ASSESSING THE EFFECTS OF GROUNDWATER QUALITY ON HUMAN HEALTH USING GIS: A CASE STUDY OF BAHAWALNAGAR

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ABSTRACT: Water is a vital natural resource for human life. Water quality is a basic standpoint that needs to be deliberated while seeing sustainable development as well as health risks. The aim of this research is the analysis of drinking groundwater quality parameters of the Bahawalnagar District of Punjab, Pakistan, and the potential health risks associated. A total of 116 samples were obtained from three study regions from Bahawalnagar District namely Bahawalnagar city, Minchinabad, and Dounga Bounga town. Each sample was tested for a total of nine water quality parameters (pH, Turbidity, TDS, Calcium, Magnesium, Total Hardness, Total Alkalinity, Chloride, and Electrical Conductivity). The spatial interpolation approach named Inverse Distance Weighting through GIS is used to provide spatially dispersed groundwater quality mapping of the water quality index. This research shows that across the study area, the percentage of polluted groundwater samples varies spatially, as, in Dounga Bounga, Minchinabad, and Bahawalnagar city, a total of 96%, 63%, and 64% sample are polluted respectively. Laboratory analysis reveals that pH total dissolved solids, magnesium, calcium, total hardness are considerably higher than WHO-permissible standards. Such low quality of the water might exacerbate severe waterborne diseases in the region.

Keywords: Water quality parameters, WHO standards, Bahawalnagar, waterborne diseases

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INTRODUCTION

Safe drinking water, as well as sanitary facilities, are a global priority. A safe and hygienic water supply is not a privilege, but a must for healthy living and is considered an individual's right. (Hasnain *et al*., 2014). Any government should give the highest priority to all the provision of clean and safe drinking water.

Pakistan's population has risen exponentially and therefore the drinking water need has grown and thus the accessible water supplies have been overused. (WEB1). As groundwater quality varies from one area to another, and changes over time, it is considered essential to distinguish those complex changes and differences using the most proven management method. Standard mapping of groundwater quality within each region is required to identify the prospective recommendations for future waterborne diseases.

Groundwater pollution has become one of the world's most influential concerns (Khan and Jhariya, 2017). Unnecessary levels of physical, biological, and chemical contamination of drinkable water affect public health. (Meride and Ayenew, 2016). Waterborne disease is perhaps one of the most important causes of death for children throughout the world when every fifth inhabitant is affected by waterborne diseases. Polluted water is causing various illnesses, including diarrhea, gastroenteritis, dehydration, dysentery, renal diseases, and so on. (Khalil *et al*., 2005). The situation in Pakistan is not different. Approximately 70% of Pakistan's inhabitants are utilizing groundwater, particularly for drinking and household purposes. Unfortunately, for many regions around the world, including Pakistan, the drinking water quality including urban and rural areas is not adequately controlled or monitors. The results of several studies show that the much of drinking water supplies are tainted with physical contamination. (Naeem Khan *et al*., 2012)

The magnitude of enteric conditions depends on the quality. Hepatitis B, Enteric fever, Typhoid fever, and many other enteric infections are widespread and are transmitted through polluted water. Cholera is a common waterborne illness in several under-developed countries related to contaminated water (Soomro, M & Hussain, 2011).

Relatively underdeveloped regions of Punjab like Bahawalnagar District need special attention in this regard as these areas lack infrastructural as well as research frameworks to monitor drinking water quality. The primary aim of this research is to assess and document the quality of drinking water in the selected study regions of Bahawalnagar and related possible health hazards, which will be accomplished by achieving the following objectives:

1. To conduct detailed field surveys for water quality sampling and laboratory analyses of the samples.

2. Execute GIS-based analysis to conclude the spatial differences in groundwater quality and pinpoint zones with water quality problems.
3. Detect potential health threats linked through the water.

MATERIALS AND METHODS

Study Area: Bahawalnagar is an important city and district (administrative unit) within the southeast portion of Pakistan's Punjab province and lies between 30.5508° N, 73.3908° E (See Figure1). The focus of this research is on three selected regions of Bahawalnagar District which encompass a)- Bahawalnagar City
b) - Dunga Bounga Town
c) - Minchinabad city.

The first region, the city of Bahawalnagar, is the district headquarter with a population of 762,111 as per the 2017 census and has an area of 8,878km^2. The Bahawalnagar city is partitioned into 31 administrative divisions (locally known as Union Councils). The second region, the city of Minchinabad, is located within Bahawalnagar District and is a tehsil headquarter with a population of 526,428 and a total area of 1,818 km^2.

The third study region of this study is called Dounga Bounga, a town in Bahawalnagar District with an approximate population of 100000. The eastern and southern part of Bahawalnagar district borders India and the groundwater hydrology of the northwestern part is affected by the river Sutlej. The location of the study regions is shown in Figure 1.

