

Water Practice and Technology

Evaluating the Impact of Nalla lai Contamination on Drinking Quality of Groundwater in Rawalpindi city, Pakistan --Manuscript Draft--

Manuscript Number:	WPT-D-22-00282
Full Title:	Evaluating the Impact of Nalla lai Contamination on Drinking Quality of Groundwater in Rawalpindi city, Pakistan
Article Type:	Research Article OA
Section/Category:	Drinking Water Quality
Keywords:	Groundwater, Wastewater, Percolation, Nalla lai, E.coli, Rawalpindi
Manuscript Region of Origin:	PAKISTAN
Abstract:	<p>The scientific report assessed the impact of Nalla lai wastewater on the groundwater quality of Rawalpindi city, Pakistan. A total of nineteen wastewater and forty-nine groundwater samples were collected during September and October 2016 and have been analyzed in the laboratory to detect different water quality parameters. The results revealed that BOD, COD, Iron and Cadmium values in many wastewater samples were beyond the recommended value of the National Environmental Quality Standards 1997 (NEQs, 1997). In groundwater samples, the results of iron, cadmium, manganese, zinc, TDS, pH, color and hardness were found elevated from the standard values in one or more samples as compared to the National Standard for Drinking Water Quality, 2010 (NSDWQ, 2010). The decreasing metal concentration order in groundwater samples was Iron > Zinc > Manganese > Copper > Cadmium. Very interestingly, hardness was found at elevated levels in 75% of investigated groundwater samples. Microbiological contamination was detected in 83% of the analyzed groundwater samples. The study revealed the percolation of heavy metals and microbial contamination in the bore water, tube wells, hand pumps, springs, and hand-dug wells located nearby the Nalla lai wastewater stream.</p>
Corresponding Author:	Shahid Ali Khan, MS in Environmental Science International Islamic University, Islamabad Islamabad, Federal Territory PAKISTAN
Other Authors:	Muhammad Tariq Rafiq, PhD Environmental Science
	Farzana Altaf Shah, MS in Environmental Science
	Ammar Yasir, MS in Hydrology
	Asif Iqbal, MS in Environmental Science

ABSTRACT

The scientific report assessed the impact of Nalla lai wastewater on the groundwater quality of Rawalpindi city, Pakistan. A total of nineteen wastewater and forty-nine groundwater samples were collected during September and October 2016 and been analyzed in the laboratory to detect different water quality parameters. The results revealed that BOD, COD, Iron and Cadmium values in many wastewater samples were beyond the recommended value of the National Environmental Quality Standards 1997 (NEQs, 1997). In groundwater samples, the results of iron, cadmium, manganese, zinc, TDS, pH, color and hardness were found elevated from the standard values in one or more samples as compared to the National Standard for Drinking Water Quality, 2010 (NSDWQ, 2010). The decreasing metal concentration order in groundwater samples was Iron > Zinc > Manganese > Copper > Cadmium. Very interestingly, hardness was found at elevated levels in 75% of investigated groundwater samples. Microbiological contamination was detected in 83% of the analyzed groundwater samples. The study revealed the percolation of heavy metals and microbial contamination in the bore water, tube wells, hand pumps, springs, and hand-dug wells located nearby the Nalla lai wastewater stream.

Keywords: Groundwater, Wastewater, Percolation, Nalla lai, E.coli, Rawalpindi

HIGHLIGHTS

- This scientific study evaluates the impact of Nalla lai wastewater stream on the groundwater quality of Rawalpindi city, Pakistan.
- BOD, COD, Iron and Cadmium concentration in many wastewater samples were beyond the recommended value of the National Environmental Quality Standards, 1997.
- Iron, Cadmium, Manganese, Zinc, TDS, pH, Color and Hardness concentration in groundwater samples were detected elevated in one or more samples as compared to the National Standards for Drinking Water Quality, 2010.
- The decreasing metal concentration order in groundwater samples was Iron > Zinc > Manganese > Copper > Cadmium.
- Hardness was elevated from the standard value in 75% of the investigated groundwater samples and microbial contamination was detected in 85% of the analyzed groundwater samples.

1. INTRODUCTION

Groundwater is the drinking water source of one-third of the global population. It is a valuable freshwater resource used for household, farming, and industrial purposes (Li et al. 2013; International Association of Hydrogeologists 2020). The freshwater of Earth is about 2.5 % and 30 % of this resource exists in groundwater (USGS 2016). The world is facing a crisis of water quality due to the contamination of freshwater resources from rapid urbanization and industrialization (Poonia et al. 2021). The organic pollutants such as oil and pesticides in groundwater are present mostly due to anthropogenic activities whereas geological sources are the cause of inorganic pollutants in groundwater (Memon et al. 2011). In groundwater heavy metals can be present from natural and anthropogenic sources (Reza & Singh 2019; Singh & Kamal 2017). Environmental contaminants including heavy metals, pesticides, trace organic contaminants, nanoparticles, hydrocarbons and microplastic are a menace to both human health and ecological services, and also to sustainable social and economic development (Li 2020; Li & Wu 2019). Groundwater contamination is a well-known topic in research studies which is a huge challenge to human populations (Lin 2010). Groundwater remediation is challenging as well as costly because it is found in surface geological strata (Wang et al. 2020; Su et al. 2020). Due to the presence of groundwater in subsurface geological strata, its remediation is challenging as well as expensive. The sources of groundwater pollution in metropolitan areas include point sources, non-point sources, and linear sources (Choi et al. 2005). The natural remediation process of groundwater can take ten years to hundreds of years, even if the contamination source is removed (Tatti et al. 2019). Heavy metals and metalloids are a danger to both human health and the natural environment. The metals present in groundwater include zinc, mercury, chromium, lead, cadmium and metalloids such as arsenic and selenium. Although a small concentration of these elements is a necessary micronutrient but exposure to these chemical substances can cause severe poisoning (Hashim et al. 2011). Groundwater used for irrigation if contaminated with heavy metals can results in health risks due to the accumulation of toxic elements in vegetables and cereals (Jenifer & Jha 2018; Yuan et al. 2019; Njuguna et al. 2019). Groundwater contamination is an environmental as well as a social issue. Therefore a mutual collaboration between the natural scientist and social scientist is mandatory (Ciner et al. 2021). The rapid economic development and population growth have built pressure on groundwater resources. There are 2.8

million wells only in China (Han 2003) and the heavy extractions of groundwater have dropped their level. Groundwater contamination is the most important concern because it is connected to the survival of humans. The identification, remediation, and assessment of groundwater contamination are the most significant topics these years (Mariani et al. 2004). Globally 3.4 million deaths occur due to waterborne diseases (Berman 2009). In developing countries, 2.2 million people lost their lives each year because of drinking contaminated water and inappropriate sanitation system (WHO & UNICEF, 2000; UNESCO 2003). Waterborne disease such as hepatitis, diarrhea, typhoid, dysentery and cholera occupies 20-40 % of the beds in the hospital and become a cause of one-third of all mortalities in Pakistan (Farooq et al. 2008). Drinking water contaminated with heavy metals can affect vital human organs like the liver, kidney, and central nervous system (Khan & Zahoor 2011). The research study is conducted along the Nalla Lai which is a perennial wastewater stream containing both domestic and industrial effluents. It is an open sewer of twin cities (Rawalpindi and Islamabad). The study has been conducted by keeping the given prime objective to evaluate the impact of the Nalla wastewater stream on groundwater quality in its proximity.

2. MATERIAL AND METHODS

2.1 Description of Study Area

Rawalpindi is the city of Punjab province and it is located near the capital city of Islamabad. The population of the city is 2.09 million with an area of 259 km² (Atta et al. 2020). The latitude of Rawalpindi city is 33.5984° N and the longitude of the city is 73.0441° E (Shahid et al. 2019). Due to rapid urbanization, the city is facing extreme environmental conditions (Mehmood et al. 2019). Five different seasons are experienced by Rawalpindi city such as winter, summer, spring, autumn, and monsoon. June is the hottest month and January is the coldest month in Rawalpindi city with the highest and lowest recorded temperatures of 48 °C and -3.9 °C (Asghar et al. 2012; Khan et al. 2019). Water pollution, inappropriate sanitation facilities and solid waste dumping are the most significant environmental problems in the city (Nisar et al. 2008). Energy-efficient buildings, urbanization impact on groundwater, and seismic mapping are the relevant issues in the city (Maqsoom et al. 2021).

2.2 Preliminary Visit and Sampling Plan

A previsit of the research area was carried out to delineate the sampling boundary of the research area and to select the sampling point's location by using the Global Positioning System (GPS) from IJP road to Soan River. A weekly sampling plan was prepared for the effective implementation of the sampling strategy. The sampling plan includes the preparation of a list of pre-selected sampling points location, requisition or hiring of transportation, selection of sampling day and time, cleaning of water sampling bottles, preparation of preservative, Icebox, personal protective equipment (PPE), first aid box, DO meter, pH meter, TDS meter, notebook, permanent marker, ballpoint pen, and checklist.

2.3 Sample Collection

To characterize the wastewater and groundwater quality of the research area the samples were collected by following the internationally recognized sampling procedure "Standard Methods for the Examination of Water and Wastewater" APHA (2012). Water sampling of the study area was divided into two types.

- I. Groundwater sampling
- II. Wastewater sampling

II. Groundwater Sampling

Groundwater samples were collected by using the grab sampling technique (Kamble 2015). Forty-nine groundwater water samples were collected in pre-sterilized polypropylene bottles. Before sterilization, the bottles were properly washed with water (hot) and detergents followed by thrice rinsing with distilled water. The samples were collected from both source and consumer levels in September 2016 at least one week after rainfall. Thirty-six groundwater samples were collected from the proximity of Nalla lai. Thirteen control samples were taken from at least a 1 km distance from both sites of Nalla lai.

The water samples of (17) tube wells, (29) boreholes, (1) dug well and (2) springs were collected from different inhabitant colonies of the study area. Used 1000 ml (1Litre) sampling bottle and collected a water sample from each sampling point for the detection of non-metals. Similarly, a 500 ml sampling bottle was used to collect a water sample from the same point to analyze heavy metals and added preservatives of Nitric acid (-HNO₃) to bring the water sample pH <2. The sampling bottles were properly tagged or labeled with sampling type, sample number, date, time/ hour, location, and source.

II. Wastewater Sampling

Wastewater samples of Nalla Lai were collected by using a composite sampling technique (Raashid & Hussain 2014). The wastewater sampling of Nalla Lai was collected in October 2016. Wastewater samples were collected in pre-sterilized polypropylene bottles properly washed with hot tap water followed by detergent, water reagent, and then thrice rinsed with distilled water. A total of nineteen wastewater samples of Nalla Lai were collected from various distances. Sample (1) and sample (2) were collected from wastewater streams passing through the I-9 and I-10 Industrial sectors of Islamabad whereas sample (3) was collected from a junction point of I-9 and I-10 industrial wastewater streams at the point of Kataria Bridge while remaining 15 samples were collected from various distances along with Nalla Lai till Soan River. Used 1000 ml (1 Litre) wastewater sampling container and collected samples from each sampling point to detect non-metals. Likewise, a 500 ml sampling container was used to collect wastewater from the same point to analyze heavy metals and added preservatives of Nitric acid (-HNO_3) to bring the pH of the wastewater sample i.e. less than 2 pH. The sampling bottles were properly labeled with sampling type, sample number, date, time/ hour, location, and source.

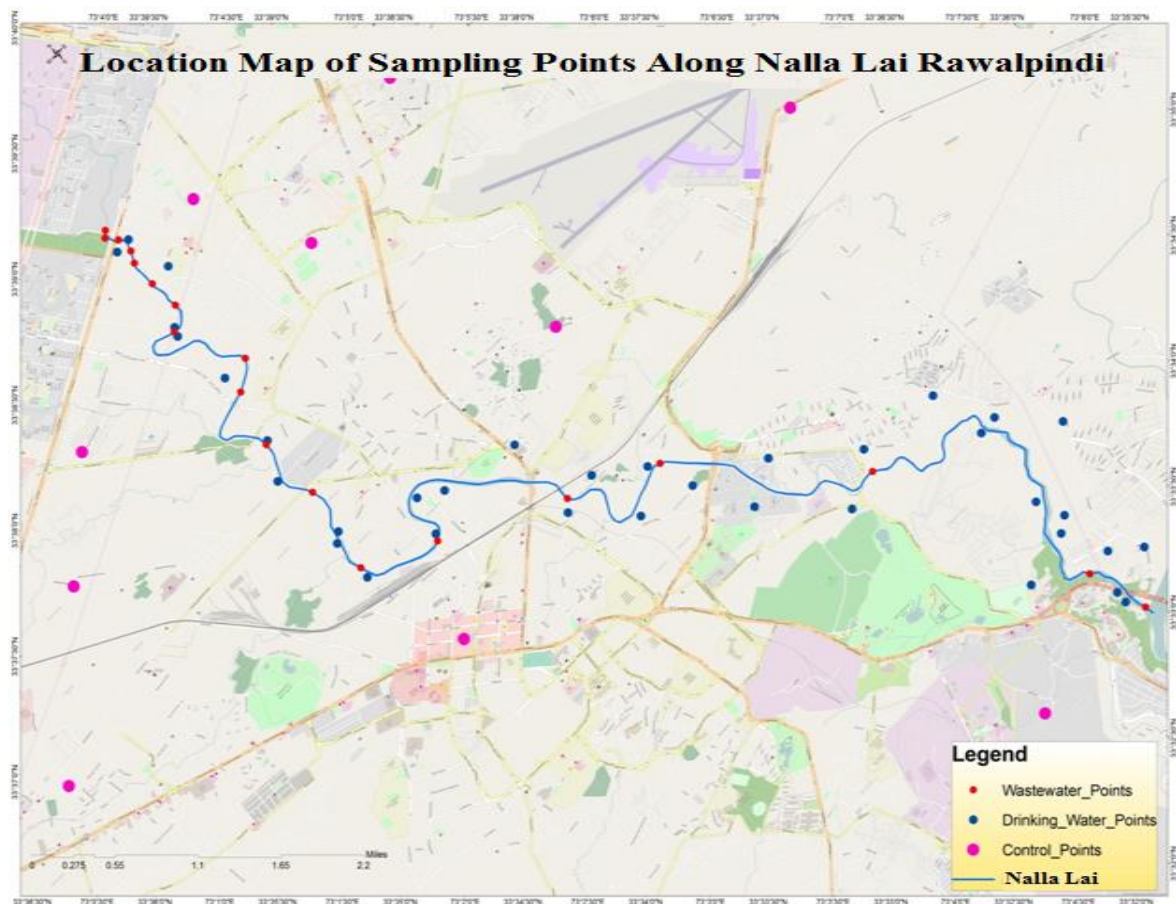


Figure 1 | GIS Map of Sampling Points Location along with Nalla Lai (Study Area)

2.4 Analytical Procedure

I) In situ Analysis

In situ water testing of parameters like pH (pH scale), Temperature ($^{\circ}\text{C}$), DO (mg L^{-1}), EC ($\mu\text{S/cm}$), and TDS (mg L^{-1}) were determined by pH Meter, Thermometer, DO Meter, and TDS Meter respectively and followed the "Standard Methods for the Examination of Water and Wastewater" (APHA 2012).

II) Detection of E.coli in Groundwater

Microbial samples of groundwater were collected by using the grab sampling technique (Tahir et al. 2011). A total of thirty-six samples were collected in October 2016 from the study area for bacteriological tests. Twenty-nine samples were collected from the proximity of Nalla Lai and seven control samples were taken from at least

a 1 km distance along with both sites of Nalla. Before collecting the water sample, the tap stand was first ignited with a lighter to remove contamination. Then opened the tap stand and left for 5-10 minutes until the temperature of the water stabilized and flushed out the stagnant water of the pipe. E. coli was analyzed in groundwater samples through water check kits. Took 50 ml water sample in a sterile container and put blister pack with care and shook well to dissolve the granules and did not touch the inner part of the container. Left enough air space in the sampling container and screwed the cap firmly. Placed the container at room temperature for 48 hours. The color changed to Blue and Green showed bacterial contamination and the samples having yellow, off-white, and brownish or no change in color represented that water was fit for drinking purposes.

III) Physico-chemical Analysis

The analysis of physicochemical parameters was performed by shifting the water samples to CLEAN laboratory Pak-EPA and left in a refrigerator at 4 °C to preserve the integrity of the samples. The analysis of chemical parameters of both groundwater and wastewater samples was performed by following the standard method mentioned by APHA (2012). Chloride was determined by potentiometric titration method and by following the “Standard Methods for the Examination of Water and Wastewater” (SMEWW) 22nd edition, part 4500 Cl⁻. Hardness was analyzed by titration method and by following SMEWW 22nd edition, part 2340. Sulfate was analyzed by using a UV/Visible Spectrometer and by following SMEWW 22nd edition, part 4500-SO₄. Chemical Oxygen Demand was determined by applying the SMEWW 22nd edition, part 5220. Biological Oxygen Demand was determined by applying the reference method SMEWW 22 edition, part 5210”. Turbidity and Color were analyzed by using the Water Analyzer and by following the reference method SMEWW 22nd edition, part 2130. Heavy metals were determined by using the instrument Atomic Absorption Spectrometer (AAS) Model: A ANALYST 800. The analytical procedure of heavy metals includes preliminary treatment of wastewater samples which can be done in two steps i.e. filtration of wastewater sample and digestion of wastewater sample.

Table 1 | Parameters with respective abbreviations Units, Holding time, Preservatives, and Analytical Methods

Parameters	Abbreviations	Units	Holding Time	Preservatives	Analytical Methods/ Instruments
Potential Hydrogen	pH	pH Unit	In Situ	None	pH Meter
Temperature	Temp	°C	In situ	None	Thermometer
Turbidity	TU	NTU	4 hours	None	Water Analyzer
Color	Col	TCU	4 hours	None	Water Analyzer
Dissolved Oxygen	DO	mg L ⁻¹	In situ	None	DO Meter
Electric Conductivity	EC	µ S/cm	In Situ	None	TDS Meter
Total Dissolved Solids	TDS	mg L ⁻¹	In situ	None	TDS Meter
Sulfate	0	mg L ⁻¹	4 days	4 °C	UV/Visible Spectrometer
Chloride	Cl ⁻	mg L ⁻¹	4days	4 °C	APHA 2012, 22 nd edition, part 4500 Cl ⁻
Hardness	Ha	mg L ⁻¹	5days	4 °C	APHA 2012, 22 nd edition, part 2340
Cadmium	Cd	mg L ⁻¹	30 days	HNO ₃ , pH<2	(AAS) Model: A ANALYST 800
Copper	Cu	mg L ⁻¹	31 days	HNO ₃ , pH<2	(AAS) Model: A ANALYST 800
Iron	Fe	mg L ⁻¹	32 days	HNO ₃ , pH<2	(AAS) Model: A ANALYST 800
Manganese	Mn	mg L ⁻¹	33 days	HNO ₃ , pH<2	(AAS) Model: A ANALYST 800
Lead	Pb	mg L ⁻¹	34 days	HNO ₃ , pH<2	(AAS) Model: A ANALYST 800
Zinc	Zn	mg L ⁻¹	35 days	HNO ₃ , pH<2	(AAS) Model: A ANALYST 800

IV) Data Analysis

The statistical analysis and interpolation maps of wastewater and groundwater high vulnerable localities were performed by using Microsoft Excel Environment, XLSTAT, and GIS tools.

3. RESULTS AND DISCUSSION

The results of many analyzed samples of wastewater of Nalla lai were beyond the standard value of NEQs, 1997. Iron was detected elevated from the recommended value in 3 wastewater samples, cadmium value was higher in 5 wastewater samples. BOD results of all wastewater samples and COD values of 13 samples were elevated from the standard values of NEQs, 1997. Maximum contamination was observed in the groundwater samples which were collected from the proximity of Nalla lai. Out of the total of forty-nine groundwater samples, thirty-six

groundwater samples were collected from the proximity of Nalla lai. The analyzed results showed that iron concentration was elevated from the recommended limit value in 10 groundwater samples, cadmium was higher in 5 groundwater samples, manganese was detected in elevation concentration in 4 groundwater samples, zinc and TDS were beyond the standard limit 1 in groundwater sample, pH value was very low in 3 groundwater samples, the color value was high in 1 groundwater samples, hardness concentration was beyond the recommended value in 30 groundwater samples and microbial contamination of fecal coliform was detected in 30 groundwater samples.

