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Assessment of Groundwater Quality in Tehsil Jhang and its Impact on Human Health Using GIS Based Techniques

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Abstract. Groundwater is a vital natural resource for drinking in the world. People in the rural areas of Pakistan are using groundwater for drinking without any test and assessment of its quality. The present study focuses on spatial distributions of groundwater quality and its impact on human health in the rural area of Tehsil Jhang. Geographic Information System (GIS) techniques, considered a more reliable and authentic approach which have been adopted to assess the quality of water and the damage caused by contaminated water to people's health in this study. Sample points for groundwater were collected from 24 tube wells which are well spatially distributed in the study area. Subsequently, health data comprising of the patient's information from the same sampled location who had suffered from the water born diseases was also acquired. These water samples were analyzed against the selected total four physio-chemical parameters *i.e*. total dissolved solids, arsenic, fluoride and nitrate. Groundwater quality maps were prepared using the spatial interpolation technique of Inverse Distance Weighted (IDW) for each of the parameters and classified according to the WHO standards. Some samples from the field were selected for validation of the results by PCRWR. The data of PCRWR's closely matches the acquired data from the field. Results reveal that 67% of total samples were contaminated by arsenic and 50% nitrate and 30% fluoride samples also showed high values than the WHO standards. Results depict that the majority of the population in the study area is consuming contaminated water which causes a severe threat to health (stomach ulcer, kidney and lungs cancers, teeth problems, weakened immune system). This study concludes that the groundwater quality of the study area needs higher attention to treat the contaminated water on an immediate basis. This study shows the significance of geospatial techniques for mapping of groundwater quality on large scale and its spatial correlation with water-born disease. Furthermore, this study will be quite helpful for Government to take precautionary measures for diseases.

Keywords: GIS, geospatial, physio-chemical parameters, interpolation (IDW), PCRWR

Introduction

Water is an important component of eco-system which supports life on earth. Although, it covers 70% of total earth crust but >3% of this is available as freshwater. The extent of freshwater accessible to mankind is only 0.01% and remaining portion is in the form of glaciers and ice (Ahmad *et al*., 2015). As the population is increasing worldwide which resulted in increased demand of freshwater not only for household purposes but also for industrial and agricultural activities (Gilani *et al*., 2013). Surface water has decreased at present level due to effects of climate change and it is more easily contaminated by pollutants. However, mankind started intensive utilization of groundwater resources to meet the water demands. Therefore, groundwater is considered an imperative part of fresh water resources which plays vital role in meeting the water needs of users in various sectors worldwide. Accessible clean water which depends on water quality can guarantee a healthy life. Moreover, optimal and sustainable utilization of water resources necessarily requires assessment of water quality (Singha *et al*., 2015). Naturally, groundwater is assumed to contain less numbers of pollutants but it may vary from area to area (Gajendran *el al*., 2013). In general, groundwater quality depends on presence and absorption of various chemical constituents which are affected by replenish and geological quality of particular aquifer (Parameswari *et al*., 2018). It has

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been reported that erosion and weathering of rocks are among the important natural processes which deteriorate groundwater quality to some extent. But, anthropogenic activities such as land use change, discharge of industrial wastewater and agricultural practices including excessive use of chemical fertilizers and pesticides significantly deteriorated the groundwater quality (Rehman *et al*., 2019; Wuana and Okieimen, 2011; Soomro *et al*., 2011).

During the last two decades, industrial revolution and population outburst have significantly altered the physico-chemical and biological characteristics of groundwater. Moreover, literature suggested that anthropogenic activities dominantly contributing in deterioration of groundwater quality which resulted in groundwater contamination. Therefore, scientists from all over the world are concerned with the groundwater contamination because of widespread water-borne diseases associated with groundwater quality (WHO, 2010; Clasen *et al*., 2007). Several researchers reported that according to the report published by World Health Organization (WHO), four-by-fifth of diseases in human beings are caused by poor quality of drinking water all over the world (Adimalla, 2020; Wegahita *et al*., 2020; Amalraj and Pius, 2013). In this regard, several researchers over the globe assessed the groundwater quality and its associated health risks all over the globe (Azhar *et al*., 2021; Varol *et al*., 2021; Zhang *et al*., 2018; Sener *et al*., 2017; Singha *et al*., 2015). It has been reported that developing countries are facing severe problems of groundwater contamination due to the presence of variable amount of toxic pollutants such as synthetic chemicals, pathogenic organisms and suspended solids etc (Amin *et al*., 2012).

