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TEMPORAL VARIABILITY ASSESSMENT OF MAJOR POLLUTANTS IN WASTEWATER OF HUDIARA DRAIN AND ALLIED AQUIFERS: A POTENTIAL ENVIRONMENTAL RISK

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Abstract
Wastewater flowing through Hudiara Drain is posing serious threats to population, agriculture, livestock, and groundwater aquifers. No historical data was available regarding the drain water quality and its impact on groundwater in the allied areas. It is a nearly 100 kilometers trans-boundary Drain emanating from India with 55 kilometers reach in Pakistan where it finally falls into river Ravi. Some cattle died along its surroundings in 1998 and Directorate of Land Reclamation Punjab (now Water Resources Zone) Lahore was assigned to investigate who 0reported that the Drain carries a cumulative load of more than three hundred industries and housing societies and that the aquifer below it is directly linked with 27 villages containing As, Cu, Cd, Cr, Fe, Ni, Pb, Se, Zn, pesticides and various organic and inorganic matters which seems to be the major cause of various endemic and epidemics diseases including respiratory disorders, skin infections, gastrointestinal problems and even death in extreme situations. The current study involved eight years monitoring of this drain in which 240 samples of Hudiara Drain and 96 samples of groundwater were collected and examined during 2016-22 (Total: 336 Samples). Major water quality parameters like Electrical Conductivity (EC), Total Dissolved Solids (TDS), Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), Fe, Ni, Cu, Cr and Cd were determined for wastewater. Sodium Adsorption Ratio (SAR) and Residual Sodium Carbonate (RSC) were monitored to evaluate the irrigation water quality of the drain samples. The average values were computed, and it was found that the wastewater of drain was unfit due to high COD, BOD, TDS, Electrical Conductivity, Cu, Cd, SAR, and RSC during both Pre- and Post- Monsoon Seasons. Groundwater quality in the vicinity of Hudiara Drain indicated that all the physical parameters were within the fit range except Fe which exceeded the permissible limits. The groundwater quality regarding irrigation parameters revealed that its quality was fit for irrigation based on EC, SAR, and RSC. The temporal assessment of drain water did not provide a specific trend though a slow but steady deterioration in groundwater quality was observed. The groundwater was also found fit for irrigation quality in the whole area selected for study. An impact of wastewater on groundwater quality in adjacent areas was observed and a slow but steady increase in water quality deterioration was noticed which might be a potential threat in the upcoming years keeping in view the high urbanization rate and water scarcity. Wastewater coming from industries and allied populations must be treated to avoid the increase in waterborne diseases and to conserve the water quality.

Keywords: Hudiara Drain, groundwater, drinking water, irrigation, carcinogen, water-born diseases and temporal variability.

1. INTRODUCTION

Pollution is a growing challenge for our globe which is under intensive climate change scenarios at meso-scale **(1)**. No need to feign ignorance and be optimistic regarding abundant availability of usable water resources in the world **(2)**. Rapid urbanization and population explosion are not only responsible for diminishing water resources but also adversely polluting them **(3)**. Industrial and municipal pollution load in surface water bodies is causing serious threats to the groundwater in terms of health and hygiene which invariably enters the food-chain causing serious ailments in humans, livestock, and agricultural products **(4, 5, 6)**.

Hudiara Drain first came into the public view in 1998 when a certain number of cattle died in its vicinity and some Pakistani newspapers speculated that their cause of death was due to some toxic chemicals being released in it by India. It is a nearly 100 kilometers trans-boundary Drain emanating from Batala (India) entering Pakistan at Zero Line before Llore village. Responsibility to investigate the matter was assigned to Directorate of Land Reclamation Punjab (now Water Resources Zone), Lahore which reported that this Drain is carrying a cumulative load of more than 300 industries and housing societies in the 55 kilometers reach between the Zero Line and River Ravi and the aquifer below this Drain is directly linked with 27 villages containing heavy metals (As, Cu, Cd, Cr, Fe, Ni, Pb, Se and Zn), pesticides and various organic and inorganic matters causing various endemic and epidemics diseases **(7, 8, 9, 10, 11, 12,13)**.

The heavy metal exposure to the population and aquatic life is posing serious threats to quality of life. Short term exposure to heavy metals may cause respiratory disorders, skin infections, gastrointestinal problems and even death in extreme situations. Chronic exposure to heavy metals induces carcinogenesis, muscular, cardiovascular, neurological, renal, and liver function disorders **(14-15)**.

Hudiara drain is reported to be enriched in such contaminants due to geogenic and anthropogenic activities. A study revealed that most groundwater samples in the vicinity of Hudiara drain regarding WHO drinking water quality standards showed an upward trend especially in context of Lead and microbial contamination **(16)**.

