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Research Article

GIS-based spatial distribution of portable water quality analysis and regional suitability of drinking water in District Kasur

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Abstract

The present study was carried out to evaluate the potable water quality of the district of Kasur, Punjab, Pakistan. In this study, 100 water samples were collected in sterilized bottles (1000 ml) by using Global Positioning System (GPS) essentials from Kasur, Chunian, Pattoki, and Kot Radha Kishan of District Kasur Punjab, Pakistan. The water samples were immediately subjected to both physicochemical analysis and bacteriological examination of *Klebsiella*, *E.coli*, and *Shigella*. The data of all the tested samples indicated that pH examined from 6.52- 8.9, Electrical Conductivity (EC) from 600-4030µS/cm, Biochemical Oxygen Dissolve (BOD) from 1.2-3.4 mg/L, Total Dissolved Solid (TDS) from 170- 3070 ppm, Dissolve Oxygen (DO) from 4.56-7.9 mg/L, Cl from 100-480 mg/L and Temperature (T) from 23.5-25.5°C. These parameters exceeded the permissible limits for drinking water set by WHO and PSQCA. Colony Forming Unit (CFU) was found by using the Total Viable Count Method, which was found to be higher in Chunian at 3.800cfu/uL. The prevalence of isolated bacteria such as *Klebsiella, E.coli, and Shigella was also recorded in 76 water samples by performing different biochemical tests*. The conclusion revealed that the physiochemical and bacteriological quality of the water in these regions cannot be considered of good quality as it is highly turbid and unsafe for drinking purposes. Therefore, the water management committee must collaborate with other stakeholders to ensure proper purification and treatment of domestic water sources, underscoring the importance of collective action.

Keywords: GIS mapping, Potable water, Physiochemical analysis, Spatial trends, Risk Zone

Introduction

Water is one of the most significant and plentiful components of the environment. Currently, only 70% of the earth has water. Water is the fundamental component in all biological reactions necessary for sustaining the existence of plants and animals. Since it is a universal solvent, it dissolves all of the soil's minerals (Sohail et al., 2020). But it is scientifically demonstrated that groundwater is no longer drinkable without any treatment because we face many health-hazardous challenges tactlessly grown from water mismanagements (Shafqat et al., 2018).

Despite the current challenges, there is potential for positive change. A report from the International Union for the Conservation of Nature (IUCN) claims that groundwater supplies are the primary water supply source in most Pakistani cities (Fida et al., 2023). Poor water quality is estimated to cause 30% of all diseases and 40% of all deaths in Pakistan. According to the most recent 2017 census, Pakistan has about 208 million people, making it the sixth most populous country in the world. By increasing the current ratio, the population ratio of the nation could exceed 240 million by 2030 (WHO, 2010). However, with the right interventions, these numbers can be reduced. According to IUCN, in Pakistan, poor water quality leads to the highest death rate in Asia, with 2.5 million annual deaths from endemic diarrheal illness. Diverse bacterial pathogens most Probable coliform and *E. coli* found in water (Ahmad et al., 2020).

Physiochemical factors, including temperature, pH, EC (electrical conductivity), TDS (total dissolved solids), BOD (biological oxygen demand), DO (dissolved oxygen), turbidity, chloride, and nitrate concentration, also affect water quality (Khatun et al., 2022). The phenotypic evaluation of microbes in drinking water has only been based on cultural techniques. In Pakistan, Kasur, Chunian, Kot Rada Kishan and Pattoki are most populated area due to rapid industrialization along with urbanization and agricultural activities in its surroundings areas. The research location has grown even more complicated due to run-off action facilities (Batool et al., 2019). According to the Pakistan Council of Research in Water Resources (PSRWR), high number of metals are discharged from Kasur water (Kumar et al., 2023). A study suggested that using the interpolation methods of GS+ software and ArcGIS are efficient in the prediction of unsampled data and gave almost the same result. The primary purpose of current research is to check the spatial trends of physicochemical parameters and microbial species to assess the risk zone of the potable groundwater in district Kasur, which is known for having one of the largest leather industries in the world.