Traditional methods for assessment of groundwater quality involve intensive sampling followed by laboratory analysis and comparison of results with recommended guidelines. As a matter of fact, variation in groundwater quality of an area is due to differences in physico-chemical parameters which are primarily influenced by geological processes and anthropogenic activities (Subramani *et al*., 2005). Therefore, assessment and monitoring of spatial variability of groundwater quality is a matter of great concern not only for sustainable use of groundwater in various sectors but also for better management of groundwater with poor quality to avoid associated health risks. In this scenario, geographical information system (GIS) provide effective and promising tool for monitoring and assessment of spatial variability of groundwater quality by integration of laboratory analysis with geographic information and subsequent modeling of groundwater quality parameters with greater accuracy (Balathandayutham *et al*., 2015). Several researchers have explored the potential of GIS for assessment and monitoring of groundwater quality and its integration with spatial data (Satyajit *et al*., 2020; Megahed and Farrag, 2019; Tarawneh *et al*., 2019; Paul *et al*., 2019; Hamed *et al*., 2018; Abotalib and Heggy, 2018; Hussien *et al*., 2017; Mohamed *et al*., 2015).

Pakistan is a developing country and facing serious problems in terms of water quality because surface water as well as groundwater in country have been contaminated with various toxic compounds and pathogenic microorganisms (Azizullah *et al*., 2011). Although, various water treatment plants are installed in urban areas but most of them are not properly working. According to a survey conducted by the government, only 56% of population in Pakistan has accessibility to clean water and 44% of total population is deprived off the clean drinking water (Farooq *et al*., 2008). Another study reported that almost 70% of total population in Pakistan has no access to clean water even for drinking purposes (Amin *et al*., 2012). In another study, water quality of 12 major districts of Punjab province was monitored and found that arsenic and pathogenic microorganisms were dominant in all the areas. Almost 45% of total water samples in Kasur were found positive for microbial contamination. Moreover, it was noticed that all the water samples collected from Kasur and Lahore exhibited contamination of water resources with arsenic. Furthermore, total dissolved solids were also higher than the permissible limits in water samples collected from Sheikhupura, Faisalabad, Sargodha, Rawalpindi and Kasur (Soomro *et al*., 2011). Similarly, Shakoor *et al*. (2015) carried out physico-chemical analysis of groundwater samples collected from various rural areas of Punjab. Results revealed that water quality was unfit to be used for drinking purposes due to higher contents of toxic metals compared to the permissible limits (Cl, NO_3, SO_4, Fe, Mn and Pb). Although several studies indicted the assessment of water quality of different areas in Pakistan but there is lack of knowledge on use of remote sensing and GIS techniques for assessment and monitoring of water quality and its associated health risks. So there is dire need to develop novel strategies for monitoring and assessment of water quality not only to restrict the contamination of water resources but also to make sure the availability of clean drinking water to the people of country. In this regard, present study was conducted for assessment of groundwater quality of Tehsil Jhang and its associated health risks using GIS based techniques.

The objectives of study were:

- To assess the spatial distribution pattern of groundwater contamination in study area using geospatial techniques.
- Impact assessment of groundwater contaminants on human's being health by establishing the spatial correlation between them.

Study area. District Jhang is situated in central Punjab which lies between the 30.37-31.59 degree north latitudes and 71.37-73.13 degree east longitudes with total area of 6612 km^2. District Jhang shares its boundary with Faisalabad and Toba Tek Singh in east, with Chiniot in the north east side and in the south it connects with Khanewal. However, the true north side of district Jhang coincide with Khushab and Bhakkar and in the south it connects with Layyah. Thal desert is located in south which starts from the north and ends in the south (Fig. 1). Maximum area of this district is plain area and rich with river soil which is highly suitable for cultivation. This area has diversified cropping pattern and maximum types of crops are cultivated in the district Jhang. The present study was carried out in the rural areas of the Tehsil Jhang. All sample sites have been selected from the rural settlements of the study area.

Materials and Method

The present study was conducted to assess the water quality and its impacts on human health using GIS tools in Tehsil Jhang, Punjab, Pakistan. The data required for this study comprised of field survey and water sampling on spot water testing, PCRWR lab testing, disease data calculation and GIS based vector data sets of study area. The field data and secondary data were processed and analyzed using various software including Arc GIS 10.2, Global Mapper, Google earth, Microsoft Excel and Microsoft Word. The flow chart of methodology used in this study has been given in Fig. 2.

