpur Pirwala were deemed suitable for irrigation. However, a significant proportion was found to be unsuitable (Ahmed *et al*., 2015). Analyses of groundwater samples collected from Bahawalpur Tehsil, Pakistan, revealed that 52.78% of the samples were unfit for irrigation, while 34.37% of the samples were considered fit. This determination was based on physio-chemical tests assessing pH, EC, SAR, RSC, Ca^{2+}, Mg^{2+}, SO_4^{2+}, HCO^{3-}, CO_3^{2+}, Na^+, and Cl^- (Riaz *et al*., 2018). Research underscore the critical need for effective water management strategies in the agricultural practices of the affected regions.

Various factors, both natural and anthropogenic, contribute to the deterioration of water quality in Multan tehsil. These factors include rock weathering, runoff effluent, input of decaying organic matter, and reduced infiltration rates (Mahmood *et al*., 2021). Groundwater primarily recharges from Chenab River water flowing on the western side of the study area. The untreated municipal waste mixes with surface water, and during the monsoon, the land area near the Chenab River becomes flooded. Chenab River, at specific points, has been reported to exceed permissible mineral content levels (Earnest & Hamid, 2021). Increasing urbanization in Multan has led to elevated runoff and decreased infiltration rates crucial for groundwater recharge. Land use changes and climate variability have been confirmed to impact water resources in the region. In 2013, the urban area of Multan expanded to 206 km^2, compared to 109 km^2 in 1987, resulting in a reduction of 97 km^2 in vegetation cover. Between 2000 and 2020, the urban area expanded from 130.04 km^2 (45.44%) to 155.59 km^2 (55.34%), representing a 7.32% to 10.96% increase in the built-up area during 1990–2020 (Akram & Siddiqui, 2018). This expansion led to a decline in dense vegetation cover from 31.81 km² (11.12%) to 12.2 km² (4.28%), and a reduction in light vegetation cover from 112.94 km² (39.49%) to 105.40 km² (36.84%) during the same period (Abbas *et al*., 2022). The decline in water bodies by 0.62% from 1990 to 2020 is a significant factor contributing to a 2.92% decline in rice and sugarcane productions in the Multan region due to water shortage. Reduced precipitation rates further contribute to deteriorating water quality (Hussain *et al*., 2021). High groundwater pumping in Punjab, irrigating 20-50% of agricultural fields, remains a prominent practice. Young *et al*. (2016) reported a water table drop of 0.3 m/year in Multan city. Open disposal of solid wastes along roadsides in Multan has led to leachate issues, altering groundwater mineral content (Hifza *et al*., 2021). Therefore, proper planning for disposal sites is imperative to maintain reliable water chemistry in the region.

Implementing soil management strategies, such as incorporating organic matter (poultry manure, press mud, farmyard manure), gypsum, and acid, proves effective in managing sodicity and alkalinity in irrigated soil (Hifza *et al*., 2021). Notably, fine-textured soils appear to be more susceptible compared to coarse soils, with sandy soil demonstrating better resilience under saline water irrigation (Ahmed *et al*., 2015). In light of these findings, it is recommended that irrigation water with an EC of up to 1025 µS cm^{-1} can be safely applied for heavy-textured soils without compromising productivity. For coarse-textured soils, water with EC < 3000 µS cm^{-1}, RSC < 2.5 meq L^{-1}, and SAR of 10 meq L^{-1} can be utilized. Similarly, water with SAR meq L^{-1}, EC 2300 µS cm^{-1}, and RSC 2.3 meq L^{-1} is deemed suitable for medium-textured soils. Lastly, water with SAR 8 meq L^{-1}, EC 1500 µS cm^{-1}, and RSC 1.25 meq L^{-1} is considered appropriate for fine-textured soils (Pervaiz *et al*., 2003).

Promoting salt-tolerant crops like cotton, wheat, tomato, maize, and pepper through tailored cropping patterns is crucial in Multan, where major crops include cotton and wheat, along with rice, fodder (sorghum, maize), and sugarcane. Cotton, for instance, shows resilience under saline water conditions up to 7,000 µS cm^{-1}. Meanwhile, crops like green beans and strawberries are salt-sensitive, experiencing yield reductions at an EC of 1,000 µS cm^{-1} (Zhang, 2017). In managing salt-sensitive crops, such as deciduous fruits, nuts, and perennial citrus plants, careful selection of irrigation methods is crucial. Drip irrigation is recommended over furrow irrigation due to its ability to minimize salt accumulation near the wetting zone, while creating a desalination zone that fosters minerals flux supportive to crop growth. However, the choice of irrigation methods should also consider soil characteristics. Addressing the issue at its source, treating water sources is considered a more sustainable long-term approach than soil enhancements, which often serve as end-of-pipe solutions. Combining rainwater (with a pH of 5.6-7) and reverse osmosis (RO) water with saline water for dilution purposes can be explored. Constructing mini dams to collect rainfall runoff serves as a natural mechanism, allowing plants and light vegetation to filter seeping water by absorbing anions and cations, treating water before reaching groundwater reserves. Adequate drainage and maintaining a shallow water table contribute to keeping seeped water quality at moderate levels. To ensure sustainable water quality, the extraction of water from tube wells should be regulated. Establishing laboratories for irrigation water quality tests is imperative in monitoring and maintaining water quality standards. These measures collectively contribute to a holistic and sustainable approach to water resource management in the region.

CONCLUSION

The study illuminates the multifaceted challenges associated with water quality in the Multan region, underscoring the critical imperative for sustainable water management practices. Of the collected samples, 59% were deemed unfit for irrigation, while 33% were considered suitable, and 8% were marginally fit for irrigation, based on a comparison with standard values for agricultural crop irrigation. Furthermore, 66.1% of the samples were deemed unsuitable due to an electrical conductivity (EC) value exceeding 1250 µS cm^{-1}. Regarding specific parameters, 21.4% of samples surpassed the threshold (>10) for Sodium Adsorption Ratio (SAR), rendering them unsuitable, while 20.7% fell within the marginal suitability range (6-10) for irrigation. As for Residual Sodium Carbonate (RSC), 28.7% were deemed unsuitable (>2.50 meq L^{-1}), with an additional 10.1% falling within the marginally suitable range (1.25-2.50 meq L^{-1}). The western sites of Multan Tehsil exhibited heightened pollution intensity, with a significant percentage of water samples deemed unsuitable for irrigation due to elevated electrical conductivity. The intricate interplay of factors, including sodicity, high mineral content, and compromised groundwater quality, necessitates a comprehensive approach to address these challenges. Elevated levels of chloride, sodium, and bicarbonates in groundwater samples raise concerns about exceeding permissible limits, posing risks to both agriculture and human health. Urbanization, land-use changes, and climate variability further compound the complexity of the issue, impacting water resources and exacerbating water quality challenges. The expanding urban area and diminishing vegetation cover contribute to the reduction of water bodies, influencing agricultural production. Implementing effective soil management strategies, promoting salt-tolerant crops, and carefully selecting irrigation methods emerge as crucial components of mitigating water quality issues in the Multan region.

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