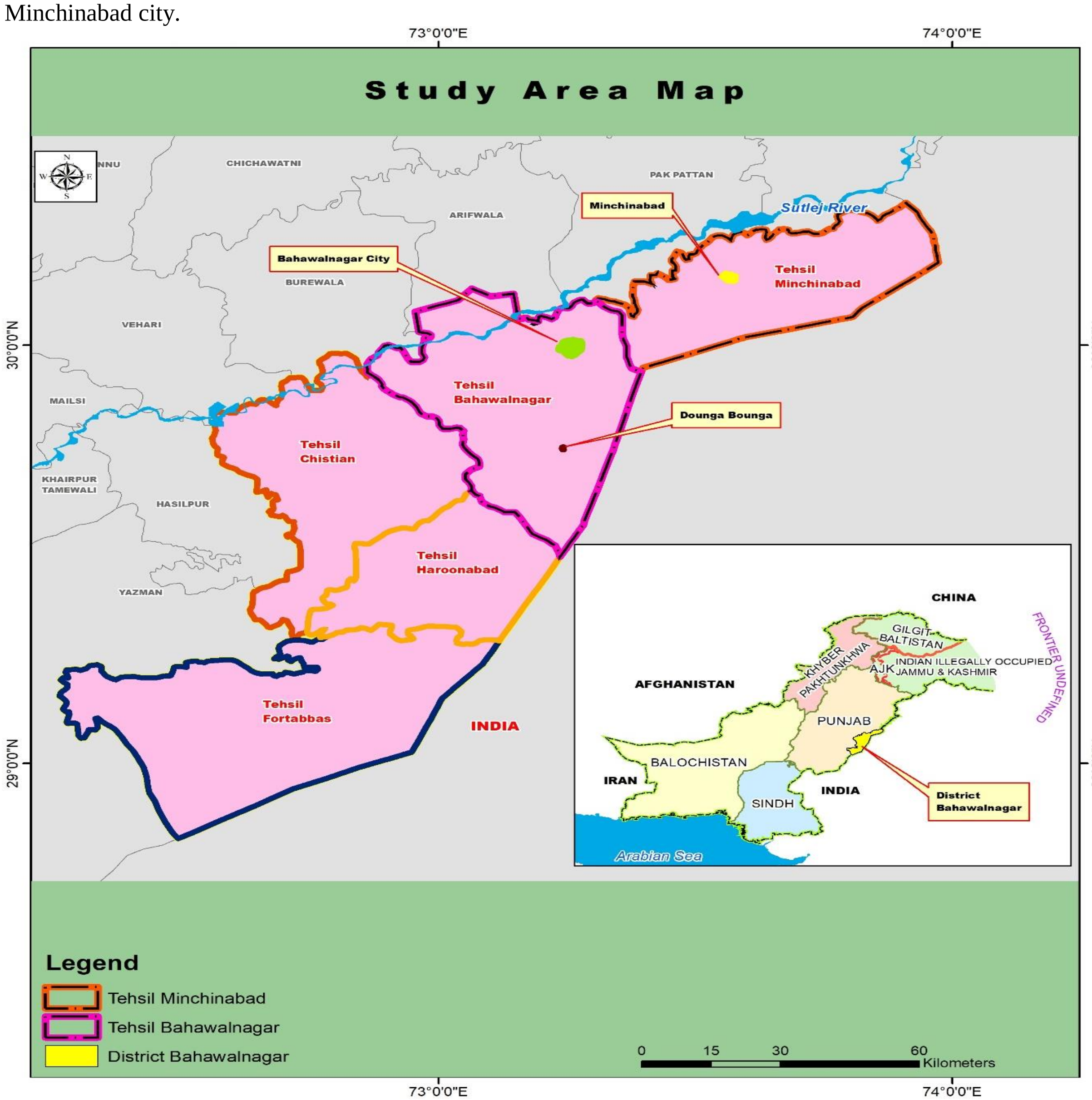

Figure 1: Location Map of Study Area

Data Acquisition and Methodology: As mentioned in the previous section**,** the current research focuses mostly on assessment of the water quality of Bahawalnagar; Minchinabad & Dounga Bounga, and this part of the study describe the rules for sampling during field surveys from two sources of drinking water i.e., the hand pumps & motor pumps. The *Simple Random Sampling* technique is used for water sampling. A total of 116 samples were collected using polyethylene terephthalate (PET) bottles from both drinking water sources. All PET bottles were rinsed thoroughly with the water before sampling. The bottles were appropriately packed, labeled correctly, and taken to the laboratory after sampling. To record the location of samples, GPS readings were also taken. The sampling visits were conducted in December 2019 in three phases. In the first phase of field visits, a total of 25 samples from Minchinabad have been collected. Similarly, from the Dounga Bounga site, 26 samples were collected during the second phase. Eventually, in the third phase, 65 samples were collected from the city of Bahawalnagar. The location of the sampling site is shown in Figure 2. Detailed information about the methodology is also presented in the flowchart given in Figure 3.

The samples were analyzed at the Public Health Engineering Research lab (PHED laboratory) of Bahawalnagar city for nine different water quality parameters (See Table 1).

Each water quality indicator is classified into three classes as following as per World Health Organization (WHO) standards,

Desirable Limit

Permissible Limit

Not Permissible Limit.