Material and methods

Study area

Kasur is a district in Punjab's Lahore Division, Pakistan. It was established on 1 July 1976. The district's total area is 3,995 square kilometers, divided into four Tehsils: Kasur, Chunian, Pattoki, and Kot Radha Kishan (Reference). The flow of the map is shown in Figure 1.

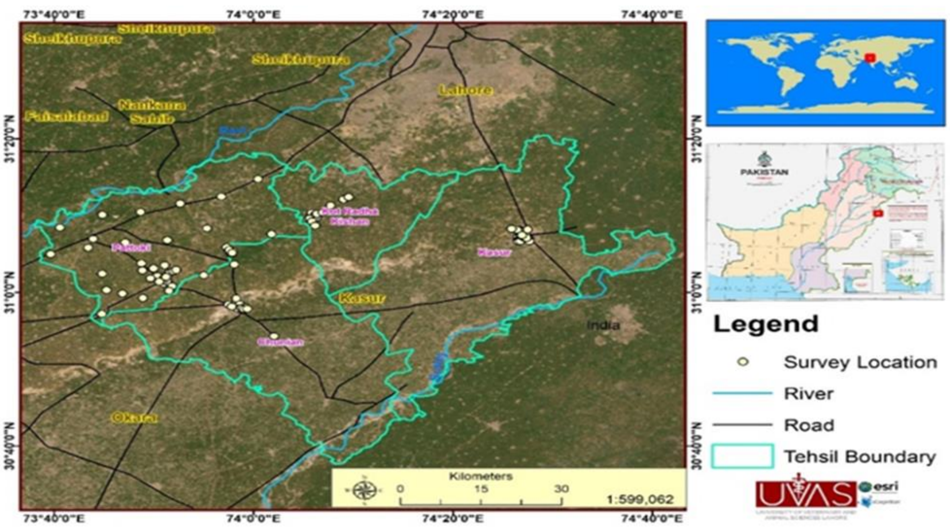

Figure 1. GIS-based map of sampling sites in district Kasur, Punjab, Pakistan

Sample collection

One hundred samples were collected in sterilized bottles (250ml) from filtration plants, bore pumps, supply lines, and taps and closed tightly to avoid environmental contamination. GPS coordinates from each sampling point were recorded for geospatial analysis. The American Public Health Association (APHA) standard sampling method was adopted to collect the samples from October to November (2023). All samples were labeled with location, sampling source, date, and GPS coordinates, as represented in Table 1.

Table 1. Water samples were collected from four tehsils in district Kasur.

Sampling area	No. of sites (n)	No. of samples (n)	Source of samples
Chunian	5	25	Tube well, tap water, filtration plants
Kasur	5	25	-do-
Kot Radha Kishan	5	25	-do-
Pattoki	5	25	-do-

Sampling sites and source of water sample

Percentages represent the proportion of each water source within the respective area. In Pattoki, the predominant water source is hand pumps, accounting for 43.20% of the total count. In Chunian, bore pumps were the most common source, representing 13.00% of the count. In KRK, most water samples were from filtration plants, making up 75.00% of the count. In Kasur, the distribution is more evenly spread, with bore pumps, tap water, and filtration plants, each contributing around 14.70% of the count, as shown in Table 2.

Table 2. Source of water samples from four tehsils of district Kasur

	District							
	Pattoki		**Chunian**		**KRK**		**Kasur**	
Sample site	**Count**	**%**	**Count**	**%**	**Count**	**%**	**Count**	**%**
Bore pump	0	0.00%	3	13.00%	12	75.00%	5	14.70%
Bore water	5	13.50%	0	0.00%	0	0.00%	0	0.00%
Hand pump	16	43.20%	0	0.00%	0	0.00%	0	0.00%
Tap water	2	5.40%	0	0.00%	0	0.00%	0	0.00%
Wate supply	1	2.70%	0	0.00%	0	0.00%	0	0.00%
Water filtration plant	4	10.80%	0	0.00%	0	0.00%	0	0.00%
Water supply line	1	2.70%	0	0.00%	0	0.00%	0	0.00%

Spatial variability analysis

GIS was used to create geographical distribution maps of water quality metrics. The distribution maps provided crucial data for identifying groundwater quality measures with concentrations under WHO (World Health Organization) allowable limits in District Kasur, Punjab, Pakistan's potable water and its implications for public health and disease control. A central tool of geostatistical methods, such as semi-variance, was applied to quantify the spatial autocorrelation of groundwater parameters based on recorded data. All the spatial trends were carried using the GS+ software.