One of the foremost grounds behind groundwater deterioration is the contamination which reaches it through polluted surface water. Groundwater is 70% source for drinking water and 80% of this amount is unfit. Consumption of this polluted groundwater is the leading cause of 80% water borne diseases **(17)** causing an income loss of USD 380-883 million on annual basis which counts for 0.6-1.44% of GDP of Pakistan **(18)**.

The wastewater of Hudiara drain is also used unlawfully to irrigate adjacent irrigation lands which is contaminating the food chain and consequently the health of consumers. A study conducted on the groundwater quality in the vicinity of Hudiara drain regarding irrigation fitness highlighted that 79% of samples were unfit for this purpose **(19)**.

The already published data on Hudiara Drain water quality does not cover the temporal trends of contaminants thus making the legislators somewhat ambiguous regarding reaching a clearcut decision for development of a policy to mitigate or reduce the contamination of groundwater and surface water bodies so that public health be improved. Temporal variability is also very helpful in developing a real-time database of pollutants. This reliable data will be fruitful in designing various pollution-mitigation and management strategies to mitigate the contaminants in our water bodies **(20-21)**. The current work was designed to generate a comprehensive database of heavy metals and irrigation water quality standards of wastewater of Hudiara drain over a period of eight years, so that temporal variability may be established. The groundwater quality for drinking and irrigation quality in adjacent areas was also monitored to predict the future trends based upon the historic data.

2. Material and Methods

2.1. Sample collection and treatment

The wastewater of Hudiara Drain was sampled biannually (Pre-Monsoon and Post Monsoon) from its various locations. Briefly 15 sites were selected along Hudiara drain from head to tail for wastewater collection and 5 sites were opted for groundwater sampling. The period of this Study ranges for eight years started in April 2016 and ended by October 2022. 30 samples of Hudiara Drain and 12 samples of groundwater were taken twice a year (pre-monsoon and post-monsoon). Thus 240 samples of Hudiara Drain and 96 samples of groundwater were examined during 2016-22 making a total of 336 Samples.

The samples were collected in polyethylene bottles from each site. Drain water samples were collected in sterilized plastic bottles. One of four samples each was treated with nitric acid (HNO_3) for bringing pH below 2 for heavy metals analysis. Samples for chemical oxygen demand (COD) were treated with sulfuric acid (H_2SO_4) and samples for biological oxygen demand (BOD) from each site were stored in ice for further placing them in the Laboratory refrigerator at -4^{o}C till their analysis. One Blank (Untreated) sample was also stored for their physico-chemical analysis. The details of sampling sites for wastewater and groundwater are given in **Table-1** and **Table-2** respectively.

Table 1. Sampling sites for wastewater collection at Hudiara Drain from Head to Tail

Sr. No.	GIS No.	Location		
		Latitude	**Longitude**	**Exact Sampling Spots**
1.	DW 1	31.4961	74.5844	Zero Line - Right Bank of Hudiara Drain just after entering Pakistan
2.	DW 2	31.4883	74.5919	Left Bank of Hudiara Drain near Llor Village
3.	DW 3	31.4883	74.5917	Right Bank of Hudiara Drain near Llor Village
4.	DW 4	31.4881	74.5919	Middle of Hudiara Drain Bridge near Llor Village
5.	DW 5	31.4736	74.5925	Left Bank of Hudiara Drain before Deosani Village
6.	DW 6	31.47	74.5894	Middle of Hudiara Drain Bridge near Deosani Village
7.	DW 7	31.4433	74.5567	Left Bank of Hudiara Drain near Hudiara Village
8.	DW 8	31.4444	74.5031	Left Bank of Hudiara Drain after Barki Road Bridge Crossing (Karbath Pull)
9.	DW 9	31.3972	74.375	Left Bank of Hudiara Drain before Ferozepur Road and near Dullo Village
10.	DW 10	31.3953	74.3617	Below the Ferozepur Road Bridge Crossing over Hudiara Drain from its Left Bank
11.	DW 11	31.3917	74.3242	From Middle of Hudiara Drain Bridge from where Kacha Town is towards its Left and Tibba Town is towards its Right
12.	DW 12	31.3989	74.1556	From Middle of Multan Road Bridge Crossing over Hudiara Drain
13.	DW 13	31.4003	74.1197	Middle of Hudiara Drain Bridge which came along the way while moving towards River Ravi
14.	DW 14	31.4061	74.1039	From Right Bank of Hudiara Drain (on the Delta) Just Before entering River Ravi (80 Feet)
15.	DW 15	31.4061	74.1036	Another Sample from Right Bank of Hudiara Drain (on the Delta) Just Before entering River Ravi (35 Feet)

Table 2. Sampling sites for Groundwater collection at Hudiara Drain from Head to Tail