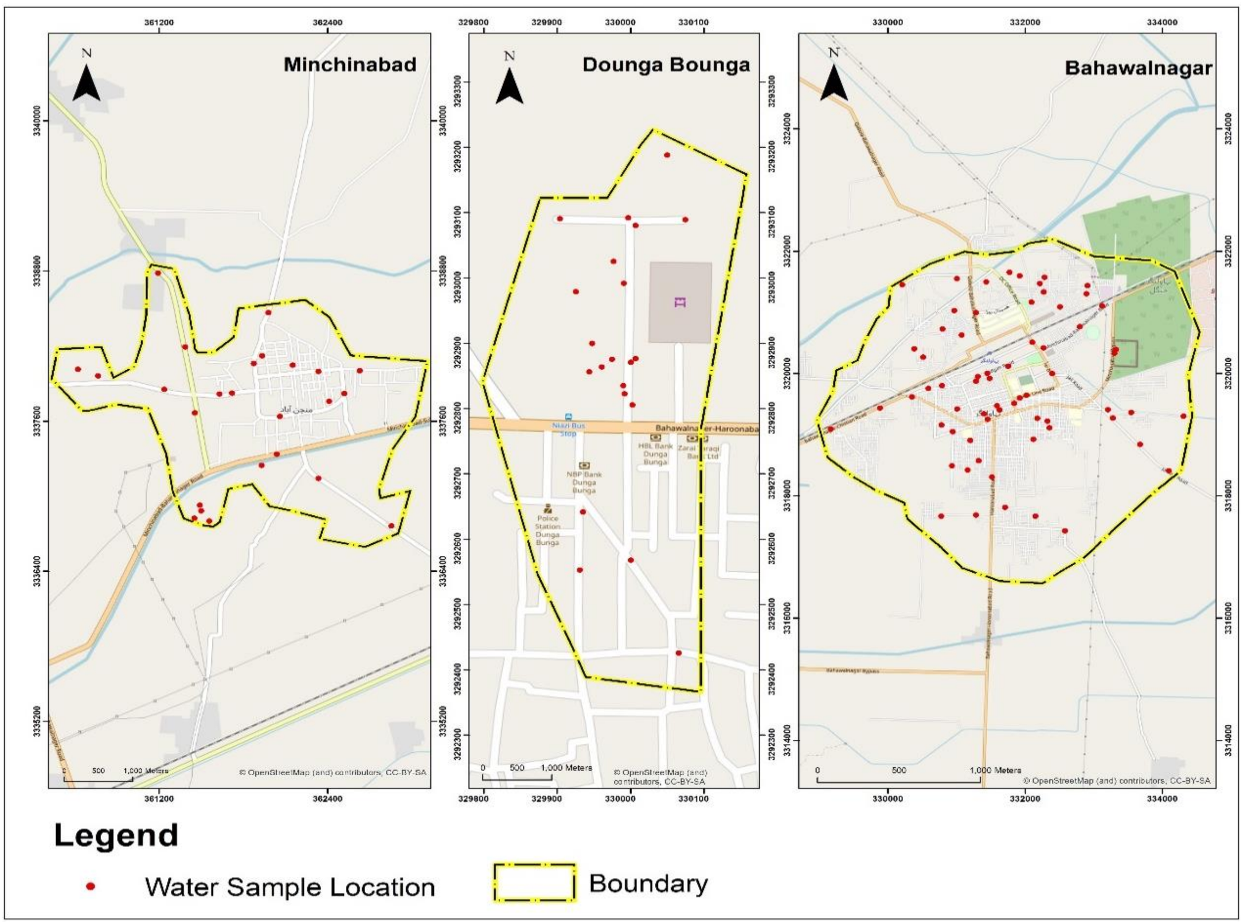

Figure 2: Map showing the spatial distribution of sampling location

The GIS is a valuable tool widely used for mapping water quality as well as spatially monitoring results (Krishnaraj *et al*., 2015). In this research, the Inverse Distance Weighting (IDW) technique is applied for the development of water quality spatial maps. These maps were prepared for each region separately for different water quality parameters. The IDW approximates values at unknown locations using the weighted average of the values available at the known locations. Hence, the value locations closest to the forecast have much more impact on the predicted value than that of the values further apart. The IDW is indeed a data interpolation spatial algorithm (WEB2). The IDW is a direct application of Tobler's First law. The geographer Waldo Tobler (1930) States that everything has been connected with something else, but closeness is more linked than distant objects.

To prepare these spatial interpolated maps, the *Geostatistical Analyst* toolbar of ArcMap software is used to reflect spatial fluctuations in groundwater quality to demonstrate the present description regarding groundwater quality throughout the region underneath coverage.

To analyze the status of waterborne diseases in the study region, data containing the number of patients infected by waterborne diseases in the study area is also obtained from the district health department for a period of 2014 to 2019.

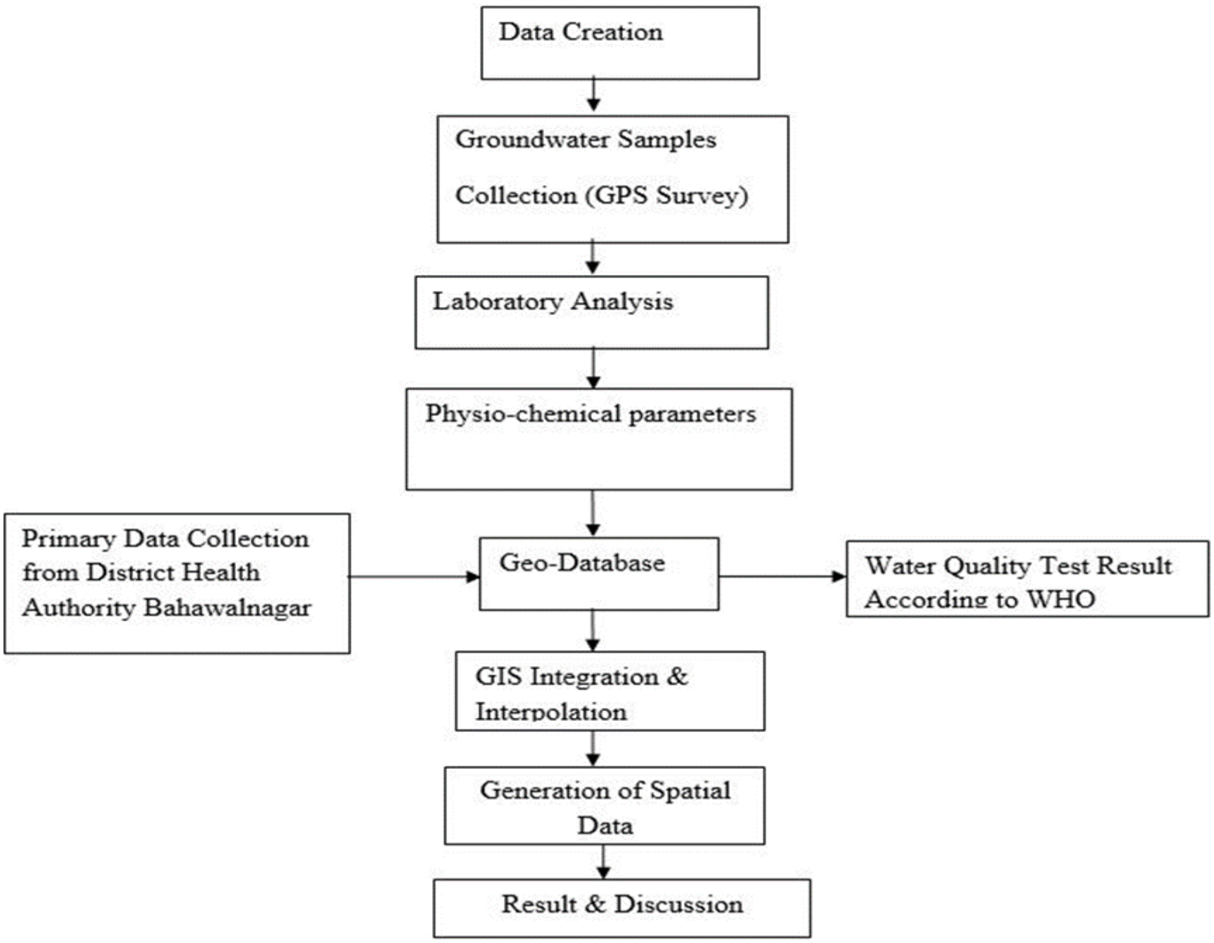

Figure 3: Methodological flowchart

RESULTS AND DISCUSSION

The inverse distance weighting (IDW) is used throughout the study to produce zone mapping of water quality parameters for the study area.