Physiochemical analysis

Physiochemical analysis was conducted in the laboratory of "The Department of Wildlife and Ecology", University of Veterinary and Animal Sciences Ravi Campus Pattoki, Punjab, Pakistan. The pH was analyzed using a pH meter (Hanna instrument, H18418). A multimeter (Milwaukee 802) was used to measure the temperature. A Smart combined meter (Milwaukee 102) was used to estimate TDS and EC. Titration methods were used to test chloride concentration (Fazal-ur-Rehman & Haider, 2018; Haider et al., 2022). DO and BOD were calculated using a DO analyzer (JPJJ-609L) and BOD meter (Oxi Direct), respectively. Each analysis was performed thrice, and the mean value was computed as shown in Table 5.

Color and taste were observed with the help of senses and odor. According to the Pakistan Council for Research in Water Resources, all physicochemical analyses were completed within 24 hours of sample collection. The necessary safety precautions were taken throughout sample collection, storage, handling, and processing (Rasheed et al., 2021).

Bacteria culture and identification

MacConkey agar, Eosin Methylene Blue agar (EMB), and Salmonella and Shigella agar were utilized to isolate bacterial species, and plates were incubated at 37˚C for 18-24 hours (Reddy, 2023).

Phenotypic and biochemical characterization of the isolates

In respective species morphology, Shigella colony was observed in light red rod shape, E.coli appeared in pink color with rounded end, and Klebsiella was observed in pink color with large rod shape under bright field microscope, respectively, as presented in Table 6. These bacterial species were further characterized biochemically by gram staining, endospore staining, methyl red test, coagulase test, motility test, Indole production test, oxidase activity, and catalase test by following the American Society for Microbiology protocol.

Standards for water quality

Physicochemical and Microbiological analyses were compared with the National Standard of Drinking Water Quality (NSDWQ) and Pakistan Standards and Quality Control Authority (PSQCA), which were approved by the Pakistan Environmental Protection Council (PEPC) in collaboration with the World Health Organization (WHO).

Enumeration of pathogenic bacteria

CFU/ml method was used to measure the number of bacterial colonies on a given medium. A series of serial dilutions were performed to estimate the CFU. After performing serial dilution from 1x 10^1 to 1x $10^{6.}$ 0.1ml of the prepared diluted samples were plated to culture media, e.g., MacConkey agar, Eosin methylene agar, and Salmonella and Shigella agar for 18-24 hours at 37˚C and also labeled as given in Table 7. The estimation of CFU was taken into account culture plates with colonies 30 to 300. Cell density was calculated as follows;

$$\text{Number of cells/mL} = \frac{\text{Colonies Counted}}{\text{Volume plated} \times \text{Dilution}}$$

Statistical analysis

The results of the physicochemical parameters were obtained using Statistica Ver. 6.0 and the analysis tool pack in Microsoft Excel. For each water quality analysis, one-way ANOVA was applied using the SAS online version to check the significant difference between different water samples at a 95% confidence interval. Arc GIS 10.8.1 software was used to map groundwater quality's spatial distribution, as mentioned in Figs. 4 and 5. Inverse distance weighting (IDW) developed the raster data set from low to high values, after which the microbial risk zones were developed, as in Figs. 2 and 3.

Results

Physicochemical analysis of potable water

The study assessed the drinking water quality in four tehsils of District Kasur Punjab Pakistan.

Temperature

The temperature of all samples ranged from 23.5 to 25.5ºC.

Taste

The distribution of water quality ratings in different areas: Pattoki, Chunian, KRK, and Kasur. These counts represent the number of occurrences for each water quality rating, while the percentages indicate the proportion of each rating within the respective area, as mentioned in Table 3.

Odor of water sample

The odor of analyzed samples which was non objectionable/odorless are presented Table 4.

Color of water sample from different tehsils:

Samples collected from all tehsils were clear (100%).