Table 2 | Physico-chemical results of wastewater parameters of Nalla Lai. (n=19)

S. No	pH	Temp	Turbidity	DO	EC	SO ₄	Cl-	Cd	Cu	Fe	Mn	Pb	Zn	BOD	COD
1	7.44	22	4610.20	0.94	1271	21.9	60	0.3	0.204	4.479	1.483	0.012	1.046	168	296
2	7.66	26	2725	2.05	1277	22.76	55.6	0.22	BDL	1.212	0.15	0.182	2.046	130	168
3	7.43	27	3113	1.03	1365	21.70	55.6	0.016	BDL	3.134	0.176	BDL	0.066	112	243
4	7.71	28	3689	0.33	1396	24.2	54.18	BDL	0.161	0.392	0.161	BDL	0.076	121	276
5	7.48	26	1940.24	0.74	1529	23.3	46.62	BDL	0.012	BDL	0.189	0.021	2.214	97	229
6	7.67	27	3635.84	0.20	1492	22.22	57.28	BDL	0.016	BDL	0.161	BDL	0.048	194	315
7	8.55	26	3645.65	1.24	1510	23.12	55.06	BDL	BDL	0.149	0.49	BDL	0.061	161	311
8	7.78	28	3459.74	1.25	1232	23.6	57.4	0.12	BDL	BDL	0.251	BDL	0.071	168	312
9	7.75	29	2313.49	0.26	1342	23.05	49.4	BDL	BDL	0.186	0.215	BDL	0.063	121	291
10	7.91	29	2111.69	1.04	1349	25.9	46.62	0.159	0.013	0.125	0.315	BDL	0.057	100	175
11	8.21	28	2543	1.65	1367	27.6	47.06	0.095	BDL	0.121	0.188	BDL	0.213	96	222
12	7.79	29	3130	0.63	1272	22.9	46.62	0.007	BDL	0.315	0.212	0.268	4.201	100	219
13	7.69	29	3343.74	0.35	1395	25.02	61.4	0.02	BDL	BDL	0.312	BDL	0.059	96	228
14	7.78	28	2981.84	0.81	1390	24.3	7.6	0.006	0.091	BDL	0.612	BDL	0.129	95	196
15	8.12	29	3399	1.14	1397	26.3	61.72	0.015	BDL	0.357	0.215	0.008	0.059	100	168
16	7.69	28	4215.73	0.69	1327	24.52	66.16	BDL	0.013	2.173	0.61	BDL	0.12	91	221
17	7.62	27	3386	0.26	1430	24.23	75.06	0.143	BDL	1.635	0.219	BDL	0.204	149	272
18	7.92	28	4155	2.80	1372	25.34	79.6	0.012	BDL	0.822	0.237	BDL	2.213	98	176
19	7.95	30	3490	2.67	1474	30.10	72.4	0.015	BDL	0.118	0.521	BDL	0.064	87	170

Table 3 | Descriptive statistics of wastewater samples of the study area: n=19

Variables	Unit	Maximum	Minimum	Average
pH	pH Unit	8.55	7.43	7.8
Temp	°C	30	22	27.58
Turbidity	NTU	4610.20	1940.24	3257.27
DO	mg L ⁻¹	2.80	0.20	1.06
EC	µ S/cm	1529	1232	1378.26
SO ₄	mg L ⁻¹	30.10	21.70	24.32
Cl-	mg L ⁻¹	79.6	7.6	55.55
Cd	mg L ⁻¹	0.3	0.006	0.09
Cu	mg L ⁻¹	0.204	0.012	0.08
Fe	mg L ⁻¹	4.48	0.12	1.09
Mn	mg L ⁻¹	1.48	0.15	0.35
Pb	mg L ⁻¹	0.268	0.008	0.10
Zn	mg L ⁻¹	4.20	0.05	0.68
BOD	mg L ⁻¹	194	87	120.21
COD	mg L ⁻¹	315	168	240.15

Table 4 | Physicochemical and Microbial Results of Groundwater of Study Area. (n=49)

S.No	pH	Tem	TU	Color	DO	EC	TDS	SO ₄	Cl	Ha	Cd	Cu	Fe	Mn	Pb	Zn	E.coli
1	7.25	22	0	4.4	5.7	356	291	24.14	12.7	616	BDL	0.11	0.26	0.038	0.003	0.52	-ve
2	6.39	24	0	10.04	3.28	1121	958	36.7	13.3	1065	0.028	0.139	4.757	0.685	0.002	2.26	-ve
3	7.34	24	0	3.66	5.83	323	267	18.34	11.32	616	BDL	BDL	BDL	0.036	BDL	BDL	-ve
4	7.45	24	0	4.79	5.64	302	254	26.11	9.1	552	BDL	BDL	0.219	BDL	BDL	BDL	-ve
5	7.35	25	0	4.62	4.58	619	498	45	23.5	536	BDL	BDL	0.101	BDL	BDL	BDL	-ve
6	7.41	23	0	5.06	6.48	772	584	41.33	49.7	1121	BDL	BDL	BDL	BDL	BDL	0.18	-ve
7	7.59	21	0	4.39	8.4	405	319	37.18	21.1	596	BDL	BDL	BDL	BDL	0.004	0.131	-ve
8	7.23	22	0	4.72	5.8	407	322	46.24	19	656	BDL	BDL	BDL	BDL	BDL	BDL	-ve
9	7.65	21	0	4.11	5.87	433	293	21.4	13.1	372	BDL	BDL	BDL	BDL	BDL	0.096	-ve
10	7.29	25	0	5.7	6.2	540	449	29.1	14	568	0.005	BDL	0.529	BDL	BDL	2.476	-ve
11	7.47	21	0	7.73	5.36	289	229	18.9	8.21	332	BDL	BDL	0.345	BDL	BDL	BDL	-ve
12	8.19	24	0	5.86	6.68	1380	996	100.2	64.4	1528	0.009	BDL	1.512	BDL	BDL	0.089	+ve
13	7.22	22	0	10.24	6.19	1408	1138	59.64	107	1122	0.005	0.038	BDL	BDL	0.038	BDL	-ve
14	8.3	22	0	5.91	5.9	637	595	22.6	17.1	1076	BDL	BDL	BDL	0.344	BDL	0.093	-ve
15	6.41	27	0	4.84	3.85	1019	844	28	22.7	896	BDL	BDL	BDL	BDL	BDL	BDL	-ve
16	7.3	21	0	5.17	5.46	446	358	34	19.32	564	0.021	BDL	BDL	BDL	BDL	0.014	-ve
17	7.65	23	0	5.78	4.39	722	419	20.1	12.21	124	0.007	BDL	0.786	BDL	BDL	0.23	+ve
18	7.7	22	0	4.74	6.93	442	360	14.7	25.1	556	0.009	BDL	0.134	BDL	BDL	0.404	-ve
19	7.35	22	0	4.63	5.61	731	551	16.8	17.32	976	BDL	BDL	0.396	BDL	BDL	0.071	-ve
20	6.86	26	0	6.22	3.73	549	451	22.2	29.1	604	BDL	BDL	BDL	BDL	BDL	0.092	-ve
21	7.25	21	0	4.96	5.46	905	691	44.34	28.2	1144	BDL	BDL	BDL	0.162	BDL	2.413	-ve
22	6.59	25	0	5	4.45	783	609	15.7	10.9	776	0.005	BDL	2.914	0.412	BDL	0.121	-ve
23	7.35	22	0	5.39	6.33	549	439	24.45	20.43	656	0.018	BDL	BDL	0.189	0.04	0.09	-ve
24	7.41	23	0	4.5	5.25	794	581	30.41	37.53	1064	BDL	BDL	BDL	0.218	BDL	BDL	-ve
25	7.07	24	0	4.94	5.88	566	464	29.91	28	776	BDL	BDL	BDL	BDL	BDL	0.386	-ve
26	7.28	25	0	5.13	6.41	1173	885	37.84	74.61	1564	BDL	BDL	BDL	BDL	BDL	0.095	-ve
27	7.40	22	0	4.99	6.15	375	301	20.42	10.7	520	BDL	BDL	BDL	0.091	BDL	BDL	-ve
28	7.32	22	0	17.89	4.4	894	719	21.54	77.72	928	0.012	BDL	1.965	0.853	BDL	0.015	-ve
29	7.25	22	0	6.11	5.89	907	485	31.4	36.64	680	0.009	BDL	BDL	0.321	BDL	5.108	-ve
30	7.68	24	0	5.75	5.35	222	201	14.5	7.6	384	BDL	BDL	BDL	0.085	BDL	3.95	-ve
31	7.61	25	0	5.77	6.71	306	346	19.63	13.8	372	BDL	BDL	BDL	0.418	BDL	BDL	-ve
32	7.16	28	0	5.18	4.36	762	611	28.65	59.73	1132	BDL	BDL	1.249	0.195	BDL	BDL	-ve
33	7.48	23	0	6.16	5.63	593	482	17.9	34.64	724	0.019	BDL	BDL	0.131	BDL	1.821	-ve
34	7.53	22	0	6.4	5.16	494	325	33.17	12	720	BDL	BDL	BDL	0.629	BDL	2.981	+ve
35	6.45	26	0	7.45	4.09	868	691	38.31	34.2	1044	0.009	BDL	2.933	0.512	BDL	1.251	-ve
36	7.53	25	0	5.39	6.56	472	383	25.6	17.54	480	BDL	BDL	BDL	0.091	BDL	BDL	-ve
37	7.54	24	0	5.63	6.34	332	272	23.9	12.21	452	BDL	BDL	BDL	0.089	BDL	0.018	+ve
38	7.48	23	0	5.36	5.23	445	366	20.4	18.7	464	BDL	BDL	BDL	0.091	BDL	BDL	-ve
39	7.76	22	0	4.74	6.43	376	391	17.44	13.1	564	BDL	BDL	BDL	0.082	BDL	1.036	-ve
40	7.47	25	0	5.94	5.31	387	301	18.09	10	480	0.016	BDL	BDL	0.149	BDL	0.785	+ve
41	7.64	21	0	6.56	6.08	473	288	14.21	8.43	524	0.021	BDL	BDL	0.164	BDL	0.25	-ve
42	7.52	23	0	4.9	5.75	468	392	21.36	28	412	0.023	BDL	BDL	0.301	BDL	0.018	-ve
43	7.29	24	0	5.26	5.15	327	375	15.07	10.7	628	0.036	BDL	BDL	0.12	0.025	1.337	-ve
44	7.44	22	0	4.9	6.78	462	378	20.37	19.32	408	0.008	BDL	BDL	0.104	BDL	0.041	-ve
45	7.26	22	0	8.17	4.53	701	597	25.52	50	448	0.009	BDL	0.316	0.569	BDL	3.242	-ve
46	7.49	24	0	5.31	5.49	524	435	32.19	24.2	576	0.007	BDL	BDL	0.098	BDL	0.051	-ve
47	7.19	23	0	4.43	5.17	705	503	37.17	36.2	844	0.021	BDL	BDL	0.161	BDL	0.01	+ve
48	7.12	23	0	5.21	5.75	653	535	27.86	43.74	788	BDL	BDL	BDL	0.17	BDL	6.195	-ve
49	7.13	24	0	5.81	5.56	807	506	17.7	68.17	732	BDL	BDL	BDL	0.269	BDL	0.2	-ve

Table 5 | Descriptive Statistics of Groundwater Samples of Study Area: n=49

Variables	Unit	Maximum	Minimum	Average
pH	pH Unit	8.3	6.39	7.35
Temp	°C	28	21	23.27
TU	NTU	0	0	0
Color	TCU	17.89	3.66	5.83
DO	mg L ⁻¹	8.4	3.28	5.58
EC	μ S/cm	1408	222	616.83
TDS	mg L ⁻¹	1138	201	484.24
SO ₄	mg L ⁻¹	100.2	14.1	28.2
Cl ⁻	mg L ⁻¹	107	7.6	27.7
Ha	mg L ⁻¹	1564	124	709
Cd	mg L ⁻¹	0.036	0.005	0.01
Cu	mg L ⁻¹	0.139	0.038	0.09
Fe	mg L ⁻¹	4.76	0.101	1.23
Mn	mg L ⁻¹	0.85	0.04	0.25
Pb	mg L ⁻¹	0.04	0.002	0.02
Zn	mg L ⁻¹	6.2	0.01	1.06

3.1 pH

The average pH value in groundwater and wastewater samples was 7.35 and 7.8. The range values of pH in groundwater samples was 6.39 - 8.3 whereas the pH values in wastewater samples were in the range of 7.43 - 8.55 respectively. The pH value in all the samples of groundwater was within the recommended limit set by NSDWQ, 2010, and WHO except for the three bore water samples where the pH value was detected below 6.5 in the analyzed results. The pH value in all wastewater samples was below the recommended limit of NEQs, 1997. The analyzed results were comparatively similar to the work conducted by Nasrullah et al. (2006) when evaluating the impact of industrial wastewater on the groundwater chemistry of Swabi, Pakistan. As stated by Dohare et al. (2014) that both acidity and basicity are specified by the pH values.

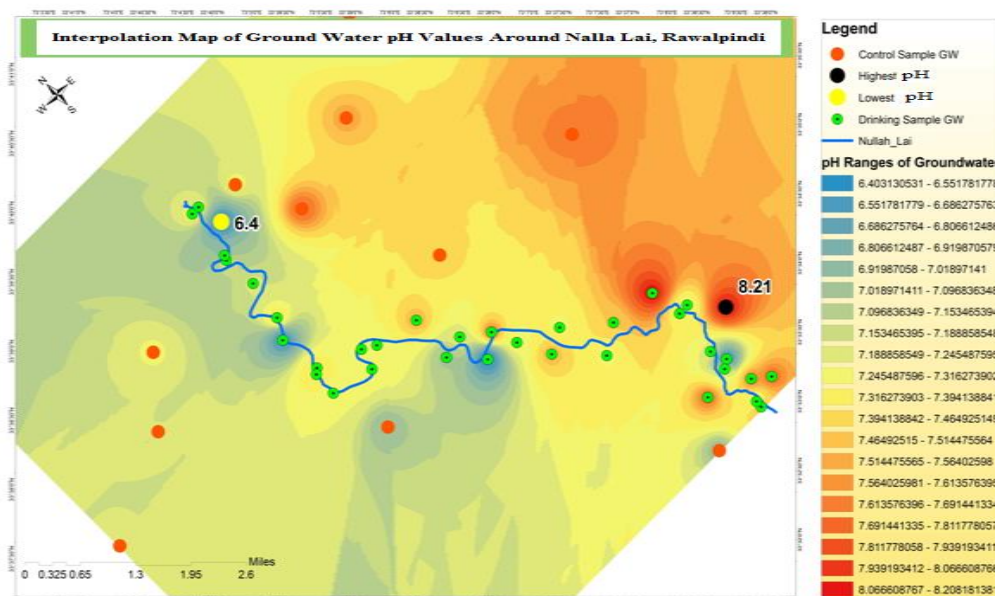


Figure 2 | Interpolation Map Showing Highest and Lowest pH Location Points of Groundwater

3.2 Temperature

The average temperature value in groundwater and wastewater samples was 23.27 °C and 27.58 °C. The range value of temperature in groundwater samples was 21 °C - 28 °C whereas temperature values in wastewater samples were in a range of 22 °C - 30 °C respectively. The analyzed results of temperature in all wastewater samples were detected below the standard limit value of NEQs, 1997. The wastewater temperature of Nalla lai almost resembled the ambient air temperature. According to the scientific study conducted by Nicholson et al. (2016) air temperature has a significant effect on the surface water of low velocity but a minor effect on groundwater. As reported by Ahmed et al. (2013) temperature plays a key role to detect microbial contamination and it has a significant role in the survival of aquatic life (Akbari et al. 2017). The increased temperature in the summer season gives a favorable environment for fecal coliform (E.coli) to grow in the wastewater stream which finally contaminates the groundwater quality by the action of percolation.

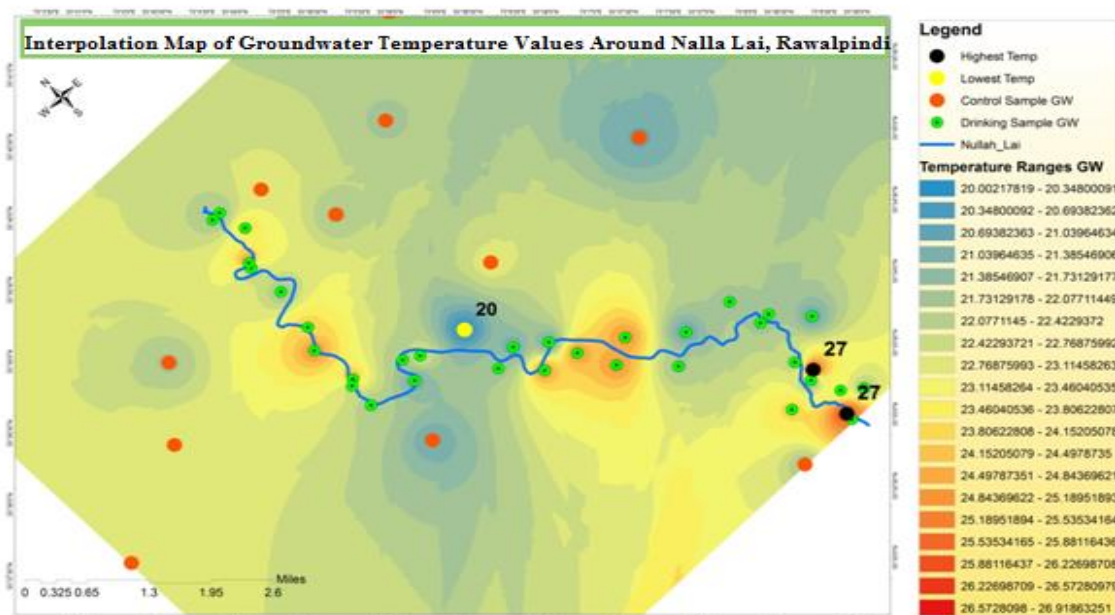


Figure 3 | Interpolation Map Showing Highest and Lowest Temperature Location Points of Groundwater

3.3 Turbidity

Turbidity was detected at zero in all groundwater samples. In wastewater samples, the average turbidity value was 3257.27 NTU. The turbidity values in wastewater samples of Nalla lai were in the range of 1940.24 NTU - 4610.20 NTU. The analyzed wastewater samples of Nalla lai showed that turbidity value was very high in sample number 1 which was collected from the wastewater stream carrying industrial wastewater of sector I-9, Islamabad and finally merged with the main wastewater stream of Nalla. The analyzed results resembled the work done by Tariq et al. (2006) on groundwater contamination due to the discharge of wastewater from the industrial locality in Hayatabad, Peshawar. Because of the high load of organic matter and various kinds of effluents, very high turbidity was observed in the wastewater of Nalla lai. The elevated level of turbidity ultimately decreases the dissolved oxygen level in the water stream. Aquatic life cannot survive in such a kind of environment. Turbidity in water is the cloudiness that happens due to pollutants such as silt, wood ash, coal, chemicals, colloidal dispersions, and microorganisms (Akhtar et al. 2014; Srivastava & Pandey 2012).

3.4 Color

The average color value in groundwater samples was 5.83 TCU. Color values in groundwater samples were in a range of 3.66 TCU - 17.89 TCU. Color values of all groundwater samples were below the recommended limit of 15 TCU except sample number 28 which was dug well water. Sample 28 was located less than a hundred meters distance from the proximity of the wastewater stream (Nalla Lai). The elevated color value in this sample shows different dissolved chemicals and it also represents the percolation of wastewater pollutants from Nalla Lai into dug well water. Water quality in this location is not safe for drinking purposes because it also contains trace metals in high concentrations along with an elevated level of hardness and bacterial contamination. Drinking

water in this locality can cause adverse health impacts. According to Tiwari (2015) color of the water is very important for domestic and industrial uses and they generally prefer colorless water.

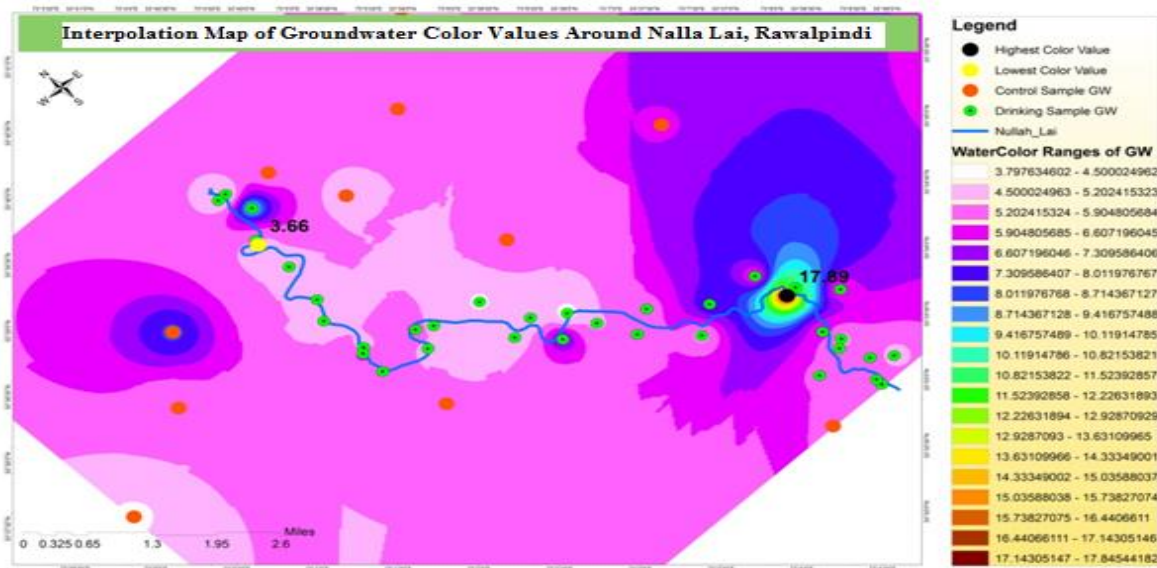


Figure 4 | Interpolation Map Showing Highest and Lowest Color Location Points of Groundwater

3.5 DO

The groundwater and wastewater samples have average DO values of 5.58 mg L^{-1} and 1.06 mg L^{-1} . The range value of DO in groundwater samples was 3.28 mg L^{-1} - 8.4 mg L^{-1} whereas DO values in wastewater samples were in a range of 0.20 mg L^{-1} - 2.80 mg L^{-1} respectively. Dissolved oxygen is an important marker to judge the quality of water (Subramani & Damodarasamy 2005). It represents the physical and biological processes occurring in the aquatic environment. DO concentration is the indicator of pollution level in the water. It is the dissolved concentration of gaseous oxygen in water (Prajapati & Dwivedi 2016). Due to elevated level of pollutants in the wastewater of Nalla lai the dissolved concentration of oxygen was low in the analyzed results.