Weights of several water quality parameters (Table 1) are incorporated in the estimation of the *Water Quality Index* (WQI). The weights and ranks have been allocated to water quality parameters as suggested in the literature (Shirshendu & Harjeet, 2017).

In GIS, The Weighted Sum operates by multiplying the designated field values by the specified weight for each input raster. To create an output raster, it

Table 1: Showing Parameters, with their Weights in the Study Area.

Parameter	Weight
pH	0.20
Turbidity	0.05
TDS	0.30
Calcium	0.20
Magnesium	0.05
Total Hardness	0.05
Total Alkalinity	0.05
Chloride	0.05
Electrical Conductivity	0.05
Total	1

then sums (adds) together with all input rasters as shown in Table 1. To construct an integrated analysis, the Weighted Sum tool of ArcMap was used to generate a WQI map of each region.

Laboratory Test Results: Each container has separate IDs allocated, as well as the samples were being sent securely to the PHED laboratory on the very same day. The results of water quality parameters are presented here in tabulated forms as well as IDW based interpolated maps for each region separately. In the Bahawalnagar region, 65 samples were tested for different physicochemical parameters, and the minimum (Min), maximum (Max), mean, and standard deviation (S.D) of Bahawalnagar city are shown in Table 2.

Table 2: Physiochemical Parameters, their maximum, minimum, mean, and standard deviation values in the Bahawalnagar City.

Sr.no	Parameters	Units	Min	Max	Mean	S.D	WHO Permissible Levels
1	pH		6.98	7.87	7.4	0.1	6.5 - 9.2
2	Turbidity	N.T.U	0.02	1.12	0.6	0.1	5 Units
3	Total Dissolved Solids	mg/L	321	9790	5055.5	1052.1	1000
4	Calcium	mg/L	35	523	279.0	54.2	200
5	Magnesium	mg/L	10	469	239.5	51.0	150
6	Total Hardness	mg/L	147	3184	1665.5	337.4	500
7	Total Alkalinity	mg/L	141	664	402.5	58.1	500
8	Chloride	mg/L	51	886	468.5	92.8	250
9	Electrical Conductivity	Us/Cm	502	15296	7899.0	1643.8	1000

The Physiochemical parameters of drinking water in the Dounga Bounga study region are shown in Table 3 as results gathered from the PHED laboratory. It is obvious from the following water quality results that most water qualities vary from area to area. Electrical Conductivity and TDS results are outside the WHO permissible levels. Only a few sample results are considered safe for drinking purposes.

In the Minchinabad region, 25 samples are taken from different locations as per the availability of groundwater from hand pumps & motor pumps and the results are shown in Table 4, which shows that many samples are above the permissible limit as per WHO standards.

Water Quality Results of Bahawalnagar Region Using IDW: Laboratory experiments are done for electrical conductivity calculation, total dissolved solids, total hardness, pH, magnesium and calcium, turbidity, alkaline content, and then spatial maps are created using GIS. These maps for the Bahawalnagar study region are presented in Figure 4.

The pH is a critical variable in the evaluation of acid-base groundwater equilibrium. This shows that the water condition is alkaline or acidic. The overall pH range between 6.5 to 9.2 is recommended by the WHO. The measurements are found to be between 6.98 to 7.87 (Figure 4) throughout the Bahawalnagar district and the spatial variations are shown in Figure 4.

Almost 95% of the human body, calcium is found within teeth and bones. The excessive shortage of calcium will lead to weak blood clotting, weak and broken bones, etc. as well as an excessively high amount will cause coronary calcium problems. The range that is allowable for drinking water as per regard to the WHO (2011) specification ranges to 200 mg/L. In the Bahawalnagar city, the range of calcium values lies between 35mg/L to 523 mg/L.

Magnesium is an essential component of natural water. According to WHO standards, the allowed magnesium range should be 150mg/L. The obtained values vary from 10 mg/L around 469 mg/L throughout the Bahawalnagar area as shown in Figure 4.

The amounts of chloride should not exceed the WHO recommendations of 250 mg/L. The chloride concentrations were found to be in the range from 51mg/L to 886 mg/L throughout the area of Bahawalnagar and are clearly shown n Figure 4. The results show that many of the samples contain chloride above the WHO recommended limit.

The use of high salt water can induce the development of human kidney stones. In the Bahawalnagar district, TDS values of the sample were from 321 mg/L to 9790 mg/L and Total hardness values are found to be in the range of 147 mg/L and 3184 mg/L. According to these results, many locations have contaminated drinking water with higher levels of TDS and total hardness which is shown in red areas in Figure 4.

Turbidity could even contribute to gastrointestinal diseases and higher Turbidity in the water can indeed be harmful to human health. The turbidity in the Bahawalnagar city area is found to be between 0.02 N.T.U and 1.12 N.T.U. In the Bahawalnagar region turbidity values are within WHO allowed recommendations. Turbidity in drinking water can trigger cramps, nausea, and headaches. Overall, these maps show that in the Bahawalnagar city region, the water quality deterioration is mainly associated with a higher amount of magnesium, chloride, TDS, and total hardness (clearly observable red areas in respective maps of Figure 4).

Table 3: Physiochemical Parameters, their maximum, minimum, mean, and standard deviation values in the Dounga Bounga Region.

Sr.no	Parameters	Units	Min	Max	Mean	S.D	WHO Permissible Levels
1	pH		7.26	7.73	7.50	0.05	6.5 - 9.2
2	Turbidity	N.T.U	0.11	1.21	0.66	0.12	5 Units
3	Total Dissolved Solids	mg/L	892	4380	2636.00	387.56	1000
4	Calcium	mg/L	43	98	70.50	6.11	200
5	Magnesium	mg/L	38	170	104.00	14.67	150
6	Total Hardness	mg/L	301	928	614.50	69.67	500
7	Total Alkalinity	mg/L	241	464	352.50	24.78	500
8	Chloride	mg/L	129	329	229.00	22.22	250
9	Electrical Conductivity	Us/Cm	1394	6844	4119.00	605.56	1000

Table 4: Physiochemical Parameters, their maximum, minimum, mean, and standard deviation values in the Minchinabad Region.