Sr. No.	GIS No.	Location		
		Latitude	**Longitude**	**Exact Sampling Spots**
1.	GW 1	31.2807	74.3437	JJ Brothers farms Japan Road (Left Bank)
2.	GW 2	31.2651	74.3412	Hudiara Police Station
3.	GW 3	31.2435	74.2530	Left Bank of Hudiara Drain, Darbar Syed Sher Shah Wali near Thattha Khurd
4.	GW 4	31.2336	74.2121	Mosque Sonan Lane 2, Gaju Matta (Right Bank)
5.	GW 5	31.2406	74.0834	Astana Khizrya Mohlanwal (Right Bank)
6.	GW 6	31.405	74.11333	Fresh Groundwater Sample taken from a Handpump near a Dwelling on the Delta between Hudiara Drain and River Ravi (25 Feet Deep)

2.2. Sample analysis procedure

The collected samples were analyzed for Fe, Cu, Ni, Cr, As, Hg and Cd on Atomic Absorption Spectrophotometer (Perkin Elmer AAnalyst 800) using APHA 3120-B methods. The EC, TDS and pH readings were taken from HANNA Portable HI 99301 and HANNA HI 8424 respectively on the spot. The COD was determined using APHA 5220-B method and BOD determined using APHA 5210-D method. Calcium, Magnesium and Hardness were also determined (APHA 2340). The Sodium and Potassium were determined using APHA 3500 Na-B and APHA 3500 K-B respectively on Flame Photometer (Cole-Palmer 2655-00, USA). The Nitrates were determined according to recommended method APHA 4500 NO3-NB **(22)**. The Chlorides (Cl), Bicarbonates (HCO_3), Carbonates (CO_3), Sulphates (SO_4) and Total Dissolved Solids (TDS) were determined according to their recommended methods **(23)**. Sodium Adsorption Ratio (SAR) and Residual Sodium Carbonate (RSC) were also calculated accordingly **(24-26)** using the following mathematical relationships:

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

$$\text{RSC} = (HCO_3 + CO_3) - (Ca + Mg)$$

3. Results and Discussion

3.1. Metal ion concentration

The metal ions including Fe, Cu, Ni, Cr and Cd were determined in all the collected samples and compared with Punjab Environment Quality Standards (PEQS) of Pakistan as per Figure 1 (Pre-Monsoon) and Figure 2 (Post Monsoon).

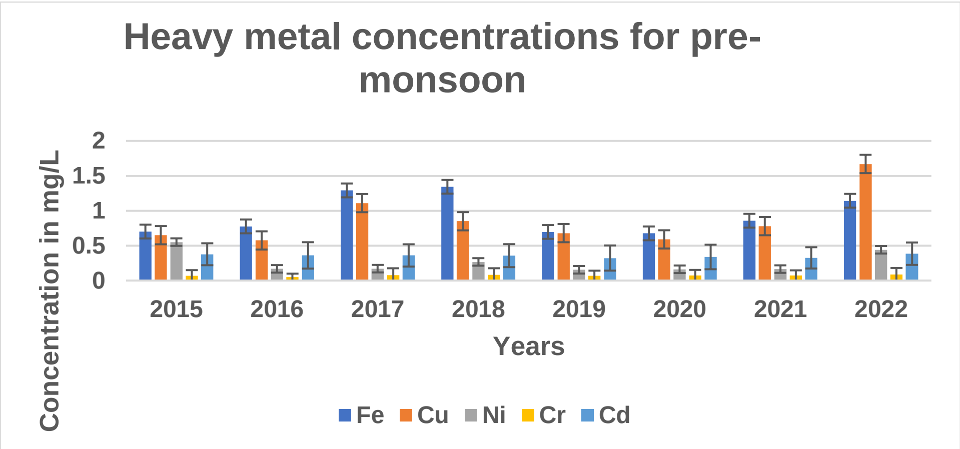

Figure 1. The heavy metal concentrations of samples collected in pre-monsoon.

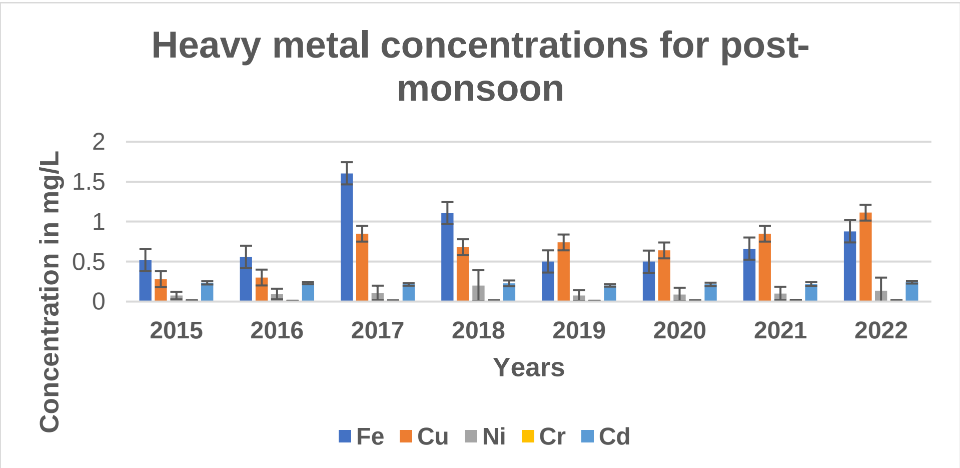

Figure 2. The heavy metal concentrations of samples collected in post-monsoon.