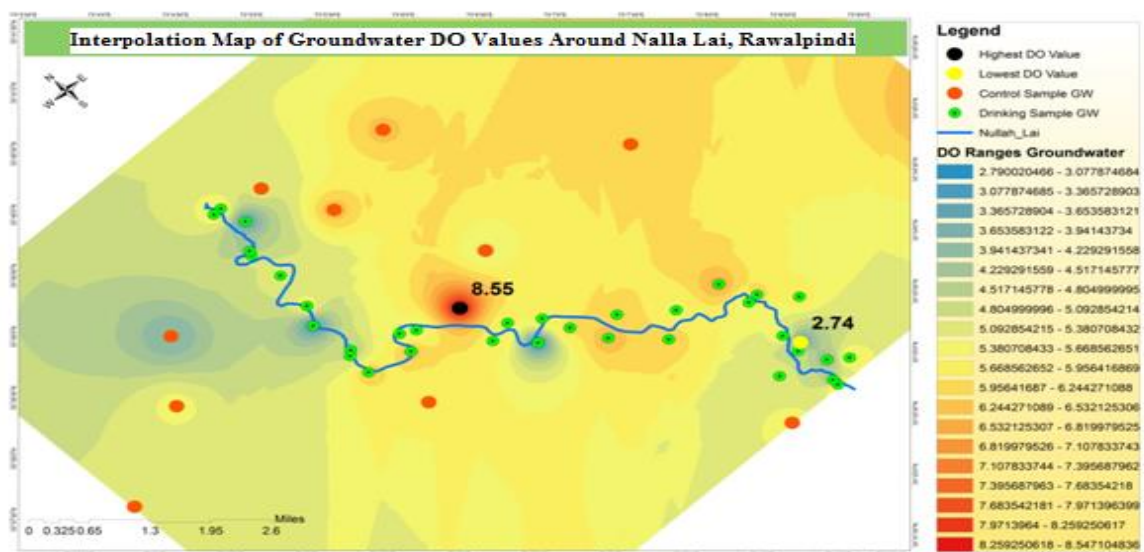


Figure 5 | Interpolation Map Showing Highest and Lowest DO Location Points of Groundwater

3.6 EC

The average EC value in groundwater and wastewater samples was 616.83 μ S/cm and 1378.26 μ S/cm. The range value of EC in groundwater samples was 222 μ S/cm - 1408 μ S/cm whereas EC level in wastewater samples was in the range of 1232 μ S/cm - 1529 μ S/cm respectively. The average values of EC in groundwater and wastewater samples were comparatively higher than the research results of Tariq et al. (2006) on groundwater contamination in Hayatabad Industrial Estate, Peshawar. The elevated concentration of EC in the analyzed samples revealed the higher concentration of dissolved ions in the wastewater stream of Nalla lai. The capacity of water to pass an electric current is measured by the EC value because it depends on the presence of free ions in water (Nasrullah et al. 2006).

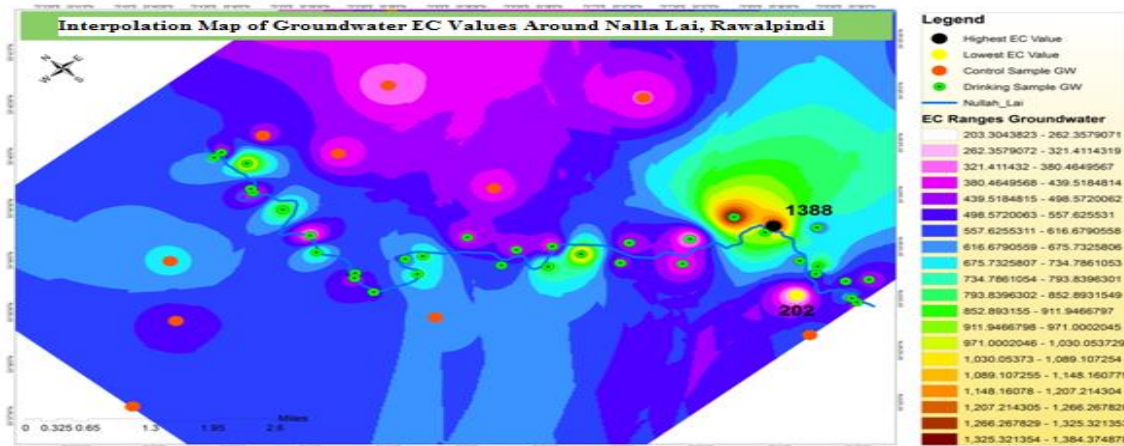


Figure 6 | Interpolation Map Showing Highest and Lowest EC Location Points of Groundwater

3.7 TDS

In groundwater samples, the average value of TDS was 484.24 mg L⁻¹. The range value of TDS in groundwater samples was between 201 mg L⁻¹ - 1138 mg L⁻¹ respectively. TDS concentration in one bore water sample was elevated from the recommended standard value which was collected from the proximity of Nalla lai. A high level of TDS may be due to the percolation of the pollutants from the wastewater of Nalla lai. As mentioned by Choi et al. (2005) the average values of TDS in groundwater are increasing due to differences in land use and the average values are escalating from forest vicinity (151 mg/l), agricultural territory (446 mg/l), residential region (374 mg/l), traffic site (446 mg/l) and industrial sector (585 mg/l). The average values reflect anthropogenic pollution. The concentration of TDS elevated from 1000 mg L⁻¹ is not fit for drinking purposes (Akhtar et al. 2014). The TDS value indicates both salinity and quality of water and a high concentration of TDS alters the taste and hardness of water (Pande et al. 2015; Akhtar et al. 2014).

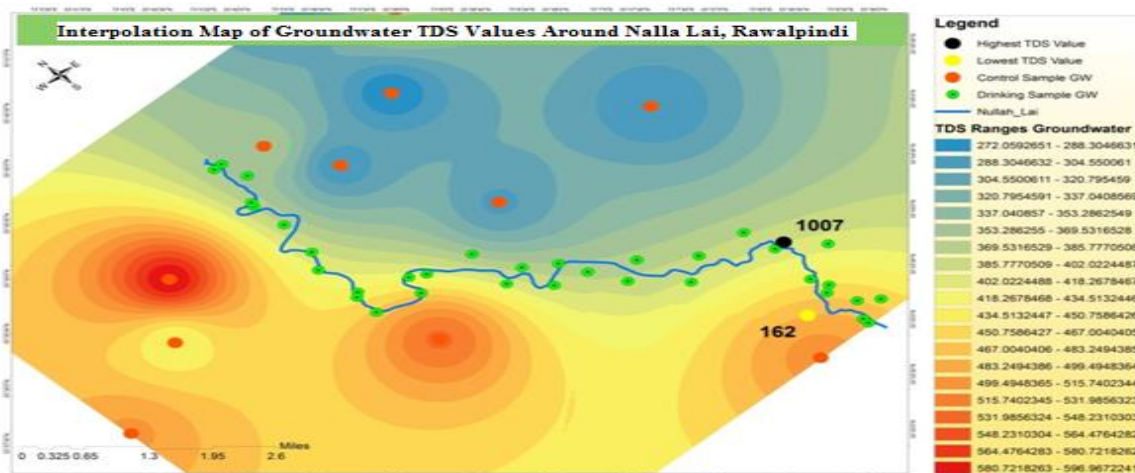


Figure 7 | Interpolation Map Showing Highest and Lowest TDS Location Points of Groundwater

3.8 Sulfate

The groundwater and wastewater samples have average Sulfate values of 28.2 mg L^{-1} - 24.32 mg L^{-1} . The range value of Sulfate in groundwater samples was 14.1 mg L^{-1} - 100.2 mg L^{-1} whereas the value of Sulfate in wastewater samples was in a range of 21.70 mg L^{-1} - 30.10 mg L^{-1} respectively. The analyzed results of Sulfate in all groundwater and wastewater samples were detected below the recommended standard of NSDWQ, 2010, NEQs 1997. The results of wastewater are in contrast with the study conducted by Raashid & Hussain (2014) on industrial effluents of two pulp and paper industries in Punjab. The results showed that the values of sulfate were beyond the recommended value of NEQs, 1997. Due to the absence of any anthropogenic source in the vicinity of Nalla lai the concentration of Sulfate was detected with the permissible limit in both surface water and groundwater in the proximity of Nalla lai. Sulfate is founded in any water supply but its elevated level can be detected in water due to the influence of anthropogenic discharges (Miao et al. 2012; Srivastava & Pandey, 2012).

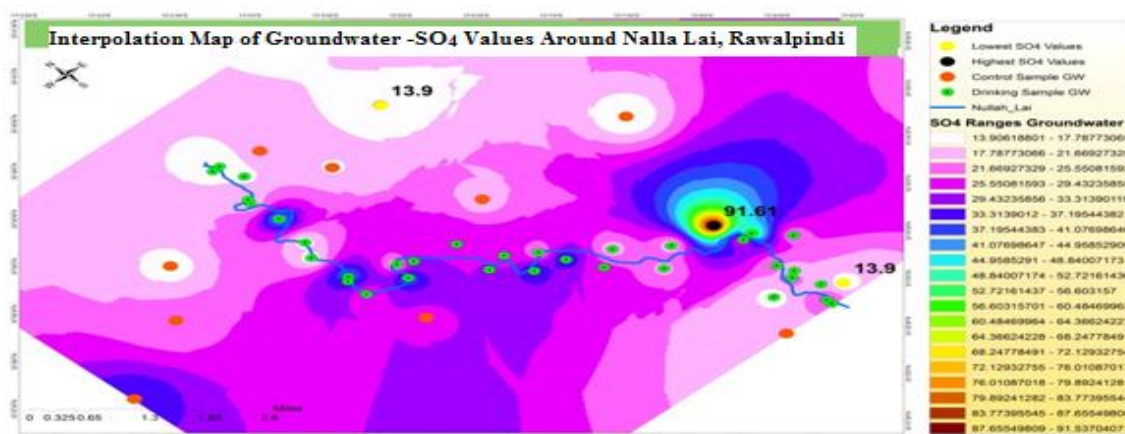


Figure 8 | Interpolation Map Showing Highest and Lowest ($-\text{SO}_4$) Location Points of Groundwater

3.9 Chloride

The average Chloride value in groundwater and wastewater samples was 27.68 mg L^{-1} and 55.55 mg L^{-1} . The range value of Chloride in groundwater samples was 7.6 mg L^{-1} - 107 mg L^{-1} whereas Chloride values in wastewater samples were in a range of 7.6 mg L^{-1} - 79.6 mg L^{-1} respectively. Chloride values in groundwater and wastewater samples were within the permissible limit NSDWQ, 2010, and NEQs 1997. Chloride occurs in natural water but both agricultural and industrial activities are responsible for its elevated concentration in any water body (Dohare et al. 2014). Its high concentration indicates heavy pollution due to inorganic fertilizers, landfill leachate, and septic tank effluents (Sarada & Bhushavanthi 2015; Subramani & Damodarasamy 2005). Due to the absence of a potential source of Chloride in the study area low concentration of Sulfate was detected in both surface wastewater and groundwater samples.

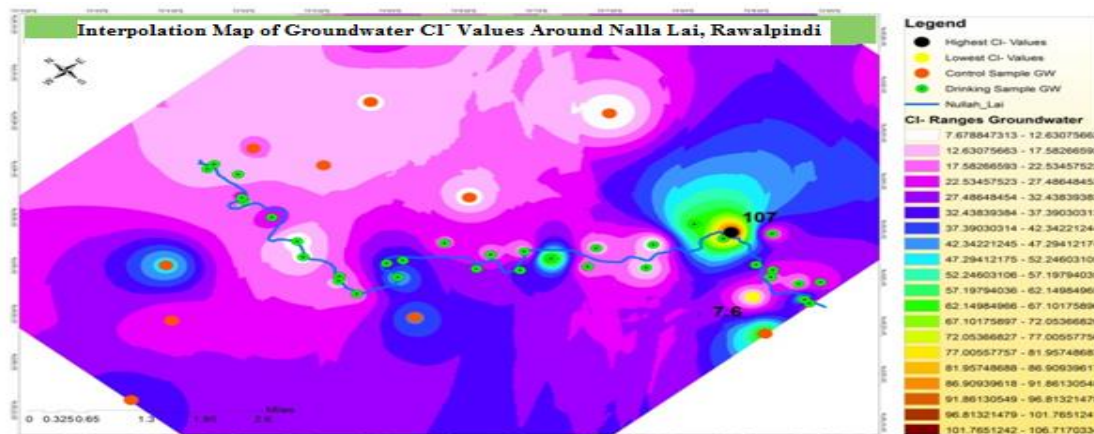


Figure 9 | Interpolation Map Showing Highest and Lowest Cl^- Location Points of Groundwater

3.10 Hardness

The average hardness value in groundwater samples was 709 mg L⁻¹. Its value in groundwater samples was in the range of 124 mg L⁻¹ - 1564 mg L⁻¹. The hardness was found at elevated levels in 75% of investigated groundwater samples including (17) bore water samples, (11) tube wells, (1) spring, and (1) dug well water. As reported by Rao (2011) and Ramya et al. (2015) water hardness primarily depends on the concentration of calcium and magnesium ions in water. The prime reason for the excess concentration of hardness in groundwater samples was the presence of high mineral contents i.e. calcium and magnesium cations. According to the National Research Council of the US (1974) Iron, zinc, strontium, magnesium, and aluminum can also contribute to water hardness, but these metals are found in very minute concentrations. Ramya et al. (2015) mentioned that water with high mineral contents is called hard water. Carbonate hardness can remove by boiling whereas non-carbonate hardness cannot be removed by boiling.

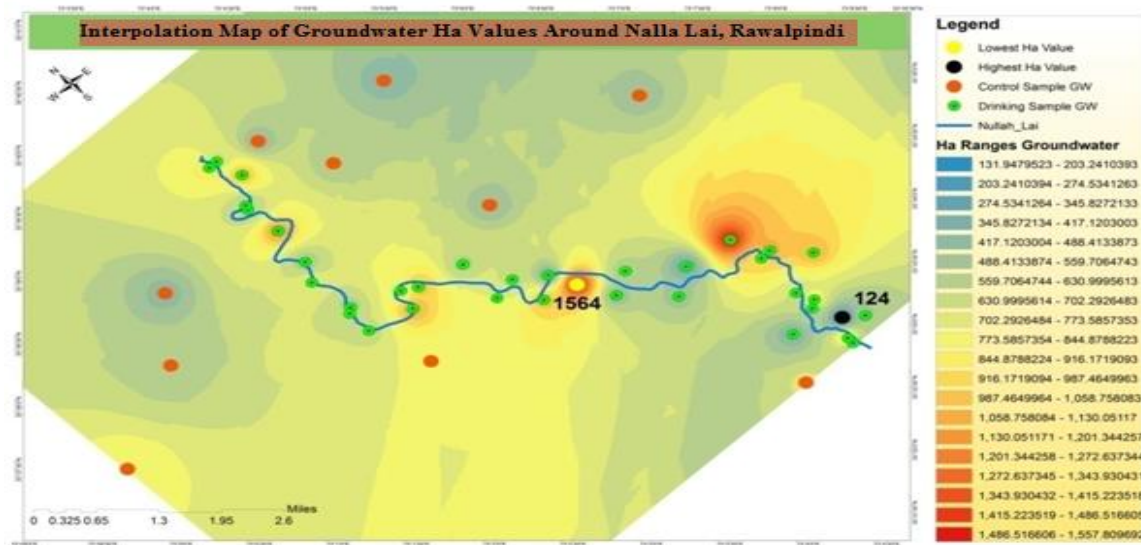


Figure 10 | Interpolation Map Showing Highest and Lowest Ha Location Points of Groundwater

3.11 Cadmium

The average Cadmium value in groundwater and wastewater samples was 0.01 mg L⁻¹ and 0.09 mg L⁻¹. The range value of Cadmium in groundwater samples was 0.005 mg L⁻¹ – 0.036 mg L⁻¹ whereas the Cadmium value in wastewater samples was in a range of 0.006 mg L⁻¹ - 0.3 mg L⁻¹ respectively. The cadmium value in 5 groundwater samples was higher than the standard value of NSDWQ, 2010 and WHO the samples were collected from the proximity of Nalla lai. The cadmium value in 5 wastewater samples was elevated than the standard of NEQS, 1997. Both surface and groundwater values of Cadmium revealed that Cadmium is also percolating from the surface wastewater of Nalla Lai to groundwater in its proximity. The research conducted by Nasrullah et al. (2006) on industrial effluents and groundwater quality revealed that Cadmium concentration was detected above the permissible limit in one tube well water sample. Nasrullah et al. (2006) reported that the Cd high concentration in drinking water (groundwater) was analyzed due to the percolation of waste effluents in the marble, steel, and aluminum industries. The major source of Cadmium in wastewater of the Nalla lai is due to the discharge of waste effluents from Iron industries, steel, and paint industries in the I-9 and I-10 Industrial areas of Islamabad. Cadmium seeks attention due to its toxic nature (Azizullah et al. 2011). Cadmium can be toxic if the concentration exceeds 0.01 mg L⁻¹ in both drinking and irrigation water (Hem 1980). Industrial and mining activities are the potential sources of Cadmium in water (Taha 2004). Cadmium ingestion can cause gastrointestinal diseases like vomiting and diarrhea (Nordberg 2004). Its long-term exposure can cause Kidney failure (Barbier et al. 2005), Reproductive diseases (Frery et al. 1993; Piasek & Laskey 1999; Johnson et al. 2006), Bones damage (Kazantzis 1979), and cancer disease (Waalkes et al. 1988).

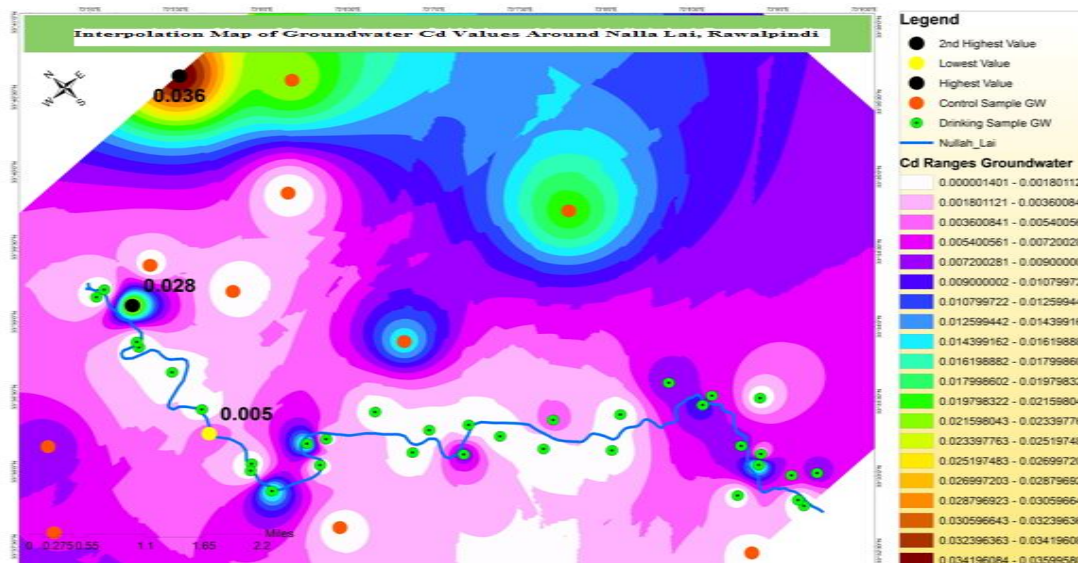


Figure 11 | Interpolation Map Showing Highest and Lowest Cd Location Points of Groundwater

3.12 Copper

The average copper value in groundwater and wastewater samples was 0.09 mg L^{-1} and 0.08 mg L^{-1} . The range value of Copper in groundwater samples was 0.038 mg L^{-1} - 0.139 mg L^{-1} whereas the Copper value in wastewater samples was in a range of 0.012 mg L^{-1} - 0.204 mg L^{-1} respectively. Copper was detected in seven wastewater samples and three groundwater samples, it was observed above the BDL (Below Detection Limit) value. Nasrullah et al. (2006) analyzed the concentration of Copper higher than the permissible limit in groundwater near the Industrial area of Swabi as well as in the wastewater sample collected from the main drain of the marble industry. Although several marble factories are located in the industrial area of Islamabad it was detected in low concentration because the marble factory's waste and effluents are not discharging in the wastewater stream (Nalla lai). Although Copper is a necessary element present in enzymes and its minute concentration is critical for the synthesis of hemoglobin (Tiwari et al. 2013). But Copper excess concentration can cause neurological problems, hypertension, kidney and liver failure (Krishna & Govil 2004). In infants, its intake can cause death, vomiting of short-lived, and diarrhea (Barzilay et al. 1999).

3.13 Iron

The average Iron value in groundwater and wastewater samples was 1.23 mg L^{-1} and 1.09 mg L^{-1} . The range value of Iron in groundwater samples was 0.101 mg L^{-1} - 4.76 mg L^{-1} whereas Iron in wastewater samples was in the range of 0.12 mg L^{-1} - 4.48 mg L^{-1} respectively. Ten groundwater samples near Nalla showed Iron concentrations higher than the set standard of NSDWQ, 2010 and WHO. Iron concentration in 3 wastewater samples was exceeding the wastewater standards of NEQS, 1997. The analyzed results revealed that Iron is percolating from the surface wastewater of Nalla Lai to groundwater in its vicinity. The major source of Iron in wastewater of Nalla lai is the discharge of waste effluents from the Iron and steel industries in I-9 and I-10 industrial areas of Islamabad. Aderemi et al. (2011) revealed that 75% of the analyzed groundwater samples (well water) collected near municipal solid waste landfill sites were contaminated with Iron concentrations above the permissible limit set by WHO. Iron is an essential micronutrient but its high consumption through drinking water can leads to liver disease (Gyamfi et al. 2012). As compared to its deficiency its excess and overexposure can cause numerous health problems such as cancer (Beckman et al. 1999; Parkkila et al. 2001), Diabetes (Ellervik et al. 2001; Parkkila et al. 2001), Heart and Liver diseases (Milman et al. 2001; Yang et al. 1998; Rasmussen et al. 2001) and neurological problems as well (Sayre et al. 2000; Berg et al. 2001).