Sr.no	Parameters	Units	Min	Max	Mean	S.D	WHO Permissible Levels
1	pH		6.92	7.58	7.25	0.07	6.5 - 9.2
2	Turbidity	N.T.U	0.02	1.01	0.52	0.11	5 Units
3	Total Dissolved Solids	mg/L	285	2280	1282.50	221.67	1000
4	Calcium	mg/L	19	565	292.00	60.67	200
5	Magnesium	mg/L	11	501	256.00	54.44	150
6	Total Hardness	mg/L	132	932	532.00	88.89	500
7	Total Alkalinity	mg/L	158	874	516.00	79.56	500
8	Chloride	mg/L	37	809	423.00	85.78	250
9	Electrical Conductivity	Us/Cm	237	3563	1900.00	369.56	1000

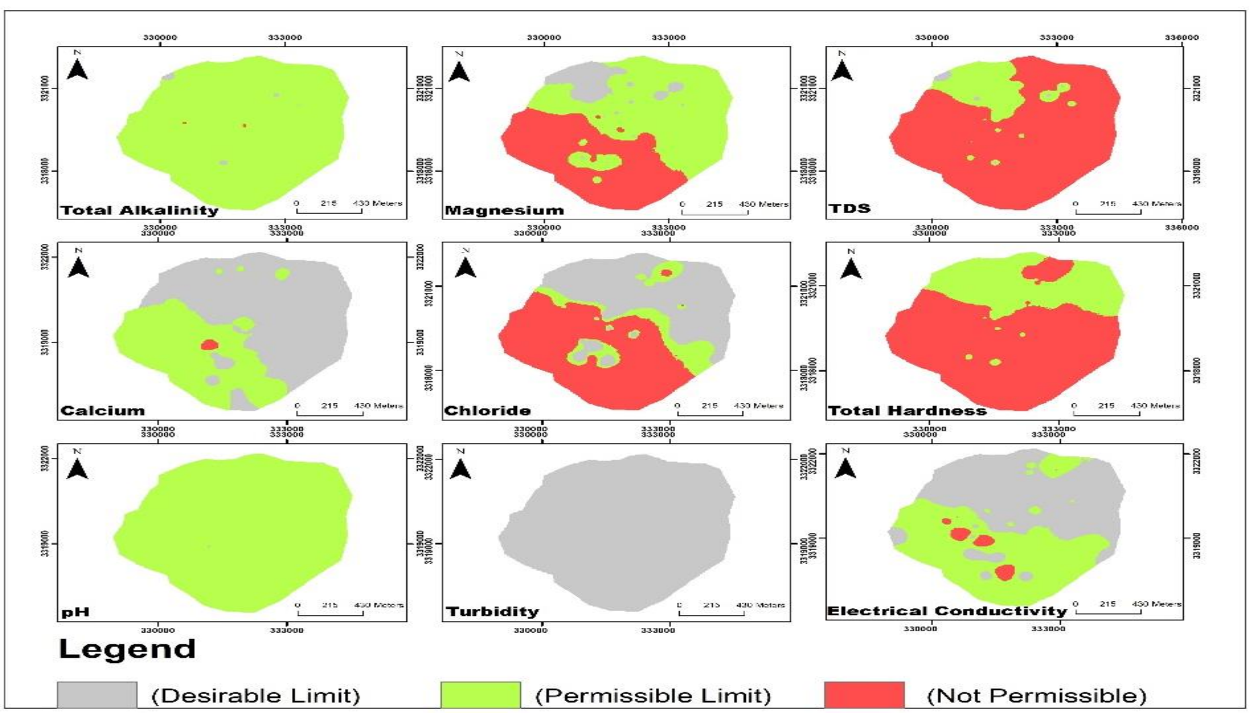

Figure 4: The Spatial Variability map of all parameters Bahawalnagar City Region

Water Quality Results of Minchinabad Region Using IDW: Water quality parameter maps are provided in Figure 5 for the Minchinabad study region. These maps show that pH values obtained are ranging from 6.92 to 7.58 throughout the Minchinabad Area as shown in Figure 5 which is within the WHO permissible limit.

The results of calcium amount in water samples of the Minchinabad region are found to be between 19 mg/L and 565 mg/L (Figure 5) suggesting that many locations exceeded the calcium limit of 200 mg/L. The allowed water magnesium standard should be 150 mg/L, which might induce laxation and disturbances to the stomach. The values of magnesium were found to be between 11 mg/L and 501 mg/L throughout the Minchinabad area. Many of the samples were above the permissible limit.

When ingested in excessive quantities, chloride might complicate cardiac complications and lead to increased blood pressure. Chloride levels should not surpass 250 mg/L following WHO standards. However, the measured values of chloride in this study region are between 37 mg/L and 809 mg/L with most of the samples above the WHO limits as can be seen from red-colored areas in Figure 5.

The total hardness results for the Minchinabad area are between 132 mg/L and 932 mg/L while as per WHO standards, these values should not exceed 500 mg/L, thus making most of the sample unfit for drinking purposes as shown by red areas in Figure 5. Similarly, the total alkalinity is found to be between 158mg/L to 874 mg/L suggesting that many samples are clearly above the WHO standards of 500 mg/L. Overall, these maps show that in the Minchinabad city region, the water quality deterioration is mainly associated with higher values of electrical conductivity, chloride, TDS, and total hardness (clearly observable red areas in respective maps of Figure 5).