Physiochemical Analysis of water sample

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In Table 5 represent the statistical analysis of water quality parameters across the four locations in District Kasur revealed significant variations in certain parameters. TDS, DO, EC, Chloride ion concentration, pH values exhibited significant differences between Pattoki and KRK compared to Chunian and Kasur. However, no significant differences were observed for BOD across all locations.

Table 3. Taste of water samples collected from study area.

	Pattoki		**Chunian**		**KRK**		**Kasur**	
	Count	%	Count	%	Count	%	Count	%
Acceptable	27	73.00%	0	0.00%	11	68.80%	31	91.20%
Salty	10	27.00%	15	65.20%	5	31.20%	3	8.80%

Table 4. The odor of water samples collected from the study area.

	Pattoki		**Chunian**		**KRK**		**Kasur**	
	Count	N	Count	%	Count	%	Count	%
Non Objectionable	37	100.00%	23	100.00%	16	100.00%	20	58.80%
Objectionable	0	0.00%	0	0.00%	0	0.00%	7	20.60%

Table 5. Physico-chemical parameters of water samples collected from the study area.

	Pattoki		**Chunian**		**KRK**		**Kasur**	
	Mean	**Standard Deviation**	**Mean**	**Standard Deviation**	**Mean**	**Standard Deviation**	**Mean**	**Standard Deviation**
TDS (ppm)	732a,b	595	1138a	698	1026a,b	781	598b	240
pH	8a	1	8b	0	8a	1	8b	0
EC (ms)	1a	1	2b	1	2a,b	1	1a	0
DO (mg/L)	7a	1	6b	1	6b	1	7b	1
BOD (mg/L)	2a	0	2a	0	2a	0	2a	1
Cl ion conc. (mg/L)	190a	48	258b	92	205a,b	79	178a	31

Note: Values in the same row and sub-table not sharing the same subscript are significantly different at p< .05 in the two-sided equality test for column means. Cells with no subscript are not included in the test. Tests assume equal variances.

Table 6. Microbiological and biochemical test results of *E.coli*, *Shigella*, and *Klebsiella* isolated from potable water of district Kasur, Punjab, Pakistan

Bio chemical test	**Bacterial species**	**Kot Radha Kishan**	**Chunian**	**Pattoki**	**Kasur**	**Status**	**Agar**

Gram staining	**Klebsiella**	-ve	-ve	-ve	-ve	red color	MacConkey agar, EMB agar, Salmonella and shigella agar
	Shigella						
	E. coli						
Endospore staining	***Klebsiella***	-ve	-ve	-ve	-ve	Red\Pink	MacConkey agar, EMB agar, Salmonella and shigella agar
	Shigella						
	E. coli						
Catalase Test	***Klebsiella***	+ve	+ve	+ve	+ve	Presence of bubble	MacConkey agar, EMB agar, Salmonella and shigella agar
	Shigella						
	E. coli						
Oxidase Test	***Klebsiella***	-ve	-ve	-ve	-ve	Presence of bubbles	MacConkey agar, EMB agar, Salmonella and shigella agar
	Shigella						
	E. coli						
Indole test	***Klebsiella***	-ve	-ve	-ve	-ve	No color change Color change	MacConkey agar, EMB agar, Salmonella and shigella agar
	Shigella						
	E. coli						
Voges Praskauer test	***Klebsiella***	+ve	+ve	+ve	+ve	Red	MacConkey agar, EMB agar, Salmonella and shigella agar
	Shigella	-ve	-ve	-ve	-ve	Yellow	
	E. coli	-ve	-ve	-ve	-ve	Yellow	
Motility Test	***Klebsiella***	Motile	Motile	Motile	Motile	Pink	MacConkey agar, EMB agar, Salmonella and shigella agar
	Shigella						
	E. coli						
Methyl Red Test pH(4)	***Klebsiella***	+ve	+ve	+ve	+ve	red	MacConkey agar, EMB agar, Salmonella and shigella agar
	Shigella						
	E.coli						

Enumeration of bacterial species in CFU/ul

A colony forming unit or CFU, is a unit commonly used to estimate the concentration of microorganism in a test sample as mentioned in Table 7. To obtained CFU/ml number of the visible colonies present on agar plate were multiplied by the dilution factor.