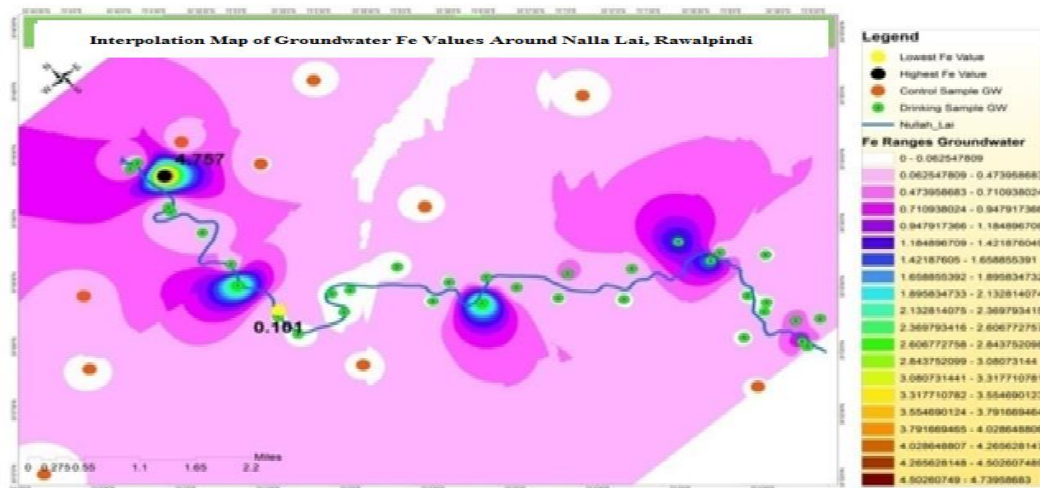


Figure 12 | Interpolation Map Showing Highest and Lowest Fe Location Points of Groundwater

3.14 Manganese

The average Manganese value in groundwater and wastewater samples was 0.25 mg L^{-1} and 0.35 mg L^{-1} . The range value of Manganese in groundwater samples was $0.04 \text{ mg L}^{-1} - 0.85 \text{ mg L}^{-1}$ whereas manganese values in wastewater samples were in a range of $0.15 \text{ mg L}^{-1} - 1.48 \text{ mg L}^{-1}$ respectively. Manganese was detected in all the samples of wastewater within the permissible limit value of NEQs 1997. Manganese was detected in elevated concentration in 4 groundwater samples which were collected from the proximity of the wastewater stream of Nalla lai. Manganese's high concentration depicts that it may be percolated from the surface wastewater of Nalla Lai. Manganese is an important trace nutrient for all living organisms (Emsley 2003). It regulates numerous enzymes of the human body but the excess dose of Manganese harms the nervous system of the brain (Crossgrove & Zheng 2004). Excess intake causes permanent neurological diseases (Barbeau 1984; Inoue 1996).

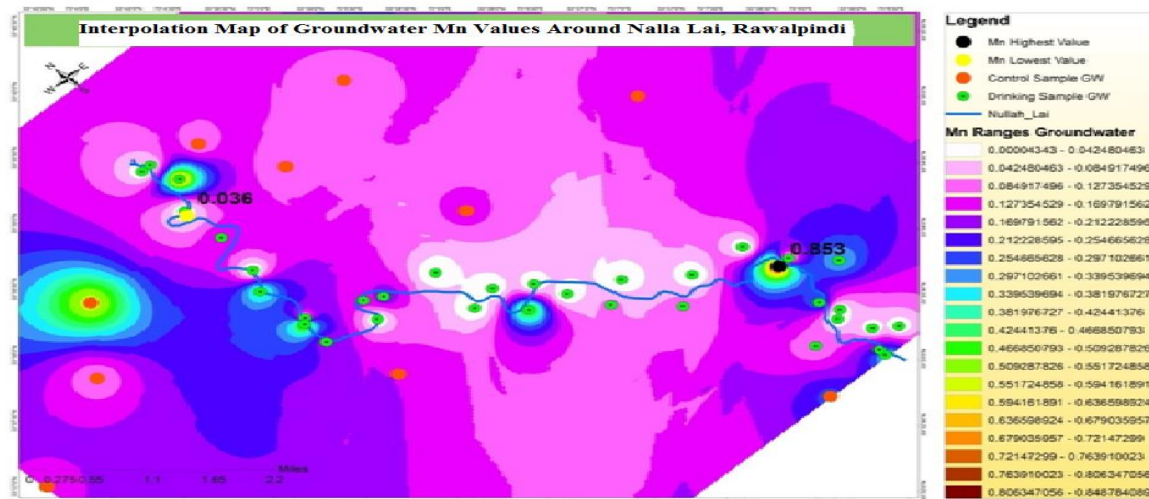


Figure 13 | Interpolation Map Showing Highest and Lowest Mn Location Points of Groundwater

3.15 Lead

The average Lead value in groundwater and wastewater samples was 0.02 mg L^{-1} and 0.10 mg L^{-1} . The range value of Lead in groundwater samples was $0.002 \text{ mg L}^{-1} - 0.04 \text{ mg L}^{-1}$ whereas the Lead value in wastewater samples was in the range of $0.008 \text{ mg L}^{-1} - 0.268 \text{ mg L}^{-1}$ respectively. The minute level of lead naturally exists in soil and water (Raviraja et al. 2008). As mentioned by Haq et al. (2009) the concentration of lead detected in

drinking water is due to industrial discharges, waste dumping, gaseous emissions from traffic sources, and domestic paints (Haq et al. 2009). Its chronic exposure can damage human organs like the digestive and nervous system, cardiovascular system, reproductive system, haematopoietic system, skeleton, and kidney (Gidlow 2004; Venkatesh 2004).

3.16 Zinc

The average Zinc value in groundwater and wastewater samples was 1.06 mg L^{-1} and 0.68 mg L^{-1} . The range value of Zinc in groundwater was $0.01 \text{ mg L}^{-1} - 6.2 \text{ mg L}^{-1}$ whereas zinc value in wastewater samples was in the range of $0.05 \text{ mg L}^{-1} - 4.20 \text{ mg L}^{-1}$ respectively. Zinc was analyzed in high concentration in one bore water sample which was collected from the proximity of Nalla lai. The elevated level depicts that zinc may also be percolated from the surface wastewater of Nalla Lai. Zinc is a necessary element for human health (Solomons & Ruz 1998). Maintaining zinc concentration in body cells is vital for human survival. Zinc releases as free ions from food during digestion in the body (Roohani et al. 2013). Its high concentration can cause health problems (Fosmire 1990; Singh et al. 2006).

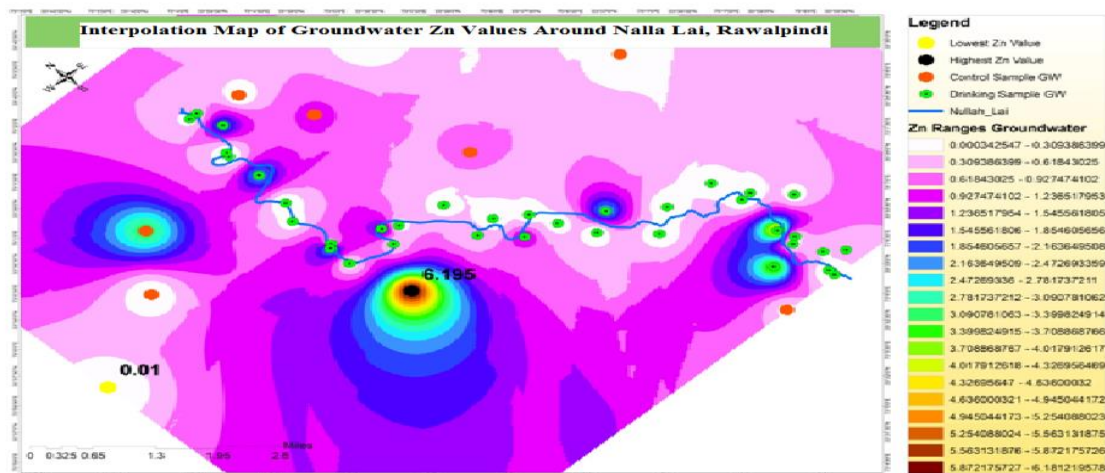


Figure 14 | Interpolation Map Showing Highest and Lowest Zn Location Points of Groundwater

3.17 BOD

The average BOD value in wastewater samples of Nalla lai was 120.21 mg L^{-1} . BOD values in wastewater samples were in the range of $87 \text{ mg L}^{-1} - 194 \text{ mg L}^{-1}$. BOD values in all wastewater samples of Nalla lai were elevated from the recommended value of NEQs, 1997. The elevated values of BOD in the analyzed samples revealed the presence of a high load of organic pollutants in the wastewater stream of Nalla lai. The guideline range of BOD in domestic wastewater is $100-300 \text{ mg/L}^{-1}$ (Abdalla & Hammam 2014). BOD measures the organic pollutants and level of gaseous oxygen in the water and BOD value reveals the microbial utilization of oxygen in the water to break down the organic substances (Anju 2015).

3.18 COD

The average COD value in wastewater samples was 240.15 mg L^{-1} . The range value of COD in groundwater samples was $186 \text{ mg L}^{-1} - 315 \text{ mg L}^{-1}$. COD results of all wastewater samples were elevated from the recommended value of NEQs 1997. The elevated COD values revealed the presence of a high concentration of both organic and inorganic pollutants in the wastewater stream of Nalla lai. Chemical Oxygen Demand is the measure of the oxygen level required to decompose both organic and inorganic matter in water (Bhatnagar 2015). COD is the chemical breakdown of pollutants where oxygen is necessary to execute absolute oxidation to carbon dioxide and water (Dogar et al. 2013).

3.19 E.coli

Microbial contamination of E. coli was detected in thirty groundwater samples out of a total of thirty-six analyzed samples. The samples were collected from the proximity of Nalla lai. The potential source of groundwater contamination was the wastewater stream of Nalla lai. The wastewater of Nalla lai percolates

downward and contaminates the groundwater in its surrounding area. The research conducted by Haq et al. (2007) revealed that due to the discharge of untreated domestic wastewater the bacteria can reach the groundwater because of the puncturing of rocks positioned below the soil. As mentioned by Shahid et al. (2015) microbial contaminations in drinking water can outbreak diseases such as diarrhea, gastroenteritis, dysentery, typhoid, nausea, etc.

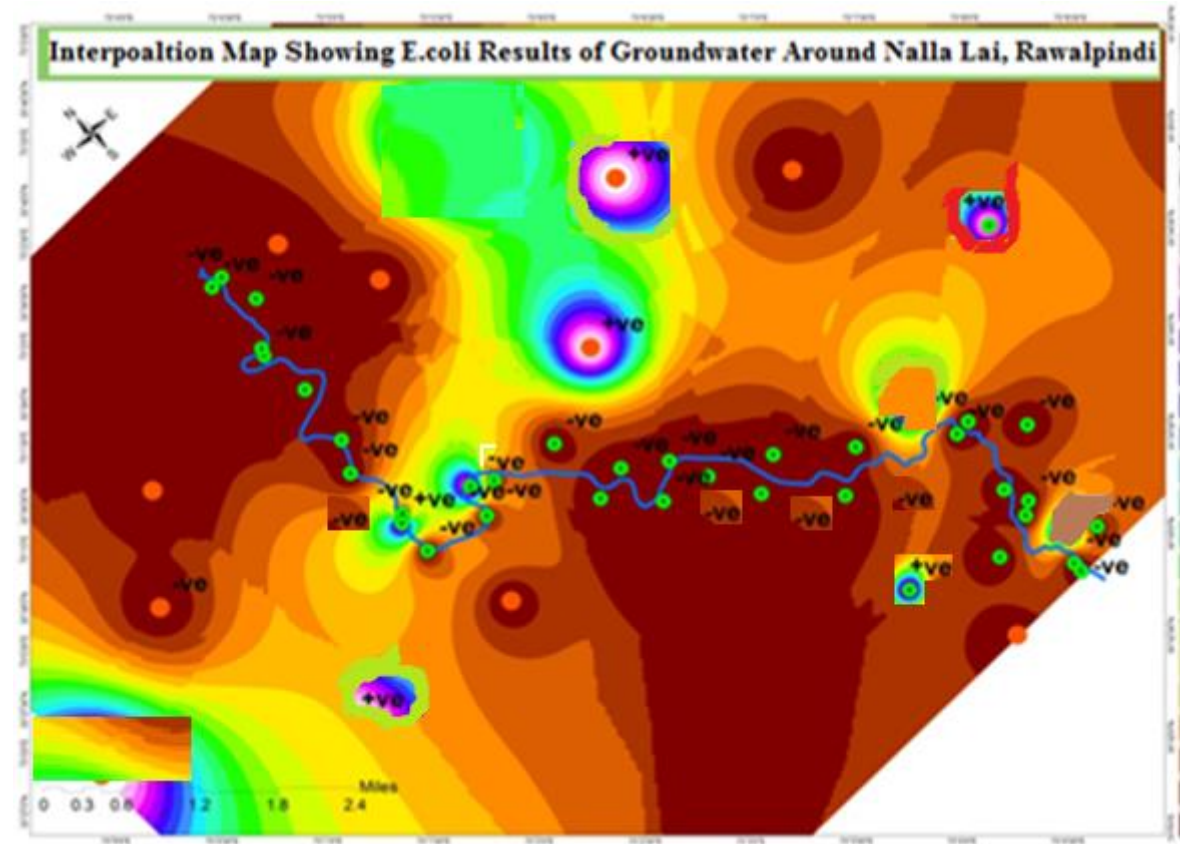


Figure 15 | Location Points of Positive (+ve) and Negative (-ve) Results of Fecal coliform (E.coli) in Groundwater

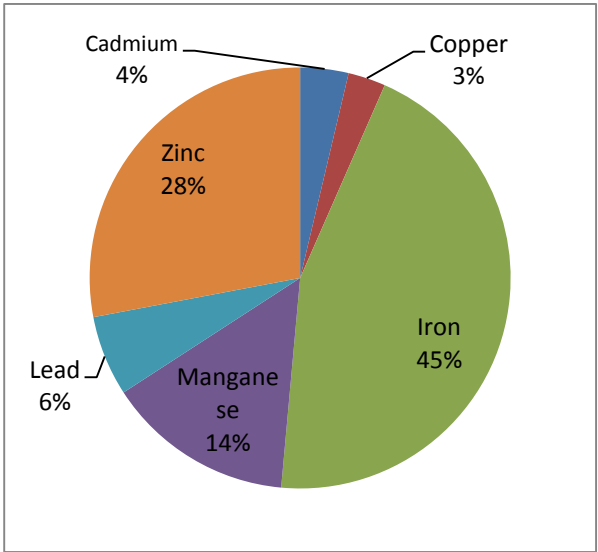


Figure 16 | Average percentage of heavy metals in wastewater samples.

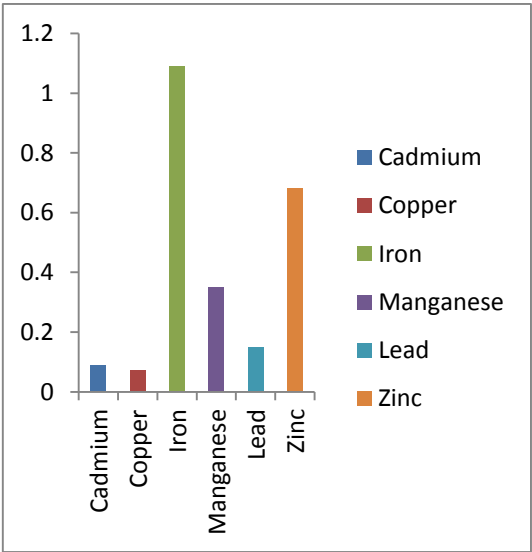


Figure 17 | Average concentration values of heavy metals in wastewater.

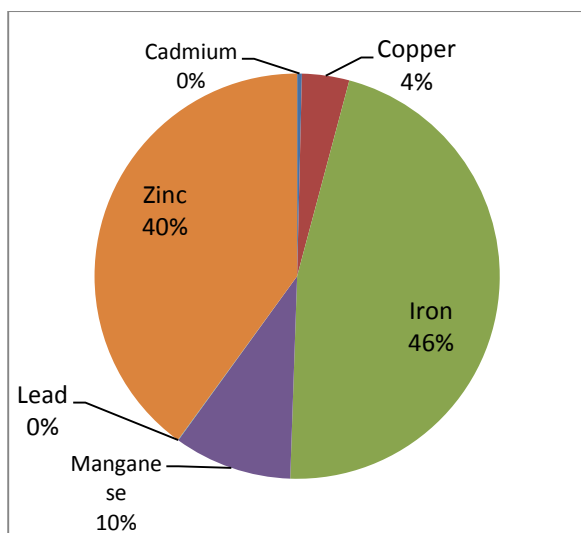


Figure 18 | Average percentage values of heavy metals in groundwater samples.

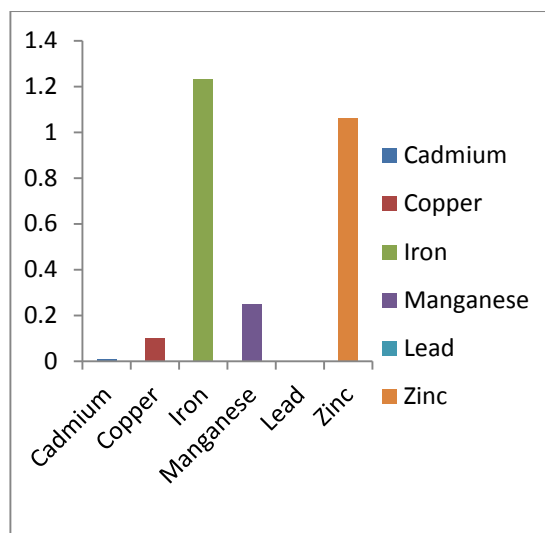


Figure 19 | Average concentration values of heavy metals in Groundwater samples.

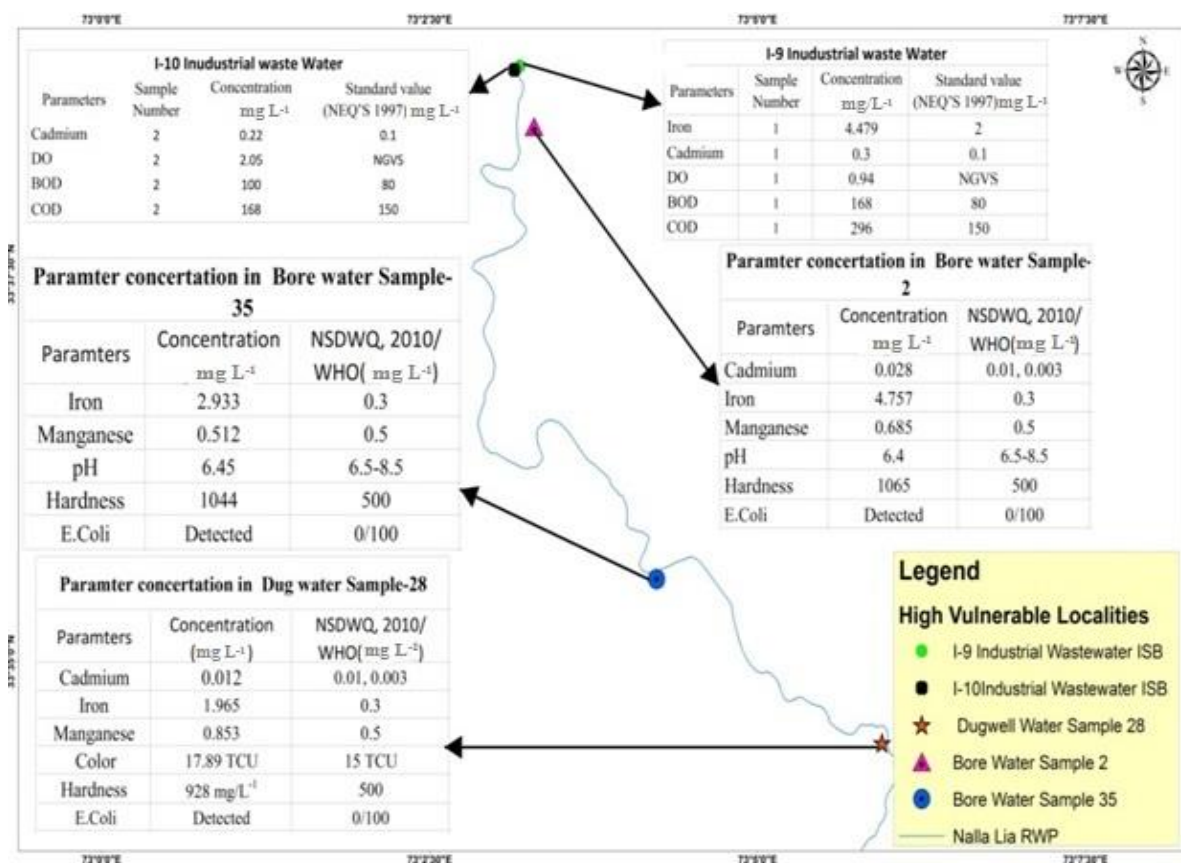


Figure 20 | High vulnerable Wastewater and Groundwater Sampling Localities of the Study Area

The GIS map with tabular results in figure (20) represents highly vulnerable wastewater and groundwater localities in terms of the maximum concentration level of heavy metals. Higher levels of BOD and COD from the recommended values of NEQs 1997 were analyzed in two wastewater streams receiving domestic, commercial, and industrial effluents from the I-9 and I-10 sectors of Islamabad. Groundwater high vulnerable samples in terms of Physico-chemical and microbial contamination were collected from the boreholes and tube wells of residential areas in the vicinity of Nallah Lai. The analyzed samples of two bore water and one Dug

well was located in the proximity of Nalla Lai where maximum percolation level and leaching of contaminants from the wastewater of Nalla lai were detected.