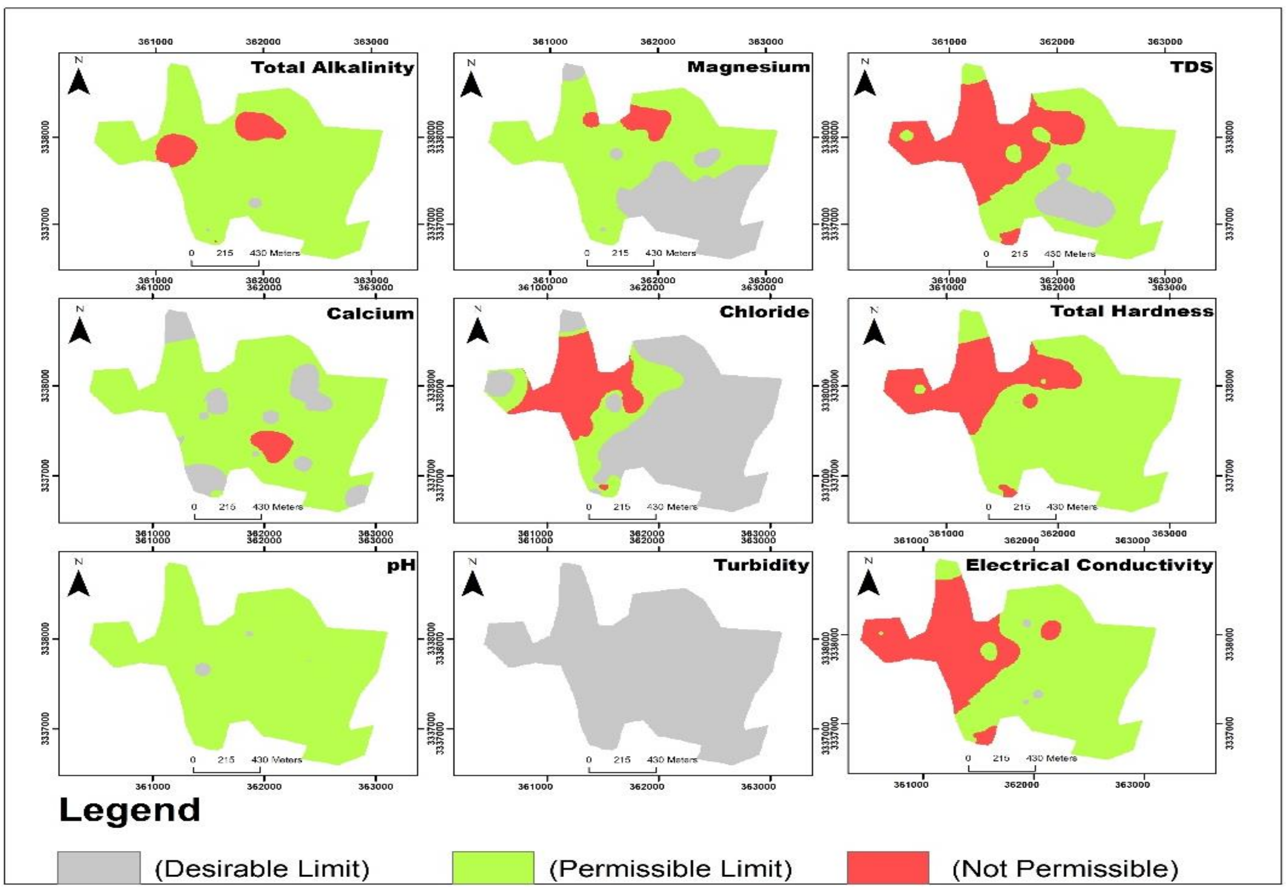

Figure 5: The Spatial Variability map of all parameters Minchinabad Region

Water Quality Results of Dounga Bounga Region Using IDW: Figure 6 presents the water quality results of the Dounga Bounga region. As long as pH is concerned, the majority of the sample lies within a permissible limit. In the Dounga Bounga region results of pH lie in the range 7.26 to 7.73 as shown in Figure 6 as well as Table 3.

The WHO approved magnesium level is 150 mg/ L in drinking water in which magnesium exists at higher concentrations (~250 mg / l each) can have a laxative cause & causes stomach disorders. In the Dounga Bounga region results of magnesium lie in the range of 38 mg/L to 170 mg/L. The majority of the sample lies in the permissible limit & not the permissible limit. That is an alarming situation and appropriate actions should be taken for the sake of a citizen who is drinking this unhealthy water.

Groundwater contains higher amounts of chloride. When ingested in excessive quantities, chloride could even exacerbate cardiac complications and result in increased blood pressure. Chloride should not cross 250 mg/L as mentioned in WHO recommendations. Chloride findings fall within the range of 129 mg/L to 329 mg/L in the study region of the Dounga Bounga with many samples lying clearly above the WHO recommended limits and making the groundwater unfit for drinking purposes.

The constant overuse of higher TDS liquid increasing contributes to stones there in the kidney which might trigger a severe health issue. TDS findings in the Dounga Bounga region are between 892 mg/L to 4380 mg/L which makes most of the water samples unfit for drinking purposes.

Gastrointestinal disorders may be caused by turbidity however, the measured values of most of the samples are found to be at the desired limit. The effects of turbidity in the Dounga Bounga zone were 0.11 N.T.U to 1.21 N.T.U.

Total Hardness values were found to be between 301 mg/L to 928 mg/L and a vast majority (approximately 96%) of samples were well above the WHO recommended limit of 500 mg/L. Overall, these maps show that in the Dounga Bounga study region, the poor water quality is mainly because of a higher amount of, TDS, and total hardness(clearly observable red areas in respective maps of Figure 6) with some locations, where the amount of chloride, electrical conductivity, and total hardness was also above WHO recommended limits.