Table 7. CFU/ul of *E. coli, Shigella and Klebsiella* in water samples of District Kasur.

Sample sites	Microbial species	No. of Colonies	CFU/ul
Chunian	*E.coli*	0-280	0 ul-2.80×10^{4}ul
	Shigella	0-39	0 ul-3.9×10^{2}ul

	Klebsiella	9-156	9×10^2ul-1.56×10^4 ul
Kot Radha Kishan	*E.coli*	0-150	0 ul-1.50×10^5ul
	Shigella	0-43	0 ul-4.3×10^3ul
	Klebsiella	0-53	0 ul-5.3×10^2ul
Pattoki	*E.coli*	0-33	0 ul-3.3×10^2ul
	Shigella	42-115	4.2×10^3ul-1.15×10^4ul
	Klebsiella	0-51	0 ul-5.1×10^2ul
Kasur	*E.coli*	0-112	0 ul-1.12×10^4ul
	Shigella	0-37	0 ul-3.7×10^4ul
	Klebsiella	0-76	0 ul-7.6×10^5ul

Water quality parameters

The analysis of variance (ANOVA) as shown in Table 8, was conducted to assess the statistical significance of differences among the tested variables. The results indicate that a significant difference between groups were observed for TDS ($F = 5.086$, $p = 0.002$), pH ($F = 10.337$, $p < 0.001$), EC and DO ($F = 8.277$, $p < 0.001$ and $F = 8.702$, $p < 0.001$, respectively) were observed. However, for BOD, Cl ion conc., *E. coli* (cfu), *Klebsiella* (cfu) and *Shigella* (cfu), there were no significant differences between groups.

Table 8. ANOVA test results from different water parameters.

		Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
TDS(ppm)	Between Groups	4966032	3	1655344	5.086	0.002*
	Within Groups	34501118	106	325482.2		
	Total	39467151	109			
pH	Between Groups	5.064	3	1.688	10.337	0.00*
	Within Groups	17.309	106	0.163		
	Total	22.373	109			
EC (ms)	Between Groups	23.481	3	7.827	8.277	0.00*
	Within Groups	100.237	106	0.946		
	Total	123.718	109			
DO(mg/L)	Between Groups	15.889	3	5.296	8.702	0.00*
	Within Groups	64.511	106	0.609		

	Total	80.4	109			
BOD(mg/L)	Between Groups	0.562	3	0.187	0.67	0.572
	Within Groups	29.656	106	0.28		
	Total	30.218	109			
Cl (mg/L)	Between Groups	98240.05	3	32746.69	8.792	0.00*
	Within Groups	394797.2	106	3724.502		
	Total	493037.3	109			
E.coli (cfu)	Between Groups	3096.461	3	1032.154	2.898	0.039*
	Within Groups	37754.23	106	356.172		
	Total	40850.69	109			
Shegilla(cfu)	Between Groups	18.802	3	6.267	1.643	0.184
	Within Groups	400.446	105	3.814		
	Total	419.248	108			
Klebsiella(cfu)	Between groups	212.690	3	6.267	1.621	0.137
	Within groups	200.535	105	3.814		
	Total	413.225	108			