4. CONCLUSIONS

Physicochemical and microbial contamination was detected in many groundwater samples collected from bore water, hand pumps, tube wells, and dug wells located in the proximity of Nalla lai. Cadmium, Iron, BOD, and COD level was elevated from the recommended values in many wastewater samples. Nalla lai was the potential anthropogenic source of groundwater contamination which carries both domestic and commercial sewage of Rawalpindi as well as the industrial effluents of sectors –I-9 and I-10, Islamabad. Many drinking water quality parameters such as pH, color, hardness, TDS, manganese, and zinc were exceeding the national standards in one or more groundwater samples that were collected from the nearest distance of Nalla lai. Microbiological contamination of fecal coliform was detected in 83% of the analyzed groundwater samples. Maximum contamination was observed in the thirty-six analyzed samples, collected from bore water and dug well located adjacent to the Nalla lai wastewater stream and minimum contamination results were obtained from the thirteen control samples that were taken from at least a 1 km distance along both sites of Nalla lai. The study concluded that pollutants enter the wastewater stream from domestic, commercial and industrial sources and percolate downward and finally contaminating the groundwater quality in the vicinity.

RECOMMENDATIONS

- Tube wells, boreholes, hand pumps and dug wells should be installed at least 300-400 meters away from Nalla lai to prevent any type of percolation and leaching from the wastewater of Nalla lai.
- There should be proper laboratory testing of physicochemical and microbiological parameters of newly installed tube well or bore water before water supply to the public.
- Periodic monitoring of all tube wells and bore water should be conducted to cope with wastewater percolation issues.
- Groundwater extraction should be promoted from the deeper aquifer and increase the depth of existing shallow water boreholes.
- Enforce effective and efficient management plan for domestic and commercial solid waste of Rawalpindi and Industrial waste effluents of sectors I-9 and I-10, Islamabad.
- Solid waste should not dump on the banks of Nalla water which increases the chances of leachate formation and percolation of contaminants into groundwater.
- Groundwater percolation can be prevented through proper management of wastewater of Nalla lai which includes the proper sanitation system of Rawalpindi city.
- Water filtration plants should be installed in each inhabitant colony to ensure public health.
- The percolation of wastewater from Nalla lai can be fully prevented through proper cementation by using concrete in the base of Nalla Lai and by the construction of concrete walls on the banks of Nalla lai.

REFERENCES

- Abdalla, K. Z., & Hammam, G. 2014 Correlation between biochemical oxygen demand and chemical oxygen demand for various wastewater treatment plants in Egypt to obtain the biodegradability indices. *International Journal of Sciences: Basic and Applied Research*, 13(1), 42-48.
- Aderemi, A. O., Oriaku, A. V., Adewumi, G. A., & Otitolaju, A. A. 2011 Assessment of groundwater contamination by leachate near a municipal solid waste landfill. *African Journal of Environmental Science and Technology*, 5(11), 933-940. DOI: 10.5897/AJEST11.272
- Ahmed, A., Noonari, T., Magsi, H., & Mahar, A. 2013 Risk assessment of total and fecal coliform bacteria from drinking water supply of Badin city, Pakistan. *Journal of Environmental Professionals Sri Lanka*, 2(1).
- Akbari, E., Alavipanah, S. K., Jeihouni, M., Hajeb, M., Haase, D., & Alavipanah, S. 2017 A review of ocean/sea subsurface water temperature studies from remote sensing and non-remote sensing methods. *Water*, 9(12), 936. <https://doi.org/10.3390/w9120936>
- Akhtar, M. M., Tang, Z., & Mohamadi, B. 2014 Contamination potential assessment of potable groundwater in Lahore, Pakistan. *Polish Journal of Environmental Studies*, 23(6), 1905-1916.
- APHA., AWWA., WEF., 2012 'Standard methods for the examination of water and wastewater' 22th ed., American Public Health Association, American Water Works Association and Water Environment Federation., Washington, DC, USA.
- Asghar, A., Ali, S. M., & Yasmin, A. 2012 Effect of climate change on apple (*Malus domestica* var. ambri) production: A case study in Kotli Satian, Rawalpindi, Pakistan. *Pakistan Journal of Botany*, 44(6), 1913-1918.
- Atta, U., Hussain, M., & Malik, R. N. 2020 Environmental impact assessment of municipal solid waste management value chain: A case study from Pakistan. *Waste Management & Research*, 38(12), 1379-1388. <https://doi.org/10.1177/0734242X20942595>
- Azizullah, Azizullah, Muhammad Nasir Khan, S., & Zahoor Khattak, Peter Richter, and Donat-Peter Häder. "Water pollution in Pakistan and its impact on public health—a review." *Environment International* 37, no. 2 2011 479-497. <https://doi.org/10.1016/j.envint.2010.10.007>
- Barbeau, A. 1984 Manganese and extrapyramidal disorders (a critical review and tribute to Dr. George C. Cotzias). *Neurotoxicology*, 5(1), 13-35.
- Barbier, O., Jacquillet, G., Tauc, M., Cougnon, M., & Poujeol, P. 2005 Effect of heavy metals on, and handling by, the kidney. *Nephron Physiology*, 99(4), p105-p110. <https://doi.org/10.1159/000083981>
- Berman, J. 2009 WHO: Waterborne disease is world's leading killer. *VOA News*, 29.
- Barzilay, J. I., Weinberg, W. G., & Eley, J. W. 1999 The water we drink: Water quality and its effects on health. Rutgers University Press.
- Beckman, L. E., Van Landeghem, G. F., Sikstrom, C., Wahlin, A., Markevarn, B., Hallmans, G., & Beckman, L. 1999 Interaction between haemochromatosis and transferrin receptor genes in different neoplastic disorders. *Carcinogenesis*, 20(7), 1231-1233. <https://doi.org/10.1093/carcin/20.7.1231>
- Berg, D., Gerlach, M., Youdim, M. B. H., Double, K. L., Zecca, L., Riederer, P., & Becker, G. 2001 Brain iron pathways and their relevance to Parkinson's disease. *Journal of neurochemistry*, 79(2), 225-236. <https://doi.org/10.1046/j.1471-4159.2001.00608.x>
- Bhatnagar, A. 2015 Assessment of physico-chemical characteristics of paper industry effluents. *Rasayan J Chem*, 8, 143-145.
- Choi, B. Y., Yun, S. T., Yu, S. Y., Lee, P. K., Park, S. S., Chae, G. T., & Mayer, B. 2005 Hydrochemistry of urban groundwater in Seoul, South Korea: effects of land-use and pollutant recharge. *Environmental Geology*, 48(8), 979-990. DOI 10.1007/s00254-004-1205-y
- Ciner, F., Sunkari, E. D., & Şenbaş, B. A. 2021 Geochemical and multivariate statistical evaluation of trace elements in groundwater of Niğde Municipality, South-Central Turkey: implications for arsenic contamination and human health risks assessment. *Archives of Environmental Contamination and Toxicology*, 80(1), 164-182. <https://doi.org/10.1007/s00244-020-00759-2>
- Crossgrove, J., & Zheng, W. 2004 Manganese toxicity upon overexposure. *NMR in Biomedicine: An International Journal Devoted to the Development and Application of Magnetic Resonance In Vivo*, 17(8), 544-553. <https://doi.org/10.1002/nbm.931>
- Dogar, N. A., Nawaz, M., Majeed, M., & Saeed, A. B. Characterization and Treatment of Wastewater from Sapphire Textile Industry, Pakistan.
- Dohare, D., Deshpande, S., & Kotiya, A. 2014 Analysis of groundwater quality parameters: a Review. *Research Journal of Engineering Sciences* ISSN, 2278, 9472.
- Domínguez-Mariani, E., Carrillo-Chávez, A., Ortega, A., & Orozco-Esquivel, M. T. 2004 Wastewater reuse in Valsequillo agricultural area, Mexico: environmental impact on groundwater. *Water, air, and soil pollution*, 155(1), 251-267.

- 1 Ellervik, C., Mandrup-Poulsen, T., Nordestgaard, B. G., Larsen, L. E., Appleyard, M., Frandsen, M & Birgens,
2 H. 2001 Prevalence of hereditary haemochromatosis in late-onset type 1 diabetes mellitus: a
3 retrospective study. The Lancet, 358(9291), 1405-1409. [https://doi.org/10.1016/S0140-6736\(01\)006526-6](https://doi.org/10.1016/S0140-6736(01)006526-6)
- 4 Emsley, J. 2003 Book Review: Nature's building blocks: an AZ guide to the elements/Oxford University Press,
5 New York, 538 pp., 2002, ISBN 0-198-50341-5. Astronomy, 31(2), 87-88.
- 6 Farooq, S., Hashmi, I., Qazi, I. A., Qaiser, S., & Rasheed, S. 2008 Monitoring of coliforms and chlorine residual
7 in water distribution network of Rawalpindi, Pakistan. Environmental monitoring and
8 assessment, 140(1), 339-347. DOI 10.1007/s10661-007-9872-2
- 9 Fosmire, G. J. 1990 Zinc toxicity. The American journal of clinical nutrition, 51(2), 225-227.
10 <https://doi.org/10.1093/ajcn/51.2.225>
- 11 Frery, N., Nessmann, C., Girard, F., Lafond, J., Moreau, T., Blot, P., ... & Huel, G. 1993 Environmental
12 exposure to cadmium and human birthweight. Toxicology, 79(2), 109-118.
13 [https://doi.org/10.1016/0300-483X\(93\)90124-B](https://doi.org/10.1016/0300-483X(93)90124-B)
- 14 Gidlow, D. A. 2004 Lead toxicity. Occupational Medicine, 54(2), 76-81.
15 <https://doi.org/10.1093/occmed/kqh019>
- 16 Gyamfi, E. T., Ackah, M., Anim, A. K., Hanson, J. K., Kpattah, L., Enti-Brown, S., ... & Nyarko, E. S. 2012
17 Chemical analysis of potable water samples from selected suburbs of Accra, Ghana. Proceedings of the
18 international academy of ecology and environmental sciences, 2(2), 118.
- 19 Han, Z. 2003 Groundwater resources protection and aquifer recovery in China. Environmental Geology, 44(1),
20 106-111.
- 21 HAQ, N. 2009 Drinking water contamination by chromium and lead in industrial lands of Karachi. J Pak Med
22 Assoc, 59(5), 270.
- 23 Hashim, M. A., Mukhopadhyay, S., Sahu, J. N., & Sengupta, B. 2011 Remediation technologies for heavy metal
24 contaminated groundwater. Journal of environmental management, 92(10), 2355-2388.
25 <https://doi.org/10.1016/j.jenvman.2011.06.009>
- 26 Hem, J. D. 1980 Redox coprecipitation mechanisms of manganese oxides. Particulates in water, 45-72.
27 DOI: 10.1021/ba-1980-0189.ch003
- 28 Inoue, N. 1996 Neurological aspects in human exposure to manganese. Toxicology of metals.
- 29 International Association of Hydrogeologists 2020 Groundwater—more about the hidden resource. <https://iah.org/education/general-public/groundwater-r-hidden-resource>. Accessed 13 Nov 2020
- 30 Islam-UI-Haq, C. W., & Ahmed, C. N. 2007, December Multifaceted groundwater quality and recharge
31 mechanism issues in a mega-city (Rawalpindi, Pakistan), and mitigation strategies. In 6th International
32 IAHS Ground Water Quality Conference (2–7 December 2007), Fremantle, western Australia.
- 33 Jenifer, M. A., & Jha, M. K. 2018 Comprehensive risk assessment of groundwater contamination in a weathered
34 hard-rock aquifer system of India. Journal of Cleaner Production, 201, 853-868.
35 <https://doi.org/10.1016/j.jclepro.2018.08.005>
- 36 Johnson, S., Saikia, N., & Kumar, A. 2006 Analysis of pesticide residues in soft drinks. Centre for Science and
37 Environment Report 41, 2006, Tughlakabad institutional area, New Delhi, 110062.
- 38 Kamble, R. K. 2015 Comparison of Two Analytical Methods for Measurement of Iron Concentration in
39 Groundwater in Chandrapur District, Central India. International Journal of Scientific Research in
40 Environmental Sciences, 3(4), 129. DOI:10.12983/ijres-2015-p0129-0136
- 41 Kazantzis, G. 1979 Renal tubular dysfunction and abnormalities of calcium metabolism in cadmium
42 workers. Environmental health perspectives, 28, 155-159. <https://doi.org/10.1289/ehp.7928155>
- 43 Khan, A. A., Ashraf, M. I., Malik, S. U., Gulzar, S., & Amin, M. 2019 Spatial trends in surface runoff and
44 influence of climatic and physiographic factors: A case study of watershed areas of Rawalpindi
45 district. Soil & Environment, 38(2). DOI:10.25252/SE/19/81787
- 46 Khan, S., & Zahoor, S., & Zahoor, U. 2011 Ihsanullah and Zubair, A., Levels of selected heavy metals in
47 drinking water of Peshawar City. Int. J. Sci. Nat, 2, 648-652.
- 48 Krishna, A. K., & Govil, P. K. 2004 Heavy metal contamination of soil around Pali industrial area, Rajasthan,
49 India. Environmental Geology, 47(1), 38-44. DOI 10.1007/s00254-004-1124-y
- 50 Li, P. 2020 To make the water safer. Exposure and health, 12(3), 337-342. <https://doi.org/10.1007/s12403-020-00370-9>
- 51 Li, P., & Wu, J. 2019 Sustainable living with risks: meeting the challenges. Human and Ecological Risk
52 Assessment: An International Journal, 25(1-2), 1-10. <https://doi.org/10.1080/10807039.2019.1584030>
- 53 Li, P., Wu, J., & Qian, H. 2013 Assessment of groundwater quality for irrigation purposes and identification of
54 hydrogeochemical evolution mechanisms in Pengyang County, China. Environmental Earth
55 Sciences, 69(7), 2211-2225. DOI 10.1007/s12665-012-2049-5
- 56 Lin, H. 2010 Earth's Critical Zone and hydrogeology: concepts, characteristics, and advances. Hydrology and
57 Earth System Sciences, 14(1), 25-45. <https://doi.org/10.5194/hess-14-25-2010>

- 1 Maqsoom, A., Aslam, B., Gul, M. E., Ullah, F., Kouzani, A. Z., Mahmud, M. A., & Nawaz, A. 2021 Using
2 Multivariate Regression and ANN Models to Predict Properties of Concrete Cured under Hot
3 Weather. *Sustainability*, 13(18), 10164. <https://doi.org/10.3390/su131810164>
- 4 Mehmood, Y., Zahoor, H., & Ullah, F. 2019 Economic-efficiency analysis of rawalpindi bypass project: A case
5 study. In *Innovative Production and Construction: Transforming Construction Through Emerging*
6 *Technologies* (pp. 531-555). https://doi.org/10.1142/9789813272491_0030
- 7 Memon, M., Soomro, M. S., Akhtar, M. S., & Memon, K. S. 2011 Drinking water quality assessment in
8 Southern Sindh (Pakistan). *Environmental monitoring and assessment*, 177(1), 39-50.
- 9 Miao, Z., Brusseau, M. L., Carroll, K. C., Carreón-Diazconti, C., & Johnson, B. 2012 Sulfate reduction in
10 groundwater: characterization and applications for remediation. *Environmental geochemistry and*
11 *health*, 34(4), 539-550. DOI 10.1007/s10653-011-9423-1
- 12 Milman, N., Pedersen, P. A., á Steig, T., Byg, K. E., Graudal, N., & Fenger, K. 2001 Clinically overt hereditary
13 hemochromatosis in Denmark 1948–1985: epidemiology, factors of significance for long-term
14 survival, and causes of death in 179 patients. *Annals of hematology*, 80(12), 737-744. DOI
15 10.1007/s002770100371
- 16 Nasrullah, R. N., Bibi, H., Iqbal, M., & Durrani, M. I. 2006 Pollution load in industrial effluent and groundwater
17 of Gadoon Amazai Industrial Estate (GAIE) Swabi, NWFP. *Journal of agricultural and biological*
18 *science*, 1(3), 18-24.
- 19 National Research Council (US). Subcommittee on Nutrient, & Toxic Elements in Water. 1974 *Nutrients and*
20 *Toxic Substances in Water for Livestock and Poultry: A Report*. National Academy Press.
- 21 Nicholson, K., Hayes, E., Neumann, K., Dowling, C., & Sharma, S. 2016 Drinking water quality in the
22 Sagarmatha national park, Nepal. *Journal of Geoscience and Environment Protection*, 4(04), 43.
23 DOI: 10.4236/gep.2016.44007
- 24 Nisar, H., Ejaz, N., Naushad, Z., & Ali, Z. 2008 Impacts of solid waste management in Pakistan: a case study of
25 Rawalpindi city. *WIT Transactions on Ecology and the Environment*, 109, 685-691. DOI
26 10.2495/WM080701
- 27 Njuguna, S. M., Makokha, V. A., Yan, X., Gituru, R. W., Wang, Q., & Wang, J. 2019 Health risk assessment by
28 consumption of vegetables irrigated with reclaimed wastewater: a case study in Thika (Kenya). *Journal*
29 *of environmental management*, 231, 576-581. <https://doi.org/10.1016/j.jenvman.2018.10.088>
- 30 Nordberg, G. F. 2004 Cadmium and health in the 21st century—historical remarks and trends for the
31 future. *Biometals*, 17(5), 485-489.
- 32 Pande, G., Sinha, A., & Agrawal, S. 2015 Impacts of leachate percolation on groundwater quality: a case study
33 of Dhanbad City. *Glob. Nest J*, 17, 162-174.
- 34 Parkkila, S., Niemelä, O., Savolainen, E. R., & Koistinen, P. 2001 HFE mutations do not account for
35 transfusional iron overload in patients with acute myeloid leukemia. *Transfusion*, 41(6), 828-831.
36 <https://doi.org/10.1046/j.1537-2995.2001.41060828.x>
- 37 Piasek, M., & Laskey, J. W. 1999 Effects of in vitro cadmium exposure on ovarian steroidogenesis in
38 rats. *Journal of applied toxicology*, 19(3), 211-217. [https://doi.org/10.1002/\(SICI\)1099-](https://doi.org/10.1002/(SICI)1099-1263(199905/06)19:3<211::AID-JAT568>3.0.CO;2-4)
39 [1263\(199905/06\)19:3<211::AID-JAT568>3.0.CO;2-4](https://doi.org/10.1002/(SICI)1099-1263(199905/06)19:3<211::AID-JAT568>3.0.CO;2-4)
- 40 Poonia, T., Singh, N., & Garg, M. C. 2021 Contamination of Arsenic, Chromium and Fluoride in the Indian
41 groundwater: a review, meta-analysis and cancer risk assessment. *International Journal of*
42 *Environmental Science and Technology*, 18(9), 2891-2902.
- 43 Prajapati, U. B., & Dwivedi, A. K. 2016 Free oxygen budget of a polluted tropical river. *Hydrology Current*
44 *Research*, 7(2), 5-8. <http://dx.doi.org/10.4172/2157-7587.1000235>
- 45 Raashid, M., & Hussain, Z. 2014 Management of industrial effluent from paper and pulp industries using
46 gravimetric circular clarifier technique. In *Proceeding of 3rd International Conference on Environment,*
47 *Chemistry and Biology* (Vol. 78, pp. 11-14). DOI: 10.7763/IPCBE. 2014. V78. 3
- 48 Ramya, P., Jagadeesh Babu, A., Reddy, E. T., & Rao, L. V. 2015 A study on the estimation of hardness in
49 groundwater samples by EDTA titrimetric method. *International Journal of Recent Scientific*
50 *Research*, 6(6), 4505-4507.
- 51 Rao, V. B. 2011 Physicochemical analysis of selected groundwater samples of Vijayawada rural and urban in
52 Krishna district, Andhra Pradesh, India. *International journal of environmental sciences*, 2(2), 710.
- 53 Rasmussen, M. L., Folsom, A. R., Catellier, D. J., Tsai, M. Y., Garg, U., & Eckfeldt, J. H. 2001 A prospective
54 study of coronary heart disease and the hemochromatosis gene (HFE) C282Y mutation: the
55 Atherosclerosis Risk in Communities (ARIC) study. *Atherosclerosis*, 154(3), 739-746.
56 [https://doi.org/10.1016/S0021-9150\(00\)00623-7](https://doi.org/10.1016/S0021-9150(00)00623-7)
- 57 Raviraja, A., Babu, V., Narayanamurthy, G., Bijoor, A. R., Menezes, G., & Venkatesh, T. 2008 Lead toxicity in
58 a family as a result of occupational exposure. *Arhiv za higijenu rada i toksikologiju*, 59(2), 127-133.
59 DOI: 10.2478/10004-1254-59-2008-1861