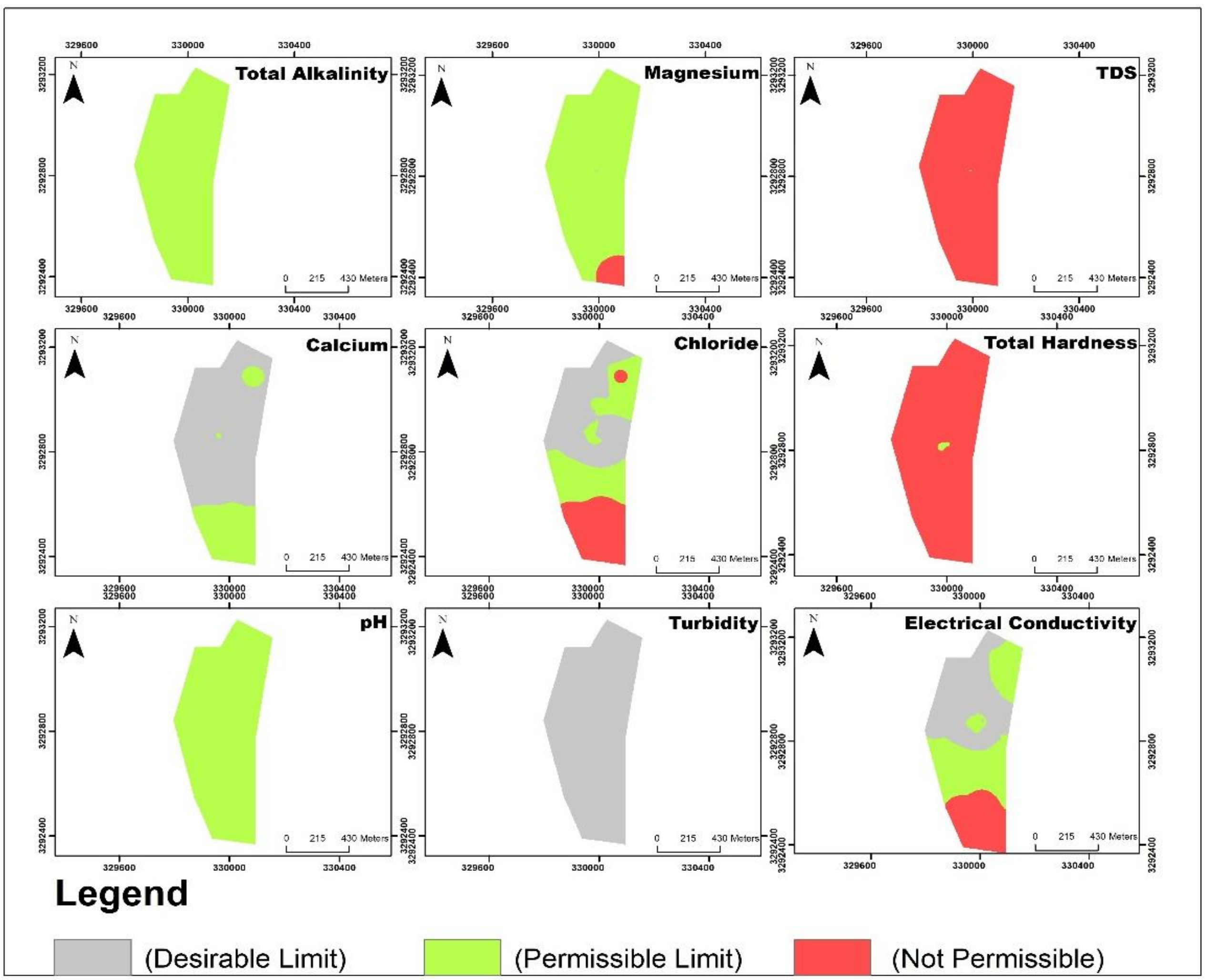

Figure 6: The Spatial Variability map of all parameters Dounga Bounga Region

Water Quality Index of Study Regions: So far, the results of water quality parameters are presented individually for each parameter. However, each parameter has a different level of criticality hence a variable effect on human health in the form of waterborne diseases. The purpose of the water quality index is to establish more comprehensive guidelines about the status of water quality of the study area by incorporating different water quality parameters based on the assigned weights. The water quality indices for each study region are presented in terms of interpolated maps in Figure 7. These maps show that there are many locations in the study regions, particularly in the Minchanabad region, where water quality is extremely unfit for drinking purposes. The people of these regions are extremely exposed to different contaminants and hence might face severe waterborne diseases. Although, individual parameters, suggests that in most of the areas of study regions, groundwater is contaminated, however, the regions with impermissible water quality index values need a quick and adequate response from the authorities to keep the population safe from the waterborne disease.