The maximum average value of Fe was observed in year 2018 pre-monsoon with value of 1.343±0.22 mg/L which was quite less than 8.0 mg/L, the prescribed limit in PEQS. The highest average concentration of Fe during post monsoon sampling was observed in 2017 with value of 1.343±0.22 mg/L which was also much below the prescribed limit of PEQS. The ANOVA indicated that the values of Fe in pre-monsoon 2018 and post-monsoon 2017 were significantly higher than the remaining years of sampling ($\rho<0.05$).
The results of Cu indicated that the maximum average value of 1.67±0.33 mg/L for Cu was noted in pre-monsoon season 2022 and maximum average value of 1.113±0.312 mg/L for Cu was observed in post-monsoon season 2022. Both the values exceeded the prescribed limit of 1.0 mg/L set for Cu in PEQS. The statistical comparison revealed that these values were significantly higher than the values observed for rest of the years with $\rho<0.05$.
As far as the Ni is concerned, its concentration remained far below the prescribed limit in PEQS during all the sampling periods. The results of Cr indicated that Cr concentration also remained within the prescribed limit of PEQS throughout the sampling years. No significant or abrupt change was observed for Cr. The Cd concentration remained above the prescribed limit (0.01 mg/L) throughout the sampling period. The Cd concentration ranged from 0.322±0.179 mg/L (2019) to 0.385±0.160 mg/L (2022) during pre-monsoon season. In post-monsoon season the Cd concentration ranged from 0.202±0.015 mg/L to 0.242±0.017 mg/L for the years 2019 and 2022, respectively. It was observed that the Cu and Cd concentrations in wastewater samples were found above the permissible level set for wastewater in PEQS which is alarming. Both Cu and Cd were reported to have moderate to severe health impacts on humans, plants and animals. The phenomenon of contamination of the food chain and its consequent impacts on consumers are of serious concern **(27)**.
The exposure to heavy metals including Cu and Cd is a multidimensional process. The leaching of heavy metals from wastewater to groundwater is an important process which cannot be ignored. The groundwater is the major source of drinking water in Lahore and Punjab, Pakistan. The consumption of such contaminated water may pose serious health impacts on consumers. Moreover, the groundwater is also used for livestock and irrigation practices which is a key contributor in food chain toxification through process of biomagnification **(28)**.
The TDS, COD and BOD were also determined for the collected samples (Figure 3-4).

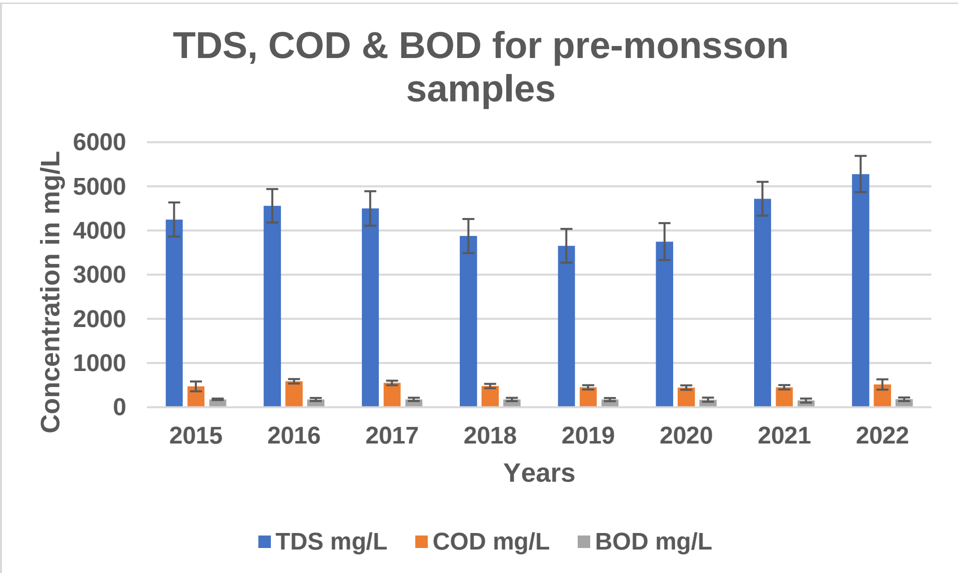

Figure 3. The TDS, COD & BOD level in samples collected in pre-monsoon.