Note: “*” indicates the significant results

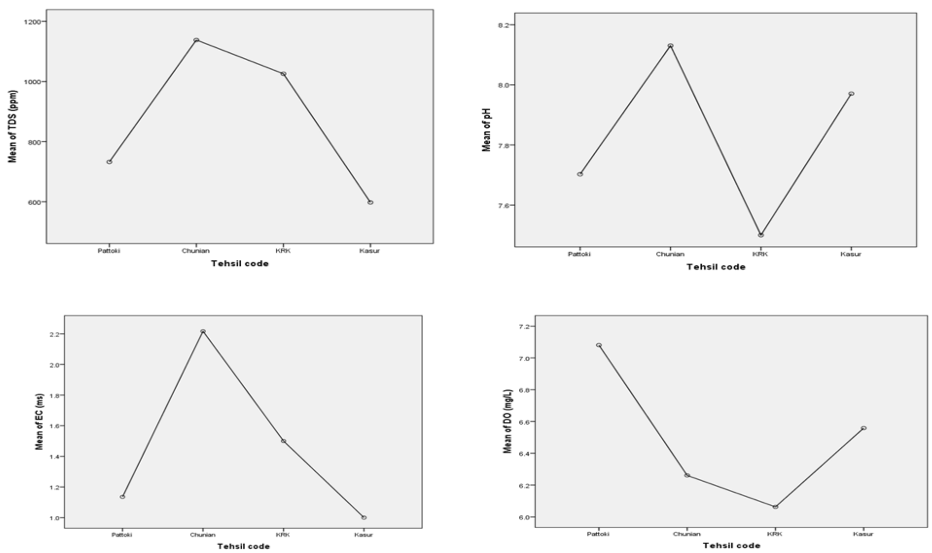

Fig. 2. Mean plot for the influence of physiochemical parameter (pH, EC, TDS and DO) on water quality index

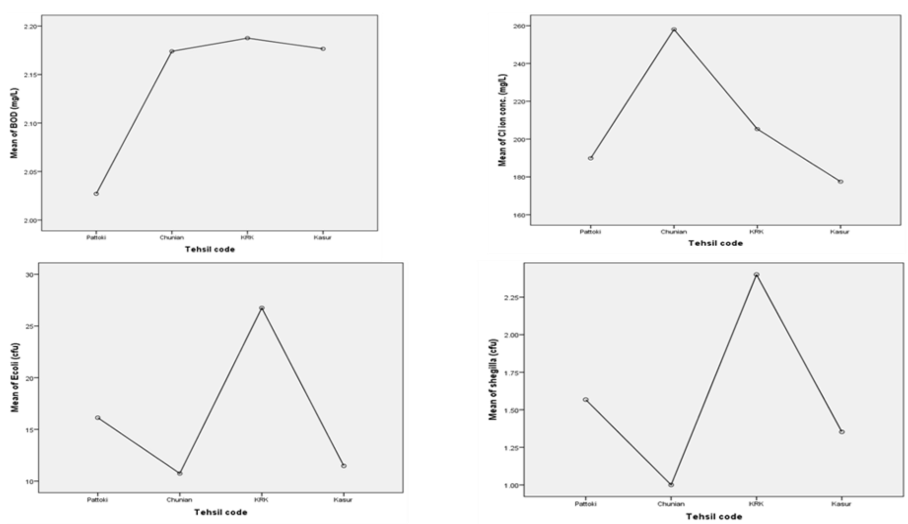

Figure 3. Mean plot indicated the influence of microbial and physiochemical parameter (BOD, Cl and CFU of *E.coli* and *Shigella*) on water quality index

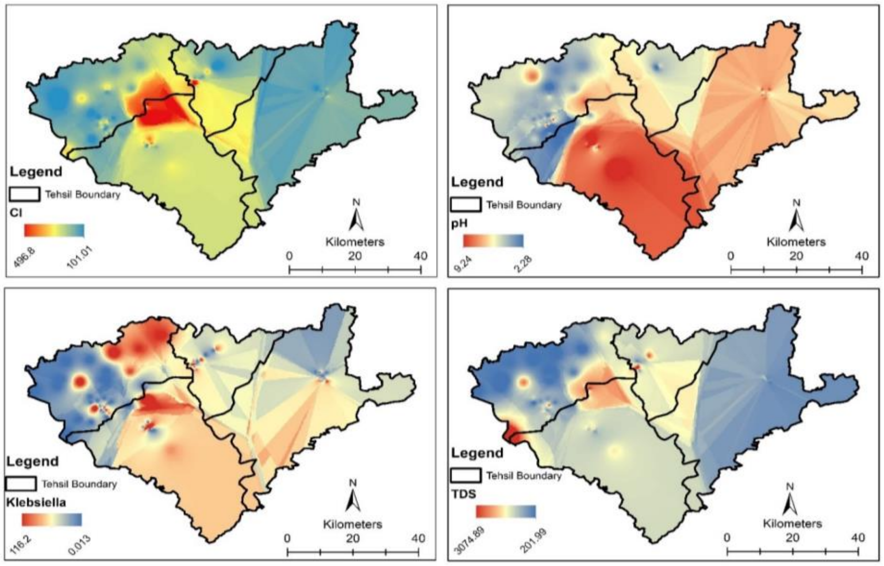

Figure 4. Spatial distribution map for the risk assessment of *Shigella*, EC, DO and *Ecoli.* Red color indicating high conc. and blue color indicating low conc.