- 1 Reza, R. I. Z. W. A. N., & Singh, G. U. R. D. E. E. P. 2019 Application of heavy metal pollution index for
2 groundwater quality assessment in Angul District of Orissa, India. *International Journal of*
3 *Environmental Sciences*, 5(1), 118-122.
- 4 Roohani, N., Hurrell, R., Kelishadi, R., & Schulin, R. 2013 Zinc and its importance for human health: An
5 integrative review. *Journal of research in medical sciences: the official journal of Isfahan University of*
6 *Medical Sciences*, 18(2), 144.
- 7 Sarada P D., and Bhushanavathi P D., 2015 Analysis Of Groundwater Samples of Gnanapuram Area of
8 Visakhapatnam City in Andhra Pradesh, India for Sodium, Potassium And Chloride : The Potability
9 Concern., GJRA - Global Journal For Research Analysis, Volume-4, Issue-10, ISSN No 2277
- 10 Sayre, L. M., Perry, G., Atwood, C. S., & Smith, M. A. 2000 The role of metals in neurodegenerative
11 diseases. *Cellular and molecular biology (Noisy-le-Grand, France)*, 46(4), 731-741.
- 12 Shahid, I., Chishtie, F., Bulbul, G., Shahid, M. Z., Shafique, S., & Lodhi, A. 2019 State of air quality in twin
13 cities of Pakistan: Islamabad and Rawalpindi. *Atmósfera*, 32(1), 71-84.
14 <https://doi.org/10.20937/atm.2019.32.01.06>.
- 15 Shahid, N., Zia, Z., Shahid, M., Faiq Bakhat, H., Anwar, S., Mustafa Shah, G., & Rizwan Ashraf, M. 2015
16 Assessing Drinking Water Quality in Punjab, Pakistan. *Polish Journal of Environmental Studies*, 24(6).
17 DOI: <https://doi.org/10.15244/pjoes/41533>
- 18 Singh, K. P., Singh, V. K., Malik, A., & Basant, N. 2006 Distribution of nitrogen species in groundwater
19 aquifers of an industrial area in alluvial Indo-Gangetic Plains—a case study. *Environmental*
20 *geochemistry and health*, 28(5), 473-485. DOI 10.1007/s10653-006-9053-1
- 21 Singh, G., & Kamal, R. K. 2017 Heavy metal contamination and its indexing approach for groundwater of Goa
22 mining region, India. *Applied Water Science*, 7(3), 1479-1485.
- 23 Solomons, N. W., & Ruz, M. 1998 Trace element requirements in humans: an update. *The Journal of Trace*
24 *Elements in Experimental Medicine: The Official Publication of the International Society for Trace*
25 *Element Research in Humans*, 11(2-3), 177-195. [https://doi.org/10.1002/\(SICI\)1520-](https://doi.org/10.1002/(SICI)1520-670X(1998)11:2/3<177::AID-JTRA9>3.0.CO;2-5)
26 [670X\(1998\)11:2/3<177::AID-JTRA9>3.0.CO;2-5](https://doi.org/10.1002/(SICI)1520-670X(1998)11:2/3<177::AID-JTRA9>3.0.CO;2-5)
- 27 Srivastava, R. K., & Pandey, D. 2012 Physico-chemical and microbiological quality evaluation of groundwater
28 for human domestic consumption in adjoining area of Omti Nallah, Jabalpur (MP), India. *International*
29 *Journal of Environmental Sciences*, 3(3), 1089-1096. DOI: 10.6088/ijes.2012030133017
- 30 Su, Z., Wu, J., He, X., & Elumalai, V. 2020 Temporal changes of groundwater quality within the groundwater
31 depression cone and prediction of confined groundwater salinity using Grey Markov model in
32 Yinchuan area of northwest China. *Exposure and Health*, 12(3), 447-468.
33 <https://doi.org/10.1007/s12403-020-00355-8>
- 34 Subramani, T., Elango, L., & Damodarasamy, S. R. 2005 Groundwater quality and its suitability for drinking
35 and agricultural use in Chithar River Basin, Tamil Nadu, India. *Environmental Geology*, 47(8), 1099-
36 1110. DOI 10.1007/s00254-005-1243-0
- 37 Taha, A. A., El-Mahmoudi, A. S., & El-Haddad, I. M. 2004 Pollution sources and related environmental impacts
38 in the new communities southeast Nile Delta, Egypt. *Emirates Journal for Engineering Research*, 9(1),
39 35-49.
- 40 Tahir, A., Kanwal, F., & Mateen, B. 2011 Surveillance of microbial indicators and physicochemical parameters
41 to investigate pollution status of Lahore canal. *Pakistan Journal of Botany*, 43(6), 2821-2824.
- 42 Tariq, M., Ali, M., & Shah, Z. J. S. E. 2006 Characteristics of industrial effluents and their possible impacts on
43 quality of underground water. *Soil Environ*, 25(1), 64-69.
- 44 Tatti, F., Papini, M. P., Torretta, V., Mancini, G., Boni, M. R., & Viotti, P. 2019 Experimental and numerical
45 evaluation of Groundwater Circulation Wells as a remediation technology for persistent, low
46 permeability contaminant source zones. *Journal of contaminant hydrology*, 222, 89-100.
47 <https://doi.org/10.1016/j.jconhyd.2019.03.001>
- 48 Tiwari, R. N., Mishra, S., & Pandey, P. 2013 Study of major and trace elements in groundwater of Birsinghpur
49 Area, Satna District Madhya Pradesh, India. *International Journal of water resources and*
50 *Environmental Engineering*, 5(7), 380-386. DOI: 10.5897/IJWREE2012.0408
- 51 Tiwari, S. 2015 Water quality parameters—A review. *International Journal of Engineering Science Invention*
52 *Research & Development*, 1(9), 319-324.
- 53 UNESCO. 2003 Water for people water for life. The United Nations world water development report. United
54 Nations Educational, Scientific and Cultural Organization (UNESCO) and Berghahn Books.
- 55 USGS. 2016 The world's water. U.S. department of the Interior. U.S. Geological Survey. Retrieved from
56 <http://water.usgs.gov/edu/earthwherewater.html>.
- 57 Venkatesh, T. 2004 The effects of environmental lead on human health-a Challenging Scenario. *Health*
58 *Focus*, 2, 8-16.

- 1 Waalkes, M. P., Rehm, S., Riggs, C. W., Bare, R. M., Devor, D. E., Poirier, L. A., ... & Balaschak, M. S. 1988
2 Cadmium carcinogenesis in male Wistar [Crl:(WI) BR] rats: dose-response analysis of tumor induction
3 in the prostate and testes and at the injection site. *Cancer research*, 48(16), 4656-4663.
- 4 Wang, D., Wu, J., Wang, Y., & Ji, Y. 2020 Finding high-quality groundwater resources to reduce the
5 hydatidosis incidence in the Shiqu County of Sichuan Province, China: analysis, assessment, and
6 management. *Exposure and Health*, 12(2), 307-322. <https://doi.org/10.1007/s12403-019-00314-y>
- 7 WHO, and UNICEF. 2000 Global water supply and sanitation assessment 2000 report. USA: World Health
8 Organization and United Nations Children's Fund. Retrieved from: [http://](http://www.who.int/water_sanitation_health/monitoring/jmp2000.pdf)
9 www.who.int/water_sanitation_health/monitoring/jmp2000.pdf
- 10 Yang, Q., McDonnell, S. M., Khoury, M. J., Cono, J., & Parrish, R. G. 1998 Hemochromatosis-associated
11 mortality in the United States from 1979 to 1992: an analysis of Multiple-Cause Mortality Data. *Annals*
12 *of Internal Medicine*, 129(11_Part_2), 946-953. [https://doi.org/10.7326/0003-4819-129-](https://doi.org/10.7326/0003-4819-129-11_Part_2-199812011-00005)
13 [11_Part_2-199812011-00005](https://doi.org/10.7326/0003-4819-129-11_Part_2-199812011-00005)
- 14 Yuan, Y., Xiang, M., Liu, C., & Theng, B. K. 2019 Chronic impact of an accidental wastewater spill from a
15 smelter, China: a study of health risk of heavy metal (loid) s via vegetable intake. *Ecotoxicology and*
16 *Environmental Safety*, 182, 109401. <https://doi.org/10.1016/j.ecoenv.2019.109401>
- 17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65

ABSTRACT

The scientific report assessed the impact of Nalla lai wastewater on the groundwater quality of Rawalpindi city, Pakistan. A total of nineteen wastewater and forty-nine groundwater samples were collected during September and October 2016 and have been analyzed in the laboratory to detect different water quality parameters. The results revealed that BOD, COD, Iron and Cadmium values in many wastewater samples were beyond the recommended value of the National Environmental Quality Standards 1997 (NEQs, 1997). In groundwater samples, the results of iron, cadmium, manganese, zinc, TDS, pH, color and hardness were found elevated from the standard values in one or more samples as compared to the National Standard for Drinking Water Quality, 2010 (NSDWQ, 2010). The decreasing metal concentration order in groundwater samples was Iron > Zinc > Manganese > Copper > Cadmium. Very interestingly, hardness was found at elevated levels in 75% of investigated groundwater samples. Microbiological contamination was detected in 83% of the analyzed groundwater samples. The study revealed the percolation of heavy metals and microbial contamination in the bore water, tube wells, hand pumps, springs, and hand-dug wells located nearby the Nalla lai wastewater stream.

Keywords: Groundwater, Wastewater, Percolation, Nalla lai, E.coli, Rawalpindi

ABSTRACT

The scientific report assessed the impact of Nalla lai wastewater on the groundwater quality of Rawalpindi city, Pakistan. A total of nineteen wastewater and forty-nine groundwater samples were collected during September and October 2016 and have been analyzed in the laboratory to detect different water quality parameters. The results revealed that BOD, COD, Iron and Cadmium values in many wastewater samples were beyond the recommended value of the National Environmental Quality Standards 1997 (NEQs, 1997). In groundwater samples, the results of iron, cadmium, manganese, zinc, TDS, pH, color and hardness were found elevated from the standard values in one or more samples as compared to the National Standard for Drinking Water Quality, 2010 (NSDWQ, 2010). The decreasing metal concentration order in groundwater samples was Iron > Zinc > Manganese > Copper > Cadmium. Very interestingly, hardness was found at elevated levels in 75% of investigated groundwater samples. Microbiological contamination was detected in 83% of the analyzed groundwater samples. The study revealed the percolation of heavy metals and microbial contamination in the bore water, tube wells, hand pumps, springs, and hand-dug wells located nearby the Nalla lai wastewater stream.

Keywords: Groundwater, Wastewater, Percolation, Nalla lai, E.coli, Rawalpindi

HIGHLIGHTS

- This scientific study evaluates the impact of Nalla lai wastewater stream on the groundwater quality of Rawalpindi city, Pakistan.
- BOD, COD, Iron and Cadmium concentration in many wastewater samples were beyond the recommended value of the National Environmental Quality Standards, 1997.
- Iron, Cadmium, Manganese, Zinc, TDS, pH, Color and Hardness concentration in groundwater samples were detected elevated in one or more samples as compared to the National Standards for Drinking Water Quality, 2010.
- The decreasing metal concentration order in groundwater samples was Iron > Zinc > Manganese > Copper > Cadmium.
- Hardness was elevated from the standard value in 75% of the investigated groundwater samples and microbial contamination was detected in 85% of the analyzed groundwater samples.

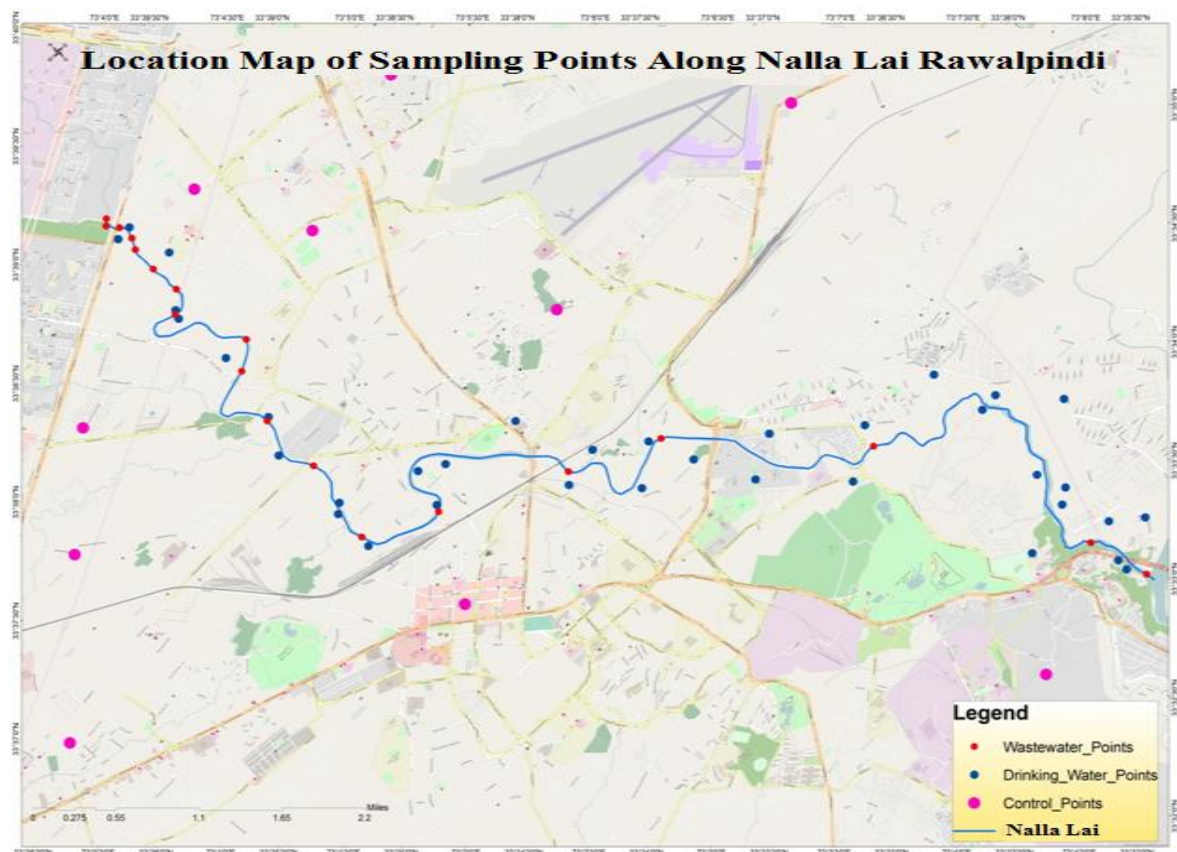


Figure 1 | GIS Map of Sampling Points Location along with Nalla Lai (Study Area)

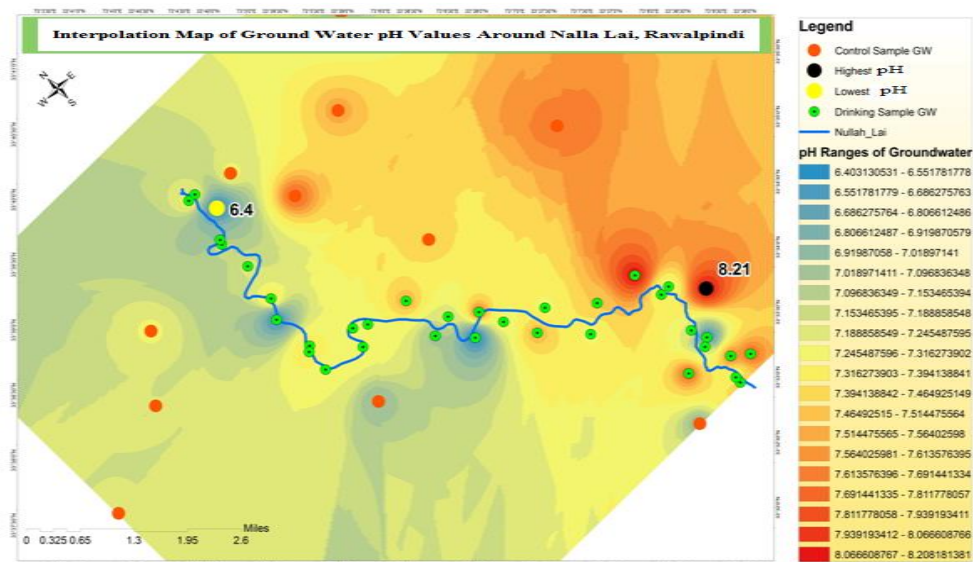


Figure 2 | Interpolation Map Showing Highest and Lowest pH Location Points of Groundwater

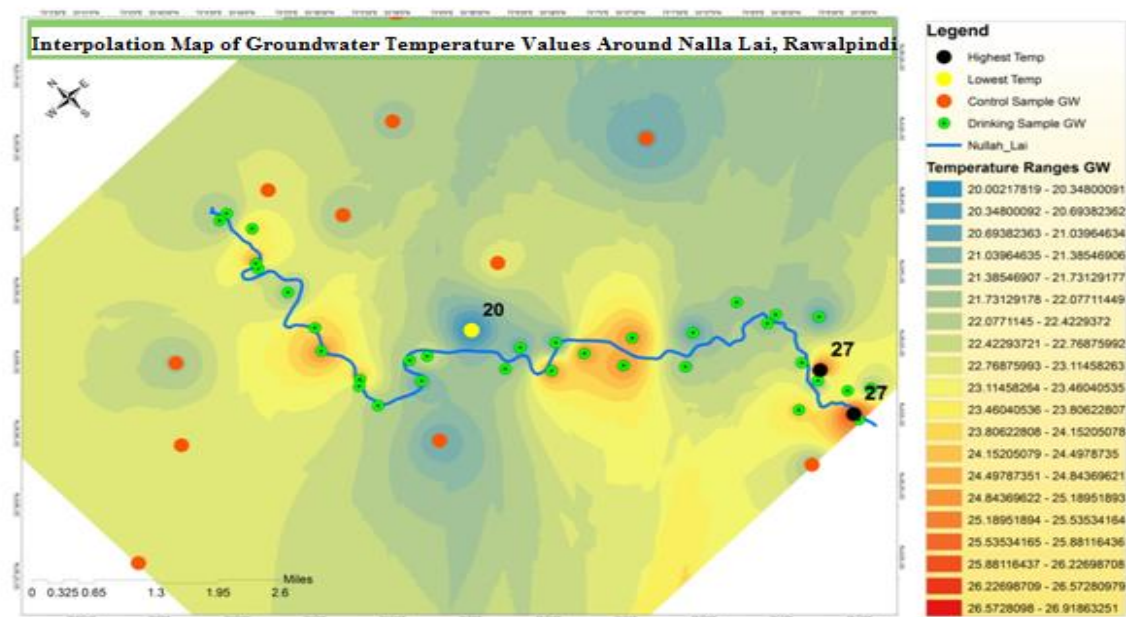


Figure 3 | Interpolation Map Showing Highest and Lowest Temperature Location Points of Groundwater

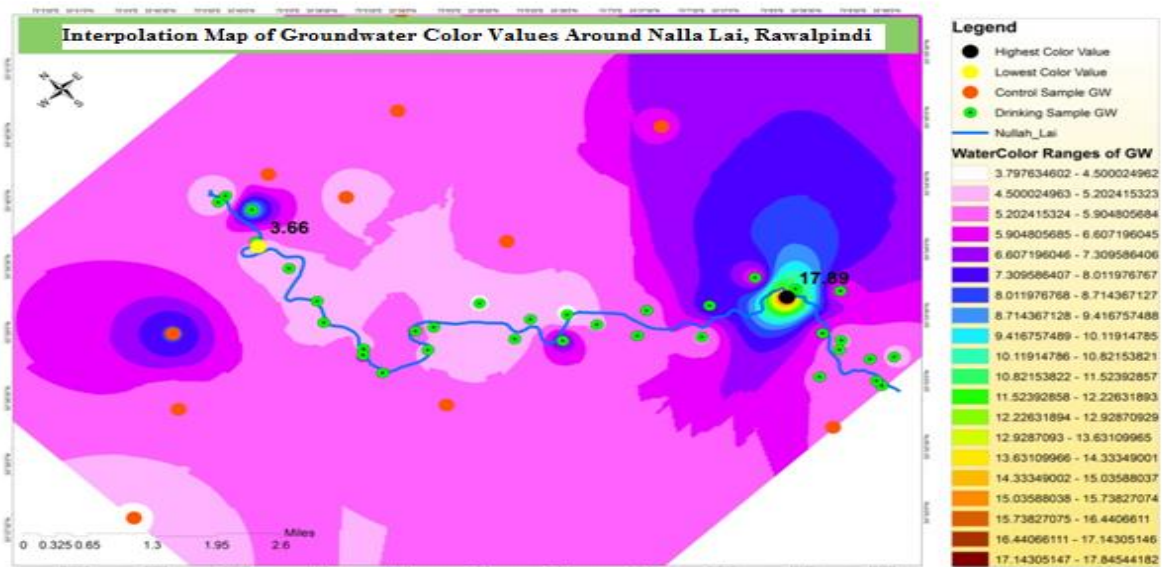


Figure 4 | Interpolation Map Showing Highest and Lowest Color Location Points of Groundwater

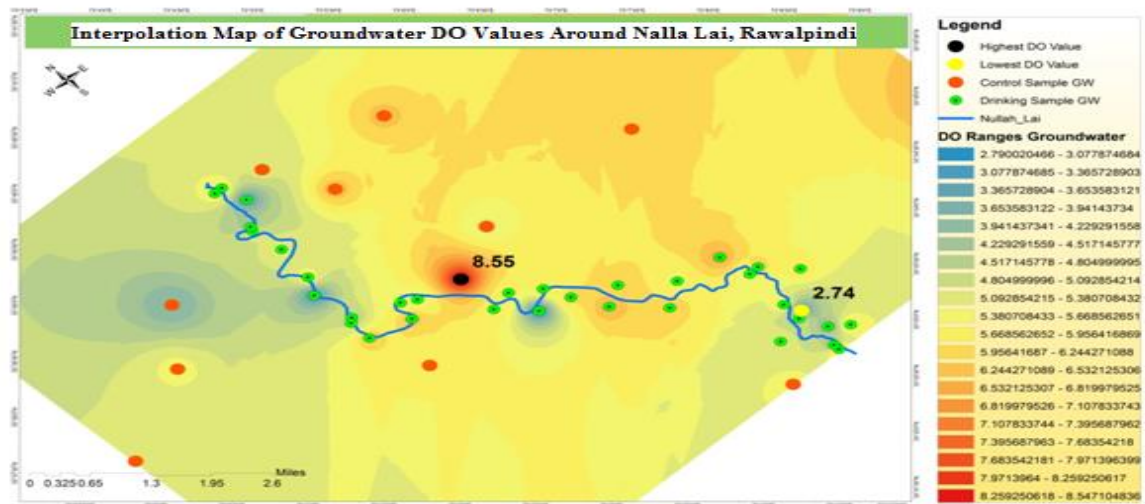


Figure 5 | Interpolation Map Showing Highest and Lowest DO Location Points of Groundwater