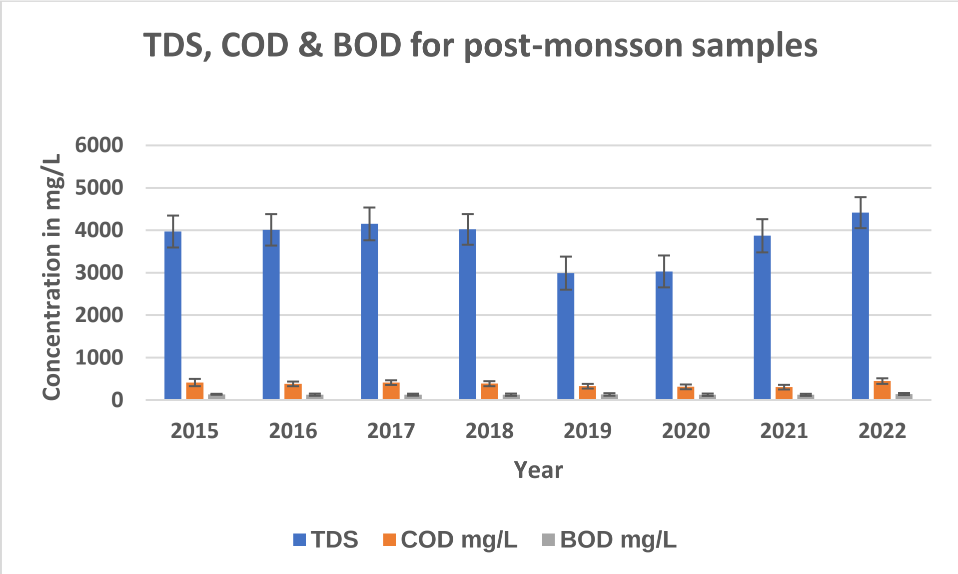

Figure 4. The TDS, COD & BOD level in samples collected in post-monsoon.

TDS is also an important parameter to determine the water quality for both drinking and wastewater. TDS values for pre-monsoon season exceeded 3500 mg/L which is the maximum allowed limit as per PEQS. The maximum average TDS value of 5280±410 mg/L was obtained in pre-monsoon sampling for the year 2022 and average maximum TDS 4415±365.1 mg/L were obtained for post-monsoon season sampling. The statistical analysis indicated that the TDS value for pre-monsoon 2022 was significantly higher among all the samples collected during pre-monsoon 2016-2022 with $\rho<0.05$, whereas the TDS values for post-monsoon season were statistically non-significant ($\rho>0.05$). All the collected samples were found unfit based on TDS. The higher levels of TDS in surface water bodies triggers many environmental damaging factors including limited use of water for irrigation, agriculture and industrial operations. High TDS destroys the quality of water by accelerating the growth of blue green algae, eutrophication process and turbidity which implicates negatively the already scarce water resources **(29-30)**.

The high level of TDS in surface water bodies also deteriorates groundwater quality by leaching through soil thus imparting consequently high levels of TDS in groundwater too. Moreover, the irrigation practices using wastewater were reported as a major contributor to destroy the groundwater quality especially in terms of TDS **(31)**.

COD and BOD are two highly important surface water quality parameters. Both are also representative of pollution levels mainly due to organic contents. COD has an inverse relation with the dissolved oxygen as COD represents the amount of oxygen required to oxidize organic matter. The values of COD are usually higher than the values of BOD **(32)**.

The average based values of COD of collected water samples remained much higher than the prescribed limit of 150 mg/L. The maximum COD value of 587.0±50.6 mg/L was noted for pre-monsoon season 2016 (statistically significant) and maximum average value of COD for post-monsoon was found to be 445.8±66.2 mg/L in 2022 (statistically significant). The average maximum value of BOD was 179.8±40.9 mg/L for pre-monsoon season samples and this maximum value was observed in the year 2022. The average maximum BOD value 140.5±24.21 was observed for post-monsoon sampling. The BOD values for both pre- and post-monsoon seasons remained above the permissible level which was 80 mg/L. The BOD values for both pre- and post-monsoon sampling remained statistically non-significant with respect to seasons.

The high levels of COD and BOD in analyzed wastewater samples indicated the presence of higher pollution levels of organic nature and in case of Hudiara drain, the organic matter entry into drain water was mainly due to industrial outflows and domestic discharges.

No significant or abrupt change was observed for pH values of collected water samples during the study period. The statistical analysis revealed that the pH values for pre- and post-monsoon seasons showed non-significant variation (ρ>0.05). The EC, SAR and RSC are important parameters to assess the suitability of water for irrigation use and crop production **(33)**. The results of pH, EC, SAR and RSC are given in Figures 5-6 for pre-monsoon and post-monsoon seasons.