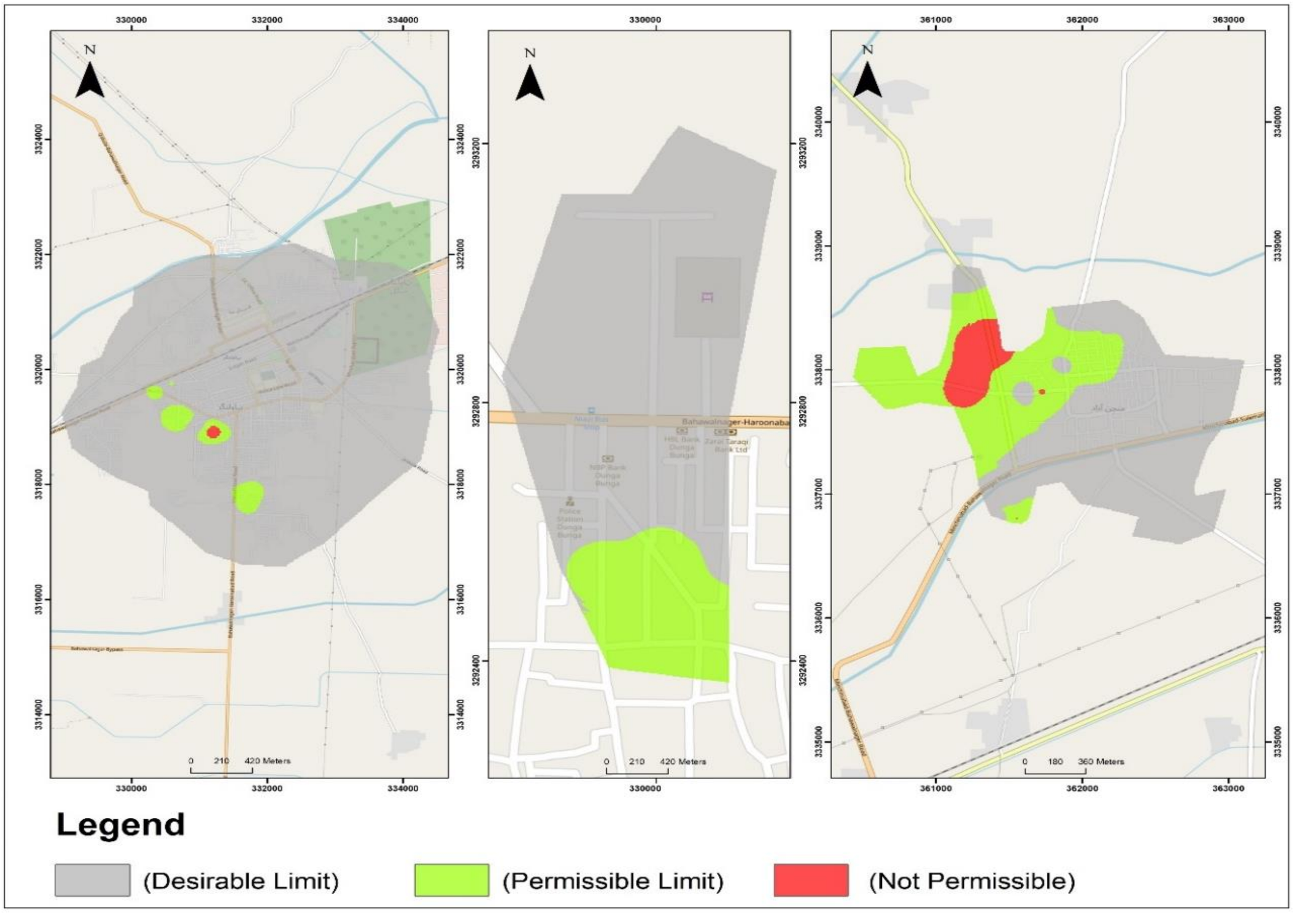

Figure 7: The WQI map of all regions

Analysis Result of Waterborne Diseases Data: Unfortunately, due to contaminated drinking water, the prevalence of waterborne diseases would be too great. The percentage of losses, therefore, affects children, in specific. It has been estimated that almost 230,000 babies in Pakistan (just under 5 years) expired with waterborne diseases in 2012 (Mohsin *et al* 2013).

The main statistics from the waterborne disease data obtained from District Health Department indicate that year after year, the number of patients at the major hospitals of the study area is increasing. Figure 8, for instance, shows a surge in the number of patients afflicted with worm infestations has already been rising since 2014. In 2018, it surpassed the highest number when more than 50 000 were registered.

Figure 8 also shows that there is steady growth in typhoid fever between 2014 and 2019. The percentage of patients with diarrhea/dysentery throughout the two age groups also has similar patterns from 2014 to 2019.

Taking into consideration the indications of poor water quality in the study region with the increasing number of patients with waterborne diseases, it becomes more clearer that these numbers are directly attributable to the deteriorating quality of the drinking water sources, which is mainly groundwater.

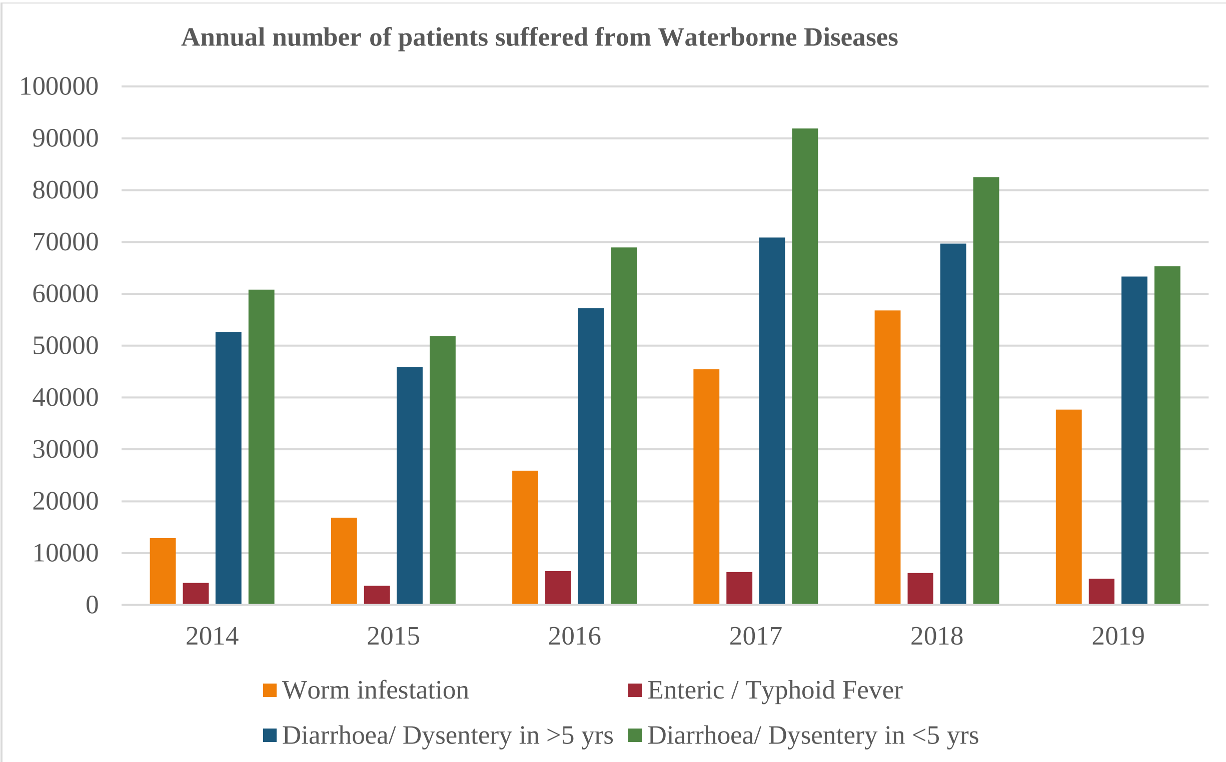

Figure 8: The annual number of patients suffered from Worm infestation disease during the years 2014-19

Conclusions: Based on the results and discussion from this study, the following conclusions are drawn.

1. The percentage of contaminated samples varies among regions. Around 63%, 96%, and 64% of groundwater samples were contaminated from Minchinabad, Dounga Bounga, and Bahawalnagar city respectively as suggested by at least one water quality parameter.
2. The large numbers of waterborne disease patients throughout the area are related to the low quality of water throughout the area and are expected to increase if this issue is not adequately dealt with.

Recommendations: Through this study, it is shown that advanced techniques like GIS can be really helpful in understanding spatial patterns in water quality. Such studies should be extended for the whole district of Bahawalnagar.

There are indeed regulatory frameworks in Pakistan like that of the Pakistan Environmental Protection Act of 1997 as well as the National Drinking Water Legislation of 2009. However, there is no clear implementation strategy throughout the neighborhood of the study area. Such legislation should be enforced for proper monitoring of water quality and the availability of safe drinking water to the residents.

Considering the deteriorating water quality of the study area and the increasing numbers of waterborne diseases, water filtration facilities must be provided at appropriate locations with adequate capacities.

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