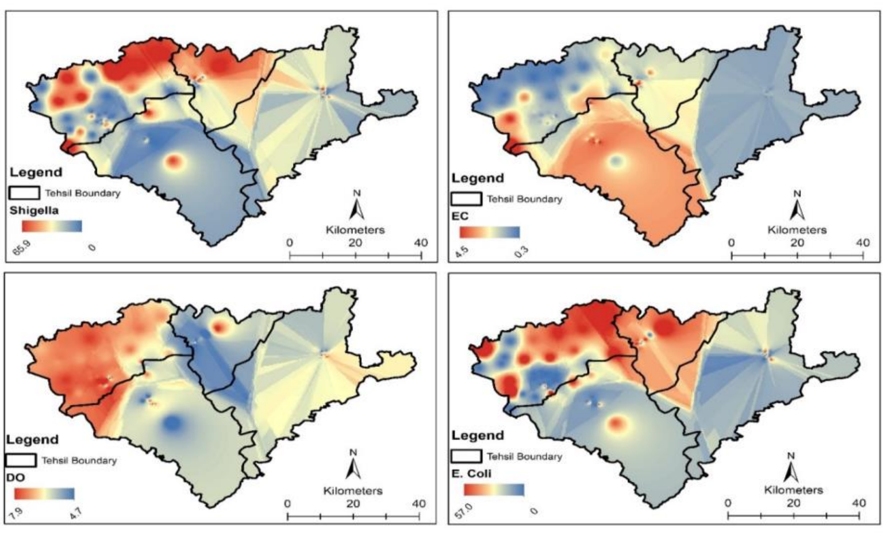

Figure 5. Spatial distribution map for the risk assessment of Cl, pH, *Klebsiella* and TDS. Red color indicating high conc. and blue color indicating low conc.

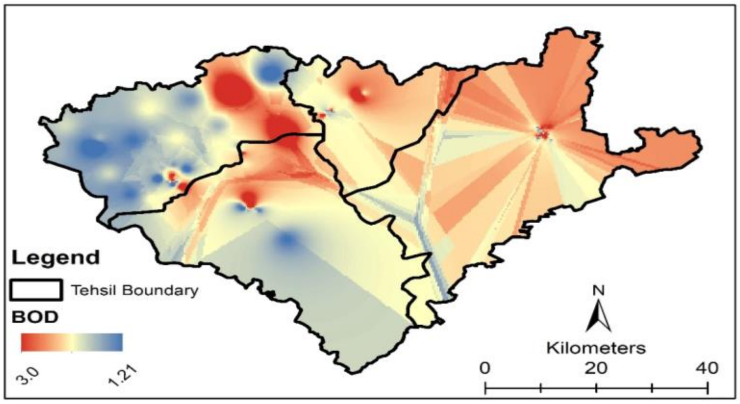

Figure 6. Spatial distribution map for the risk assessment of BOD. Red color indicates high conc. and blue color indicating low conc.

Discussion

The study assesses the drinking water quality in the Kasur, Punjab, Pakistan district. A total of 100 groundwater samples were gathered from four tehsils. These samples were examined to assess groundwater's physicochemical and bacteriological contamination. Groundwater temperature in different areas was measured using a glass thermometer, registering a range of 25-26ºC in Chunian, 23-26ºC in Pattoki, 25-26ºC in Kasur and 25-26ºC in Kot Radha Kishan. Environmental conditions influenced the temperature variations because some samples were collected in the early morning and others in the afternoon of October and November (2023). These temperature values fall within the acceptable limits defined by WHO 20-30 ºC, making the groundwater suitable for drinking. Similar findings for T are indicated in the Vihari district (Khalid et al., 2018). The taste of the water in the study area was found to be salty but acceptable for human consumption. Our study shows that the odor and color of water are nonobjectionable due to the number of organic and some inorganic substances. Water supplied to consumers should be free of objectionable odor. Previously, results with slightly reduced incidence of metals were obtained by other researchers (Dietrich & Devesa, 2019).