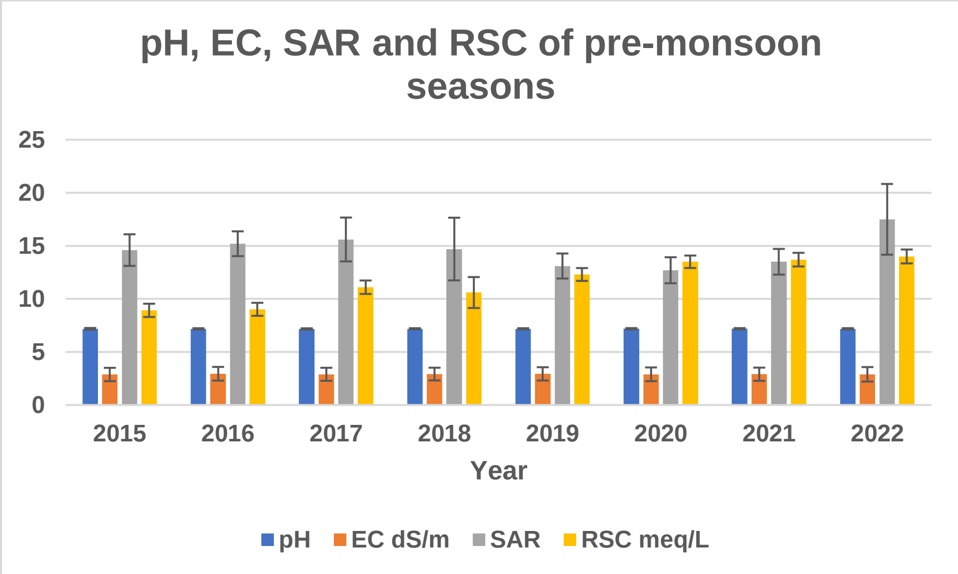

Figure 5. The pH, EC, SAR and RSC values of samples collected in pre-monsoon seasons.

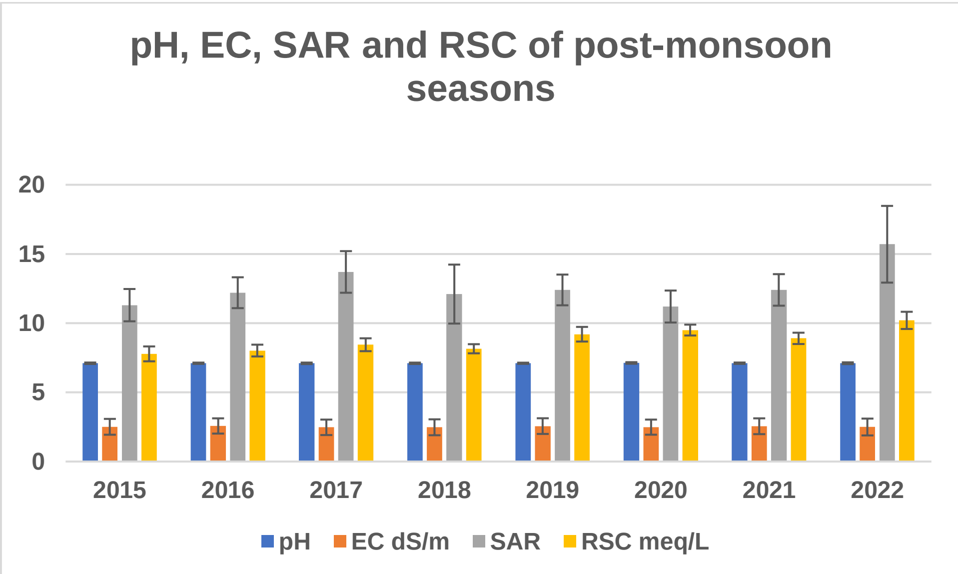

Figure 6. The pH, EC, SAR and RSC values of samples collected in post-monsoon seasons.

Due to water scarcity issues, wastewater is being used to irrigate crops and vegetables throughout the globe. A study reported that about 15 million m^3/day of untreated wastewater is used for crop production and about 10% of the population on planet feed upon the food produced by contaminated wastewater **(34)**.

The use of wastewater in agriculture sector is also a common practice in Pakistan to meet the water deficiency for irrigation which is causing serious health complications in the consumers **(35)**.

Behind, various organic and inorganic pollutants in wastewater, the disturbed ratios of calcium, sodium, magnesium, carbonates and bicarbonates results in high value of EC, SAR and RSC. Water having high values of EC, SAR and RSC individually or in combination becomes hazardous which not only deteriorates soil quality but also reduces the crop yields rendering agriculture production unsustainable **(36-37)**.

In the current study, the average value of EC ranged from 2.876±0.629 dS/m to 2.943±0.646 dS/m for pre-monsoon samples collected from 2016-2022. The average value of EC varied from 2.473±0.559 dS/m to 2.571±0.551 dS/m for post-monsoon samples collected from 2016-2022.The values for all the sampling years remained above the permissible guideline value of 1.5 dS/m. However, these values for both pre- and post-monsoon seasons were statistically non-significant ($\rho>0.05$).