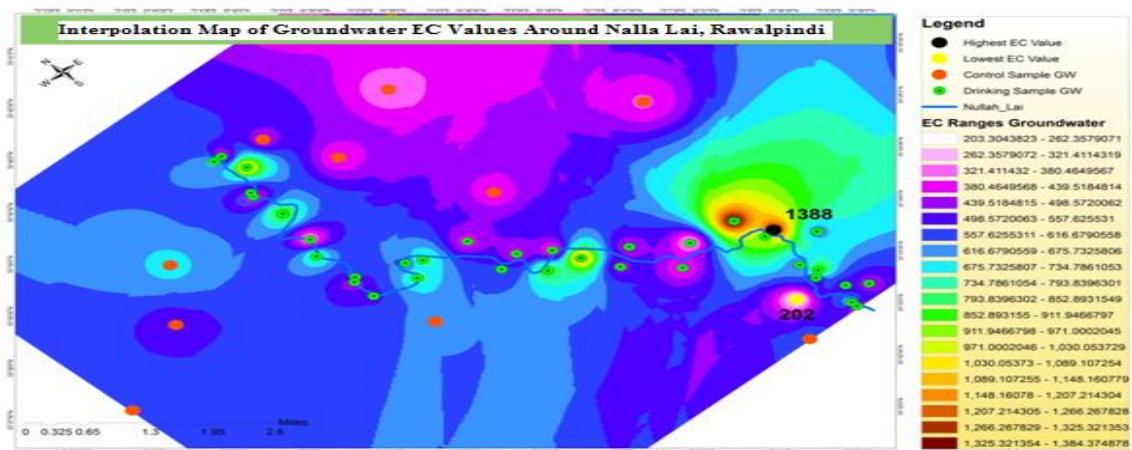


Figure 6 | Interpolation Map Showing Highest and Lowest EC Location Points of Groundwater

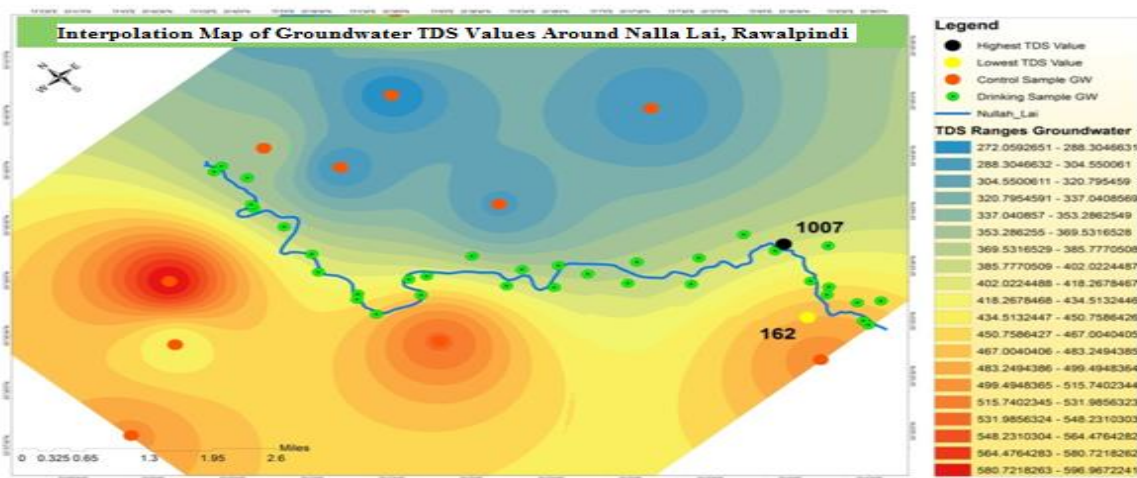


Figure 7 | Interpolation Map Showing Highest and Lowest TDS Location Points of Groundwater

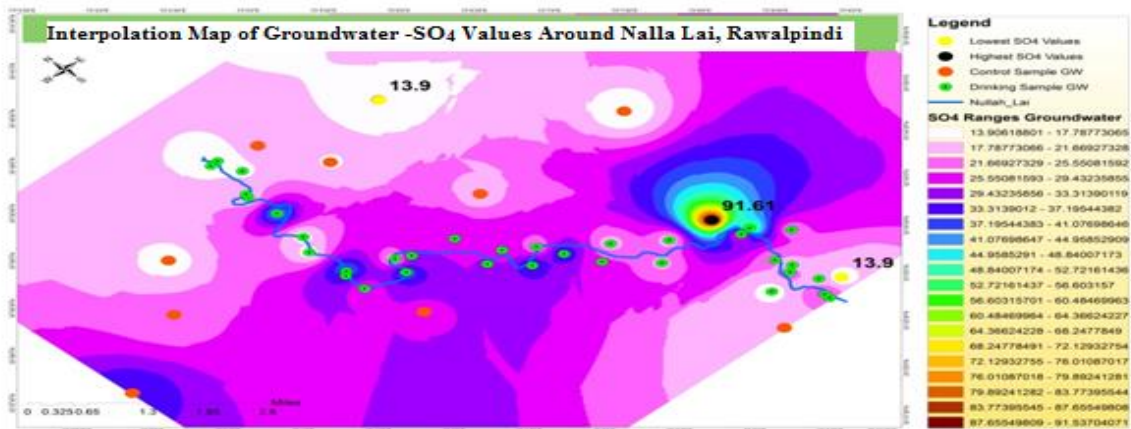


Figure 8 | Interpolation Map Showing Highest and Lowest (-SO₄) Location Points of Groundwater

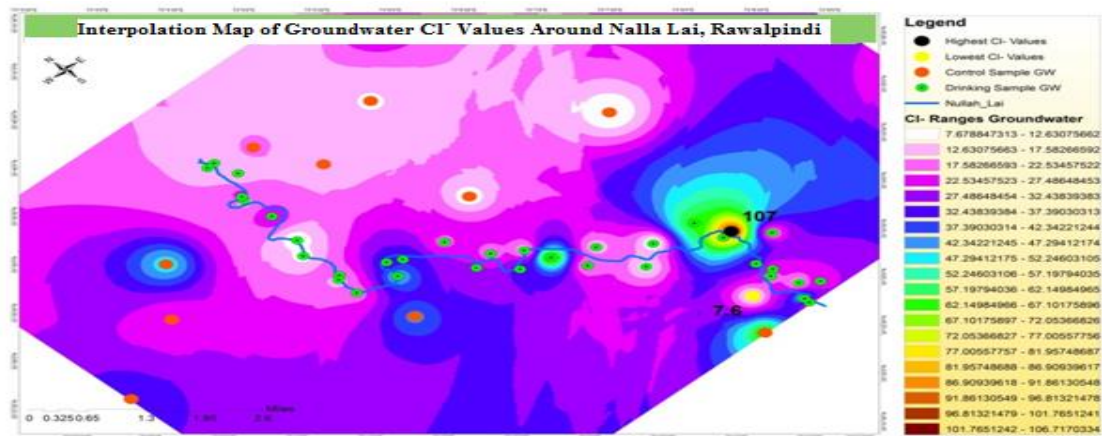


Figure 9 | Interpolation Map Showing Highest and Lowest Cl⁻ Location Points of Groundwater

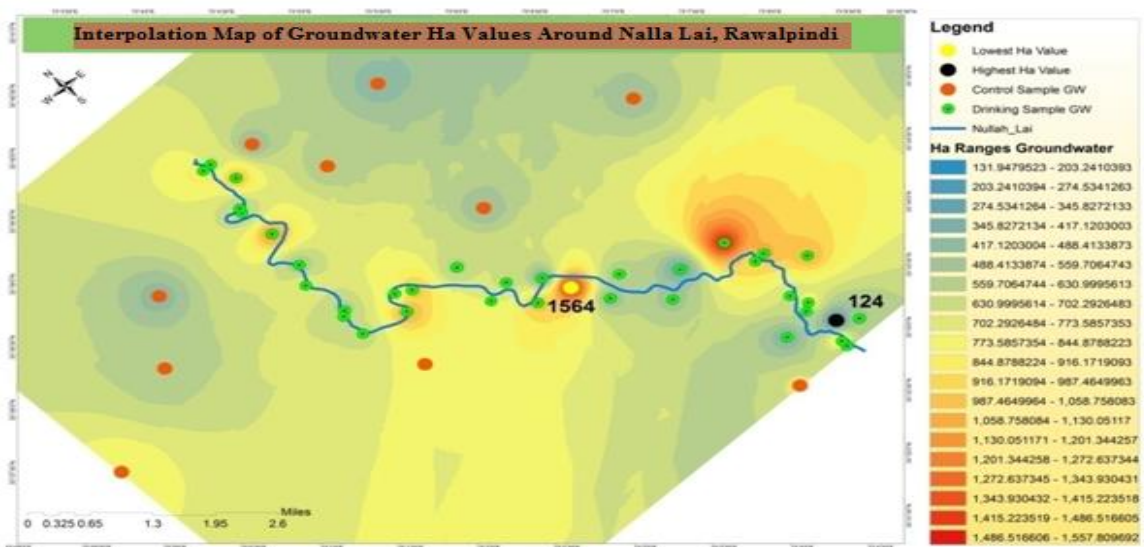


Figure 10 | Interpolation Map Showing Highest and Lowest Ha Location Points of Groundwater

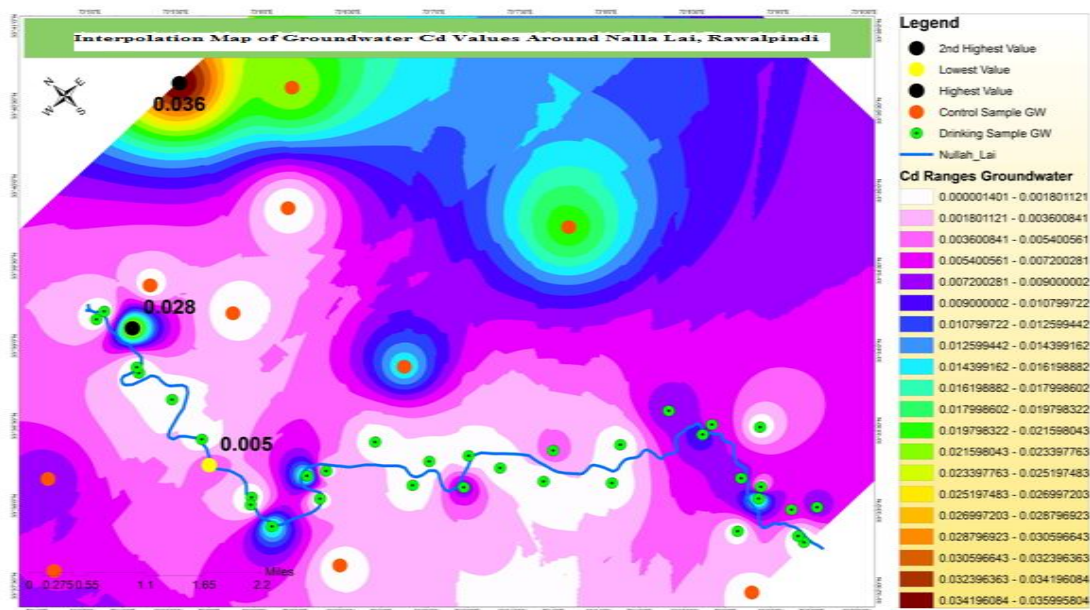


Figure 11 | Interpolation Map Showing Highest and Lowest Cd Location Points of Groundwater

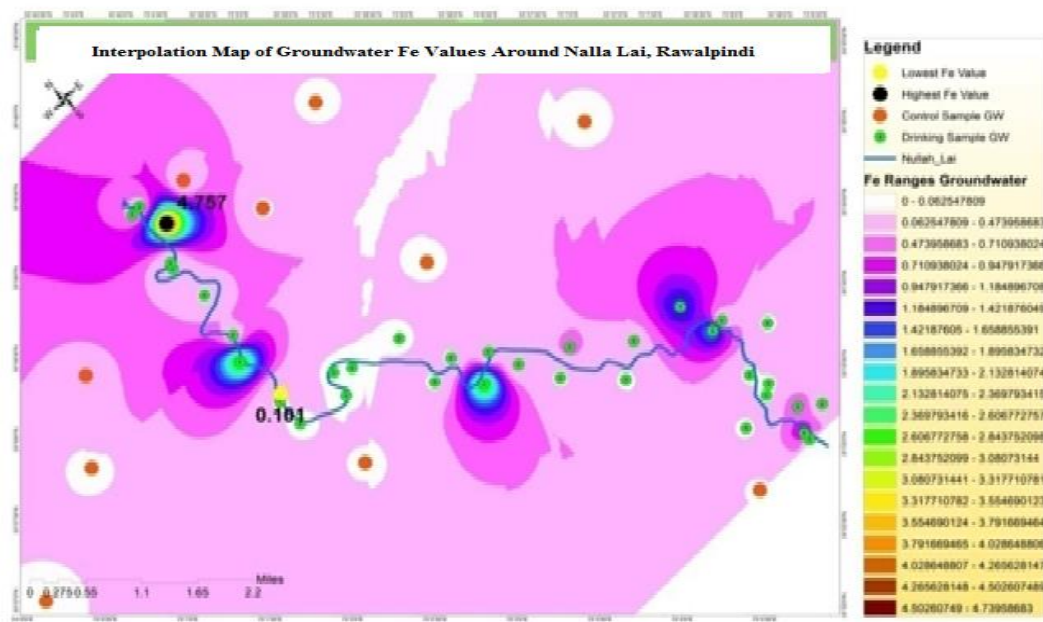


Figure 12 | Interpolation Map Showing Highest and Lowest Fe Location Points of Groundwater

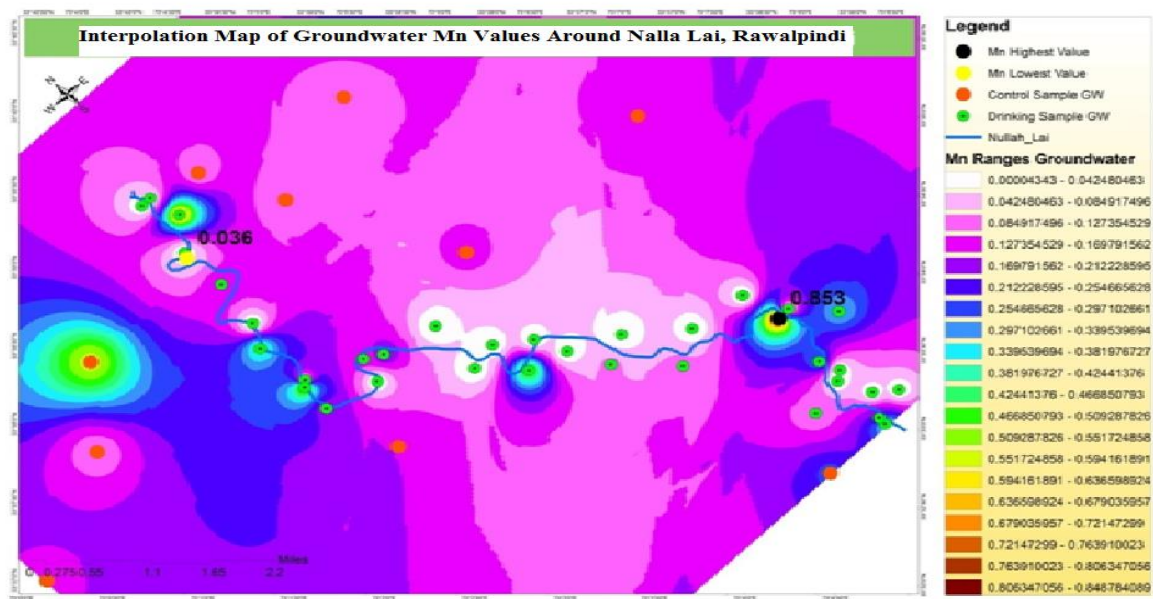


Figure 13 | Interpolation Map Showing Highest and Lowest Mn Location Points of Groundwater

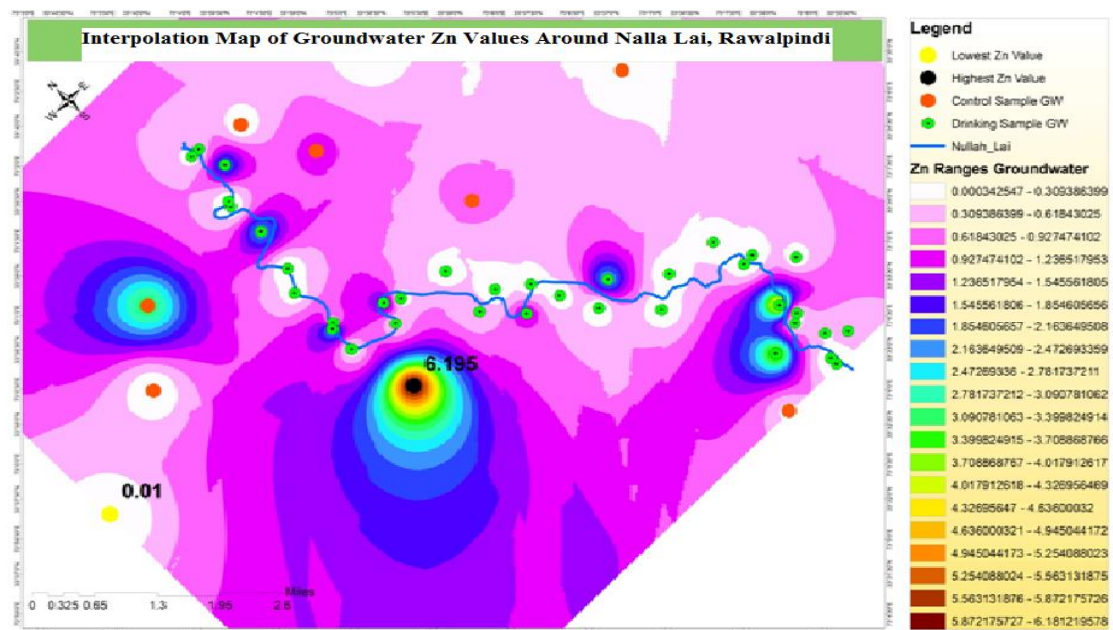


Figure 14 | Interpolation Map Showing Highest and Lowest Zn Location Points of Groundwater

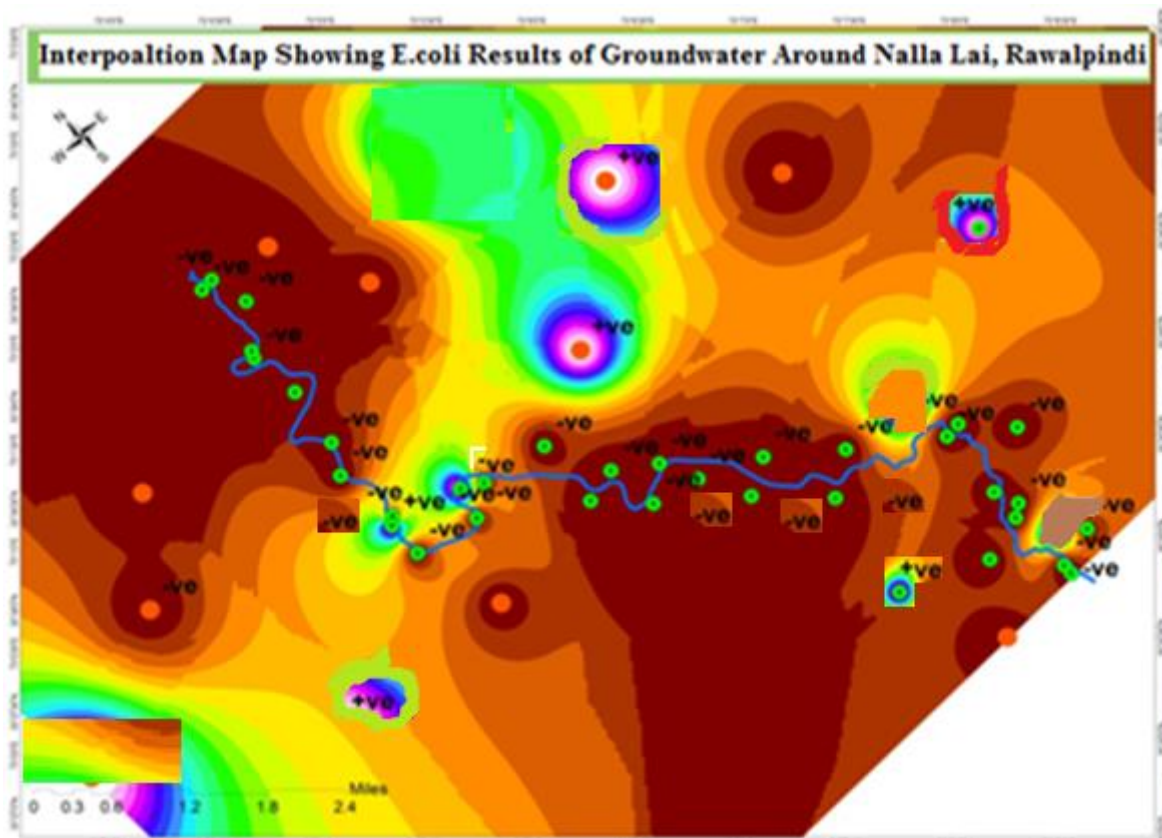


Figure 15 | Location Points of Positive (+ve) and Negative (-ve) Results of Fecal coliform (E.coli) in Groundwater

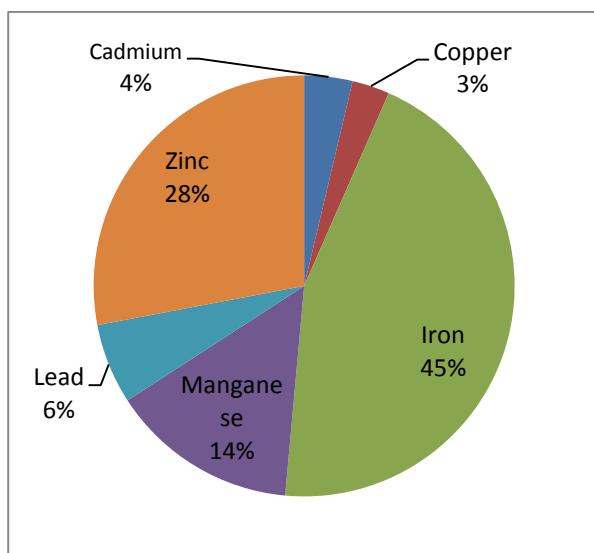


Figure 16 | Average percentage of heavy metals in wastewater samples.