The concentration of dissolved solids exhibited significant differences between Pattoki (180-3070 mg/l) and KRK (280-1700 mg/l) compared to Chunian (170-2740 mg/l) and Kasur (220-1510 mg/l) due to the involvement of industrial wastewater. WHO has prescribed less than 1000 mg/l as permissible limit for TDS. The pH levels of groundwater in different tehsils of district Kasur were measured as follows: Kasur ranged from 7.4 to 8.5, Chunian from 7.5 to 9.0, Kot Radha

Kishan from 6.8 to 7.8 and Pattoki from 6.6 to 8.7 and theses values are higher than prescribed limit by WHO 6.5-8.5. Our results are also from the earlier study in Westridge and Tench Bata in Rawalpindi (Farooq et al., 2008; Hashmi et al., 2009).

Statistically highest conductivity (EC) value was found in water samples collected from Chunian (260-4030 µS/cm), Pattoki (320-3090 µS/cm), Kot Radha Kishan (430-3200 µS/cm) and Kasur (600-2230s µS/cm) while conductivity set by WHO is 2500 (µS/ cm) at 25°C. This means that water was not suitable for drinking. The incidence of EC values ranged in Bangladesh tap water of 250-5500 µS/cm while in our study was also higher than in past research (Islam et al., 2010).

Dissolved Oxygen (DO) levels differ significantly, which was observed from 5.02-7.9 mg/l in Kasur, 4.56-7.78 mg/l in Kot Rada Kishan, 5-7.88 mg/l in Chunian, and 5.82- 7.84 mg/l in Pattoki while WHO standards for DO ranged from 4 mg/l-6.7mg/l. This study showed a high DO (7.9 mg/l), and our findings align with the study performed in another country like Saudi Arabia by Abada et al. (2019), which also demonstrated that this elevation may have developed due to fecal contamination. Statistically, the highest value of Cl was found in Chunian 100-480 mg/L and Kot Rada Kishan 130-375 mg/L water samples, while the lowest value was found in Pattoki 120-290 mg/L and Kasur 130-280 mg/L. Other researchers also found unsafe chloride levels in drinking water samples of Sheikhupura, Pakistan (Abbas & Cheema, 2015). Statistically, the highest level of BOD (1.3-3.4mg/L) was found in water samples taken from Kasur. In contrast, the lowest level of BOD (1.5-.3 mg/L) in Kot Rada Kishan (1.3-3 mg/L) in Chunian and in Pattoki (1.2-3 mg/L) was detected, respectively. High levels of BOD were due to industrial effluents. All sample results are considered within safe limits for drinking purposes and similar to other research research in Karachi (Fatima et al., 2021).

The incidence of chloride-Cl contamination and prevalence reported for coliform bacteria, *E. coli, Shigella, and Klebsiella were similar to past studies of water plants in tannery effluent-contaminated soil of Kasur, Pakistan (Bareen & Tahira, 2011). However,* factors like weather, nearby land-living, and water plant construction sometimes influence water quality while primarily affecting the geological setting of each water source.

Conclusions and recommendations

Our findings showed a high value of physiochemical parameters. A significant correlation was found between *E.coli*, *Shigella* and *Klebsiella* with the potable water of Chunian and Kot Radha Kishan as compared to Kasur and Pattoki which is not good for the health and well-being of the district's residents. Our study yields extensive data on contamination in district Kasur water sources, revealing causes of contamination and ways to identify and prevent health risks. Most water quality parameters align with prior water plant studies in Kasur, except for induced Shigella, Klebsiella, and chloride-Cl contamination rates. The geological setting primarily influenced filtration plant quality, while construction, nearby land uses, and climate also influenced certain parameters. The results revealed that the water quality of the study area is not acceptable for drinking purposes. Highly preventive measures must be taken to treat and prevent contaminated water resources.

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