The SAR results were examined and noted that the average value of SAR ranged from 11.2±1.1 to 15.7±2.7 for pre-monsoon samples collected from 2016-2022. The average value of SAR for post-monsoon season-based samples fluctuated from 12.47±1.2 to 17.5±3.3. These maximum average values of SAR were significantly higher among the remaining values for both pre- and post-monsoon season with $\rho<0.05$). The values for all the sampling years remained above the permissible guideline value of 10.0.

The average values of RSC exceeded the prescribed limit of 2.5 meq/L throughout the sampling seasons. A continuous increasing trend in RSC was observed from start to end sampling years. The statistical comparison elaborated that the values of RSC increased significantly till the end of sampling period ($\rho<0.05$).

The analyzed wastewater samples were found unfit for irrigation purposes due to exceedingly higher values of EC, SAR and RSC rendering drain water as a threat of sodicity and salinity.

Polluted Drain water of Hudiara is used by most of the farmers of adjoining lands for growing vegetables (on the presumption that they are using the most nutrient-rich water for crops) by violating the Regulatory Laws whereas the rest is drained off to River Ravi which ultimately reaches the farmlands of Lower Bari Doab through a network of canals, distributaries, and minors. The distribution of contaminants to the agricultural farms is an alarming feature with respect to human health and monitoring the levels of pollutants entering the food chain is no doubt very significant in this monitoring exercise. The use of unfit irrigation water having high values of EC, SAR and RSC above the permissible limits not only reduces the crop yields but also deteriorates the soil morphology. Continuous use of such unfit water eventually leads to permanent loss of soil fertility making agricultural lands less or poorly productive thereby directly hitting agricultural-based economy of our country **(38-40)**. The groundwater samples were also collected from 06 sites adjacent to Hudiara drain and analyzed for irrigation and drinking parameters. The EC, SAR and RSC of all collected groundwater samples were measured. The Cu, Fe, Ni, Cd and Cr were also determined along with TDS, hardness and turbidity. The results of groundwater analysis are given below.

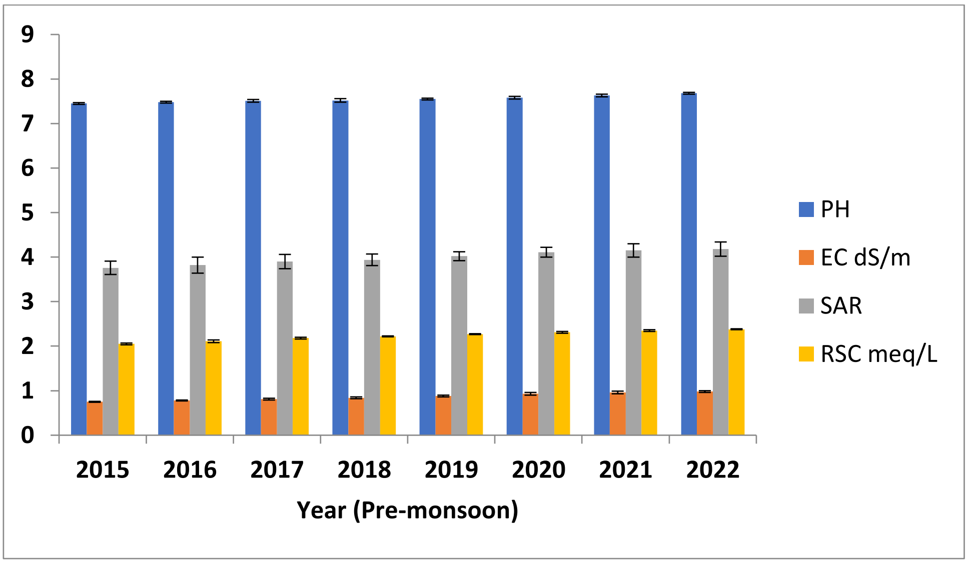

Figure 7. The pH, EC, SAR and RSC values of groundwater in pre-monsoon seasons.