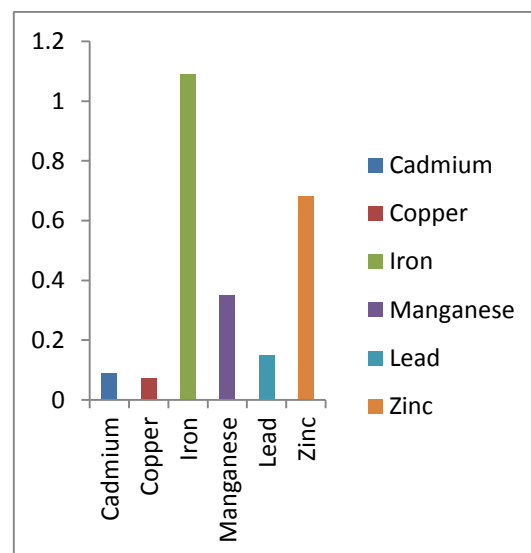


Figure 17 | Average concentration values of heavy metals in wastewater.

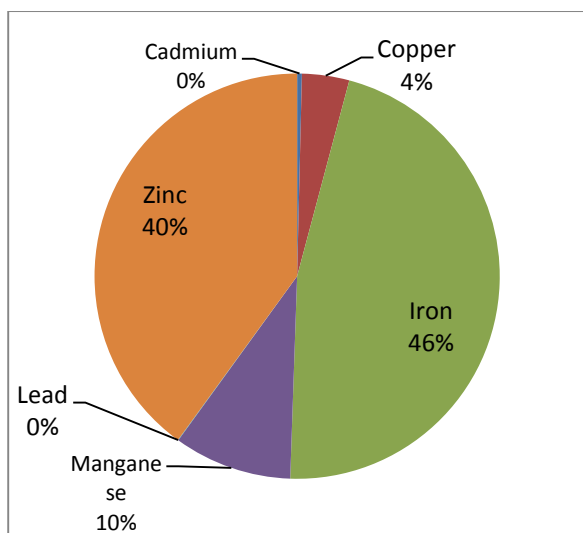


Figure 18 | Average percentage values of heavy metals in groundwater samples.

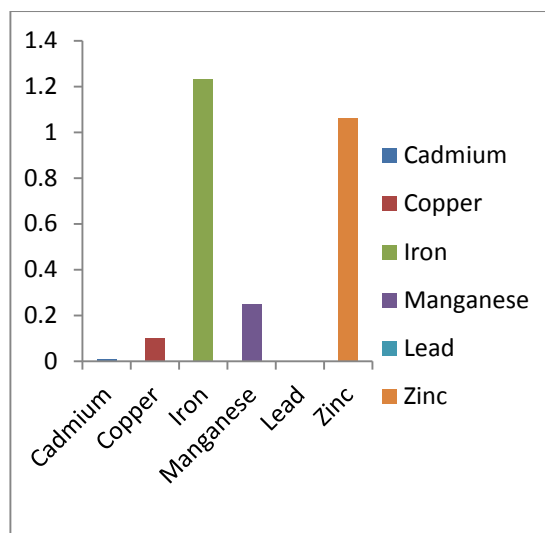


Figure 19 | Average concentration values of heavy metals in Groundwater samples.

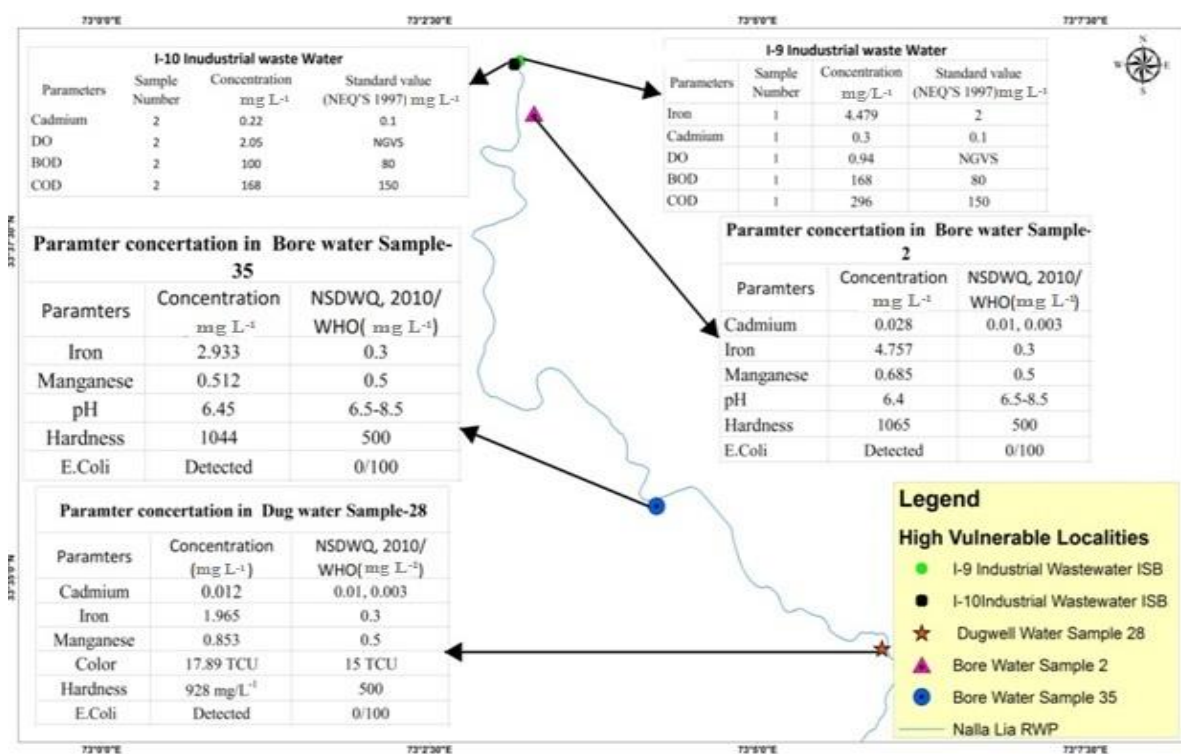


Figure 20 | High vulnerable Wastewater and Groundwater Sampling Localities of the Study Area.

Table 1 | Parameters with respective abbreviations Units, Holding time, Preservatives, and Analytical Methods

Parameters	Abbreviations	Units	Holding Time	Preservatives	Analytical Methods/ Instruments
Potential Hydrogen	pH	pH Unit	In Situ	None	pH Meter
Temperature	Temp	°C	In situ	None	Thermometer
Turbidity	TU	NTU	4 hours	None	Water Analyzer
Color	Col	TCU	4 hours	None	Water Analyzer
Dissolved Oxygen	DO	mg L ⁻¹	In situ	None	DO Meter
Electric Conductivity	EC	µ S/cm	In Situ	None	TDS Meter
Total Dissolved Solids	TDS	mg L ⁻¹	In situ	None	TDS Meter
Sulfate	0	mg L ⁻¹	4 days	4 °C	UV/Visible Spectrometer
Chloride	Cl-	mg L ⁻¹	4days	4 °C	APHA 2012, 22nd edition, part 4500 Cl-
Hardness	Ha	mg L ⁻¹	5days	4 °C	APHA 2012, 22nd edition, part 2340
Cadmium	Cd	mg L ⁻¹	30 days	HNO3, pH<2	(AAS) Model: A ANALYST 800
Copper	Cu	mg L ⁻¹	31 days	HNO3, pH<2	(AAS) Model: A ANALYST 800
Iron	Fe	mg L ⁻¹	32 days	HNO3, pH<2	(AAS) Model: A ANALYST 800
Manganese	Mn	mg L ⁻¹	33 days	HNO3, pH<2	(AAS) Model: A ANALYST 800
Lead	Pb	mg L ⁻¹	34 days	HNO3, pH<2	(AAS) Model: A ANALYST 800
Zinc	Zn	mg L ⁻¹	35 days	HNO3, pH<2	(AAS) Model: A ANALYST 800

Table 2 | Physico-chemical results of wastewater parameters of Nalla Lai. (n=19)

S. No	pH	Temp	Turbidity	DO	EC	SO ₄	Cl-	Cd	Cu	Fe	Mn	Pb	Zn	BOD	COD
1	7.44	22	4610.20	0.94	1271	21.9	60	0.3	0.204	4.479	1.483	0.012	1.046	168	296
2	7.66	26	2725	2.05	1277	22.76	55.6	0.22	BDL	1.212	0.15	0.182	2.046	130	168
3	7.43	27	3113	1.03	1365	21.70	55.6	0.016	BDL	3.134	0.176	BDL	0.066	112	243
4	7.71	28	3689	0.33	1396	24.2	54.18	BDL	0.161	0.392	0.161	BDL	0.076	121	276
5	7.48	26	1940.24	0.74	1529	23.3	46.62	BDL	0.012	BDL	0.189	0.021	2.214	97	229
6	7.67	27	3635.84	0.20	1492	22.22	57.28	BDL	0.016	BDL	0.161	BDL	0.048	194	315
7	8.55	26	3645.65	1.24	1510	23.12	55.06	BDL	BDL	0.149	0.49	BDL	0.061	161	311
8	7.78	28	3459.74	1.25	1232	23.6	57.4	0.12	BDL	BDL	0.251	BDL	0.071	168	312
9	7.75	29	2313.49	0.26	1342	23.05	49.4	BDL	BDL	0.186	0.215	BDL	0.063	121	291
10	7.91	29	2111.69	1.04	1349	25.9	46.62	0.159	0.013	0.125	0.315	BDL	0.057	100	175
11	8.21	28	2543	1.65	1367	27.6	47.06	0.095	BDL	0.121	0.188	BDL	0.213	96	222
12	7.79	29	3130	0.63	1272	22.9	46.62	0.007	BDL	0.315	0.212	0.268	4.201	100	219
13	7.69	29	3343.74	0.35	1395	25.02	61.4	0.02	BDL	BDL	0.312	BDL	0.059	96	228
14	7.78	28	2981.84	0.81	1390	24.3	7.6	0.006	0.091	BDL	0.612	BDL	0.129	95	196
15	8.12	29	3399	1.14	1397	26.3	61.72	0.015	BDL	0.357	0.215	0.008	0.059	100	168
16	7.69	28	4215.73	0.69	1327	24.52	66.16	BDL	0.013	2.173	0.61	BDL	0.12	91	221
17	7.62	27	3386	0.26	1430	24.23	75.06	0.143	BDL	1.635	0.219	BDL	0.204	149	272
18	7.92	28	4155	2.80	1372	25.34	79.6	0.012	BDL	0.822	0.237	BDL	2.213	98	176
19	7.95	30	3490	2.67	1474	30.10	72.4	0.015	BDL	0.118	0.521	BDL	0.064	87	170

Table 3 | Descriptive statistics of wastewater samples of the study area: n=19

Variables	Unit	Maximum	Minimum	Average
pH	pH Unit	8.55	7.43	7.8
Temp	°C	30	22	27.58
Turbidity	NTU	4610.20	1940.24	3257.27
DO	mg L ⁻¹	2.80	0.20	1.06
EC	µ S/cm	1529	1232	1378.26
SO4	mg L ⁻¹	30.10	21.70	24.32
Cl-	mg L ⁻¹	79.6	7.6	55.55
Cd	mg L ⁻¹	0.3	0.006	0.09
Cu	mg L ⁻¹	0.204	0.012	0.08
Fe	mg L ⁻¹	4.48	0.12	1.09
Mn	mg L ⁻¹	1.48	0.15	0.35
Pb	mg L ⁻¹	0.268	0.008	0.10
Zn	mg L ⁻¹	4.20	0.05	0.68
BOD	mg L ⁻¹	194	87	120.21
COD	mg L ⁻¹	315	168	240.15

Table 4 | Physicochemical and Microbial Results of Groundwater of Study Area. (n=49)

S.No	pH	Tem	TU	Color	DO	EC	TDS	SO ₄	Cl	Ha	Cd	Cu	Fe	Mn	Pb	Zn	E.coli
1	7.25	22	0	4.4	5.7	356	291	24.14	12.7	616	BDL	0.11	0.26	0.038	0.003	0.52	-ve
2	6.39	24	0	10.04	3.28	1121	958	36.7	13.3	1065	0.028	0.139	4.757	0.685	0.002	2.26	-ve
3	7.34	24	0	3.66	5.83	323	267	18.34	11.32	616	BDL	BDL	BDL	0.036	BDL	BDL	-ve
4	7.45	24	0	4.79	5.64	302	254	26.11	9.1	552	BDL	BDL	0.219	BDL	BDL	BDL	-ve
5	7.35	25	0	4.62	4.58	619	498	45	23.5	536	BDL	BDL	0.101	BDL	BDL	BDL	-ve
6	7.41	23	0	5.06	6.48	772	584	41.33	49.7	1121	BDL	BDL	BDL	BDL	BDL	0.18	-ve
7	7.59	21	0	4.39	8.4	405	319	37.18	21.1	596	BDL	BDL	BDL	BDL	0.004	0.131	-ve
8	7.23	22	0	4.72	5.8	407	322	46.24	19	656	BDL	BDL	BDL	BDL	BDL	BDL	-ve
9	7.65	21	0	4.11	5.87	433	293	21.4	13.1	372	BDL	BDL	BDL	BDL	BDL	0.096	-ve
10	7.29	25	0	5.7	6.2	540	449	29.1	14	568	0.005	BDL	0.529	BDL	BDL	2.476	-ve
11	7.47	21	0	7.73	5.36	289	229	18.9	8.21	332	BDL	BDL	0.345	BDL	BDL	BDL	-ve
12	8.19	24	0	5.86	6.68	1380	996	100.2	64.4	1528	0.009	BDL	1.512	BDL	BDL	0.089	+ve
13	7.22	22	0	10.24	6.19	1408	1138	59.64	107	1122	0.005	0.038	BDL	BDL	0.038	BDL	-ve
14	8.3	22	0	5.91	5.9	637	595	22.6	17.1	1076	BDL	BDL	BDL	0.344	BDL	0.093	-ve
15	6.41	27	0	4.84	3.85	1019	844	28	22.7	896	BDL	BDL	BDL	BDL	BDL	BDL	-ve
16	7.3	21	0	5.17	5.46	446	358	34	19.32	564	0.021	BDL	BDL	BDL	BDL	0.014	-ve
17	7.65	23	0	5.78	4.39	722	419	20.1	12.21	124	0.007	BDL	0.786	BDL	BDL	0.23	+ve
18	7.7	22	0	4.74	6.93	442	360	14.7	25.1	556	0.009	BDL	0.134	BDL	BDL	0.404	-ve
19	7.35	22	0	4.63	5.61	731	551	16.8	17.32	976	BDL	BDL	0.396	BDL	BDL	0.071	-ve
20	6.86	26	0	6.22	3.73	549	451	22.2	29.1	604	BDL	BDL	BDL	BDL	BDL	0.092	-ve
21	7.25	21	0	4.96	5.46	905	691	44.34	28.2	1144	BDL	BDL	BDL	0.162	BDL	2.413	-ve
22	6.59	25	0	5	4.45	783	609	15.7	10.9	776	0.005	BDL	2.914	0.412	BDL	0.121	-ve
23	7.35	22	0	5.39	6.33	549	439	24.45	20.43	656	0.018	BDL	BDL	0.189	0.04	0.09	-ve
24	7.41	23	0	4.5	5.25	794	581	30.41	37.53	1064	BDL	BDL	BDL	0.218	BDL	BDL	-ve
25	7.07	24	0	4.94	5.88	566	464	29.91	28	776	BDL	BDL	BDL	BDL	BDL	0.386	-ve
26	7.28	25	0	5.13	6.41	1173	885	37.84	74.61	1564	BDL	BDL	BDL	BDL	BDL	0.095	-ve
27	7.40	22	0	4.99	6.15	375	301	20.42	10.7	520	BDL	BDL	BDL	0.091	BDL	BDL	-ve
28	7.32	22	0	17.89	4.4	894	719	21.54	77.72	928	0.012	BDL	1.965	0.853	BDL	0.015	-ve
29	7.25	22	0	6.11	5.89	907	485	31.4	36.64	680	0.009	BDL	BDL	0.321	BDL	5.108	-ve
30	7.68	24	0	5.75	5.35	222	201	14.5	7.6	384	BDL	BDL	BDL	0.085	BDL	3.95	-ve
31	7.61	25	0	5.77	6.71	306	346	19.63	13.8	372	BDL	BDL	BDL	0.418	BDL	BDL	-ve
32	7.16	28	0	5.18	4.36	762	611	28.65	59.73	1132	BDL	BDL	1.249	0.195	BDL	BDL	-ve
33	7.48	23	0	6.16	5.63	593	482	17.9	34.64	724	0.019	BDL	BDL	0.131	BDL	1.821	-ve
34	7.53	22	0	6.4	5.16	494	325	33.17	12	720	BDL	BDL	BDL	0.629	BDL	2.981	+ve
35	6.45	26	0	7.45	4.09	868	691	38.31	34.2	1044	0.009	BDL	2.933	0.512	BDL	1.251	-ve
36	7.53	25	0	5.39	6.56	472	383	25.6	17.54	480	BDL	BDL	BDL	0.091	BDL	BDL	-ve
37	7.54	24	0	5.63	6.34	332	272	23.9	12.21	452	BDL	BDL	BDL	0.089	BDL	0.018	+ve
38	7.48	23	0	5.36	5.23	445	366	20.4	18.7	464	BDL	BDL	BDL	0.091	BDL	BDL	-ve
39	7.76	22	0	4.74	6.43	376	391	17.44	13.1	564	BDL	BDL	BDL	0.082	BDL	1.036	-ve
40	7.47	25	0	5.94	5.31	387	301	18.09	10	480	0.016	BDL	BDL	0.149	BDL	0.785	+ve
41	7.64	21	0	6.56	6.08	473	288	14.21	8.43	524	0.021	BDL	BDL	0.164	BDL	0.25	-ve
42	7.52	23	0	4.9	5.75	468	392	21.36	28	412	0.023	BDL	BDL	0.301	BDL	0.018	-ve
43	7.29	24	0	5.26	5.15	327	375	15.07	10.7	628	0.036	BDL	BDL	0.12	0.025	1.337	-ve
44	7.44	22	0	4.9	6.78	462	378	20.37	19.32	408	0.008	BDL	BDL	0.104	BDL	0.041	-ve
45	7.26	22	0	8.17	4.53	701	597	25.52	50	448	0.009	BDL	0.316	0.569	BDL	3.242	-ve
46	7.49	24	0	5.31	5.49	524	435	32.19	24.2	576	0.007	BDL	BDL	0.098	BDL	0.051	-ve
47	7.19	23	0	4.43	5.17	705	503	37.17	36.2	844	0.021	BDL	BDL	0.161	BDL	0.01	+ve
48	7.12	23	0	5.21	5.75	653	535	27.86	43.74	788	BDL	BDL	BDL	0.17	BDL	6.195	-ve
49	7.13	24	0	5.81	5.56	807	506	17.7	68.17	732	BDL	BDL	BDL	0.269	BDL	0.2	-ve

Table 5 | Descriptive Statistics of Groundwater Samples of Study Area: n=49

Variables	Unit	Maximum	Minimum	Average
pH	pH Unit	8.3	6.39	7.35
Temp	°C	28	21	23.27
TU	NTU	0	0	0
Color	TCU	17.89	3.66	5.83
DO	mg L ⁻¹	8.4	3.28	5.58
EC	μ S/cm	1408	222	616.83
TDS	mg L ⁻¹	1138	201	484.24
SO4	mg L ⁻¹	100.2	14.1	28.2
Cl ⁻	mg L ⁻¹	107	7.6	27.7
Ha	mg L ⁻¹	1564	124	709
Cd	mg L ⁻¹	0.036	0.005	0.01
Cu	mg L ⁻¹	0.139	0.038	0.09
Fe	mg L ⁻¹	4.76	0.101	1.23
Mn	mg L ⁻¹	0.85	0.04	0.25
Pb	mg L ⁻¹	0.04	0.002	0.02
Zn	mg L ⁻¹	6.2	0.01	1.06

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65