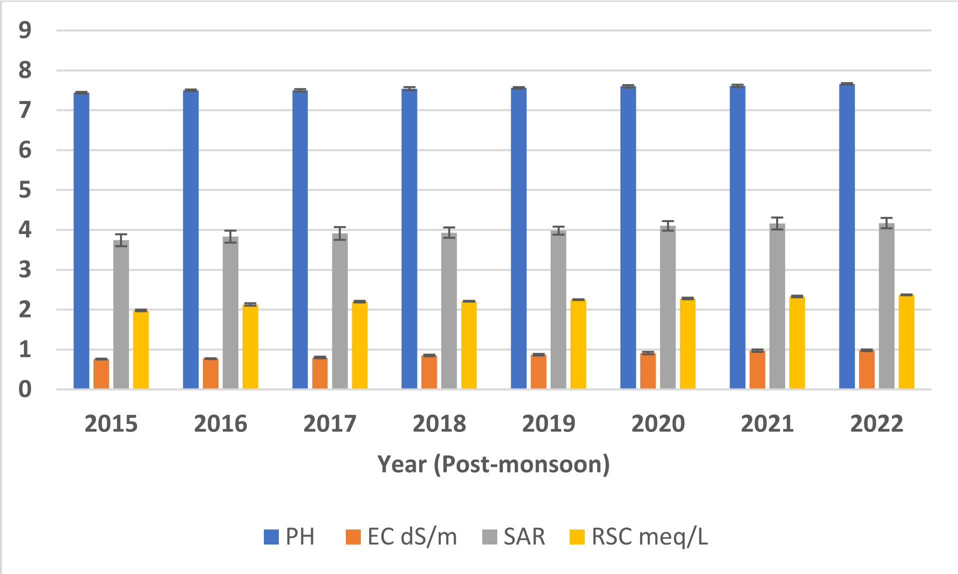

Figure 8. The pH, EC, SAR and RSC values of groundwater in post-monsoon seasons.

The values of EC, SAR and RSC for collected groundwater samples revealed that the irrigation water quality remained fit for all the groundwater samples during the study period. However, a slight but steady increasing trend was observed in EC, SAR and RSC over the period of time. This trend is threatening as if it continues, the water quality may become unfit for irrigation and RSC is the most vulnerable factor in this regard. Regarding drinking water quality, all the samples were almost fit for TDS, Hardness and turbidity for both pre- and post-monsoon seasons. Among heavy metals, Fe, Cu and Ni were detected whereas Cd and Cr were not detected in groundwater (Table 3-4). The Fe concentration exceeded the allowed limit set by WHO which is a potential risk factor.

Table 3: The drinking water quality of groundwater pre-monsoon season

Sr. No.	Year	Fe	Cu	Ni	Cr	Cd	TDS	Hardness	Turbidity
1.	2015	0.53	0.38	0.005	0	0	486.2	186.5	1.3
2.	2016	0.55	0.4	0.005	0	0	488.5	188.3	1.4
3.	2017	0.58	0.42	0.004	0	0	492.6	192.5	1.6
4.	2018	0.61	0.44	0.006	0	0	495.14	198.4	1.8
5.	2019	0.62	0.45	0.004	0	0	496.22	202.5	1.9
6.	2020	0.64	0.46	0.005	0	0	498.7	203.1	2.0
7.	2021	0.65	0.46	0.005	0	0	505.11	205.4	2.0
8.	2022	0.66	0.47	0.006	0	0	507.4	206.7	2.1

Table 4: The drinking water quality of groundwater post-monsoon season

Sr. No.	Year	Fe	Cu	Ni	Cr	Cd	TDS	Hardness	Turbidity
1.	2015	0.52	0.37	0.005	0	0	478.12	185.2	1.2
2.	2016	0.54	0.39	0.005	0	0	485.9	186.5	1.3
3.	2017	0.59	0.4	0.005	0	0	489.5	188.7	1.5
4.	2018	0.6	0.43	0.004	0	0	494.2	194.7	1.7
5.	2019	0.63	0.44	0.004	0	0	497	203.5	1.8
6.	2020	0.63	0.47	0.005	0	0	499.2	202.1	1.9
7.	2021	0.64	0.45	0.005	0	0	501.3	206.5	2.1
8.	2022	0.65	0.46	0.005	0	0	505.6	205.3	2.0

The groundwater analysis for drinking purpose indicated that both the metal ions and physical parameters continued to rise at a very low but steady rate. This trend may turn the water quality unfit during upcoming decades putting a serious threat for provision of safe water for increasing population. The increase in groundwater quality deterioration may be due to impact of leaching of contaminants from wastewater of drain to the adjacent aquifers. The contamination of groundwater through seepage of wastewater of drains or water channel is a well-established fact which must be addressed **(41)**. The unlined Hudiara drain is a serious threat to render groundwater completely unfit in future.

Conclusion

From the current investigation a temporal visibility was developed regarding surface and groundwater quality indices. The findings revealed that the drain water samples were highly polluted and were found unfit for irrigation as well. The huge pollution load is being dumped in River Ravi which is one of the major sources for irrigation and groundwater recharging, thus putting a serious threat to consumers, livestock, agriculture, groundwater regime and ecosystem. The polluted water resources may be a potential contributor to water borne diseases especially in vicinity of Hudiara drain in Lahore. The administrative departments must ensure the industries for treatment of effluents before throwing them into the Hudiara drain. A regular monitoring of groundwater quality in aligned areas must be carried out to have a temporal check on the water quality deterioration. The awareness regarding water treatment before use for drinking must be spread to reduce the quantum of water borne diseases.

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