Data acquisition. During survey, the data was collected from fields by physical visit and on spot analysis for different chemical parameters were carried out in this study to test tube well source from the equally distributed villages located in the Tehsil Jhang. These parameters include odour, colour, taste, TDS, arsenic, fluoride and

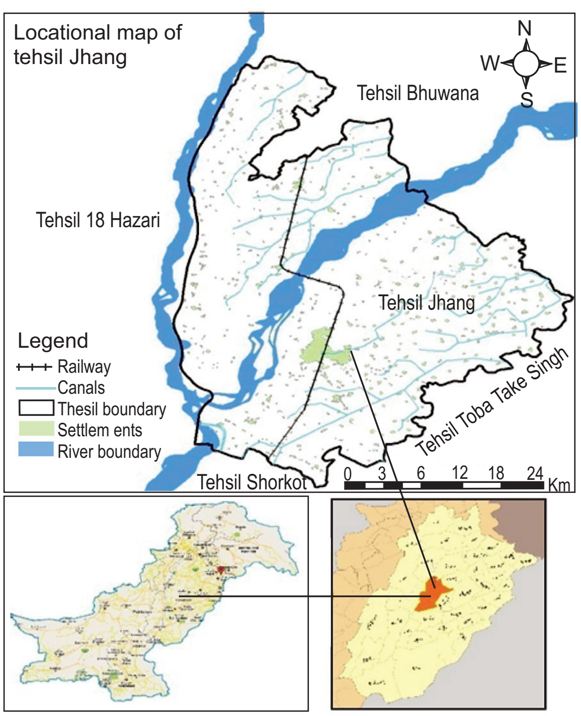

Fig. 1. Study area map.

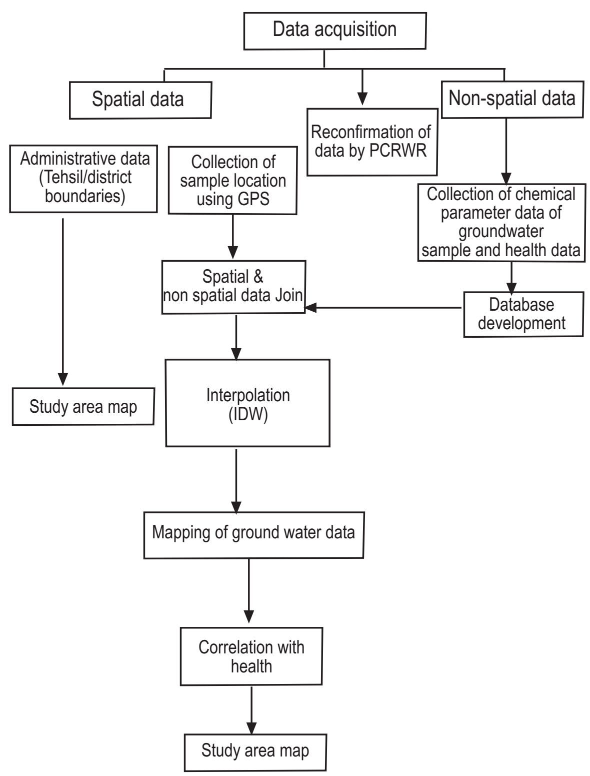

Fig. 2. Study flow chart.

nitrate contents. All the collected water samples were analyzed according to WHO Guidelines. Moreover, results were compared with threshold standards as per WHO Guidelines. After that, six samples were selected and used for confirmation of field data through lab test by PCRWR. Total 24 different locations which were equally distributed in the tehsil Jhang were choosen for testing groundwater in the villages area. The collected water samples were analyzed for above mentioned parameters and results were compared with recommended permisible limit of each parameter. Public health data was also collected from the same points selected for water samples. However, the location of different points from where data was collected has been given in Fig. 3.

On spot water testing. In this study, water samples were collected during the field survey from selected tube wells which were equally distributed in tehsil Jhang. On spot water testing of these collected water samples was performed to determine the groundwater quality. In this study, portable TDS meter was used to determine the total dissolved solids (TDS), however, arsenic, fluoride and nitrate contents were determined by using respective test kits as shown in Fig. 4. Moreover, the collected water samples were transferred to PCRWR laboratory for assessment of above-mentioned parameters to verify the field data.

Health data acquisition. The primary focus of this study was to determine the correlation of water quality parameters with human's health. Therefore, public data health acquisition was much important to determine this correlation followed by verification with survey data. Moreover, it was necessary to collect the public health data from same or nearby field survey points. Initially, health data was collected from basic health units (BHUs) and Rural Health Centers (RHCs) and then correlation with survey data was determined.

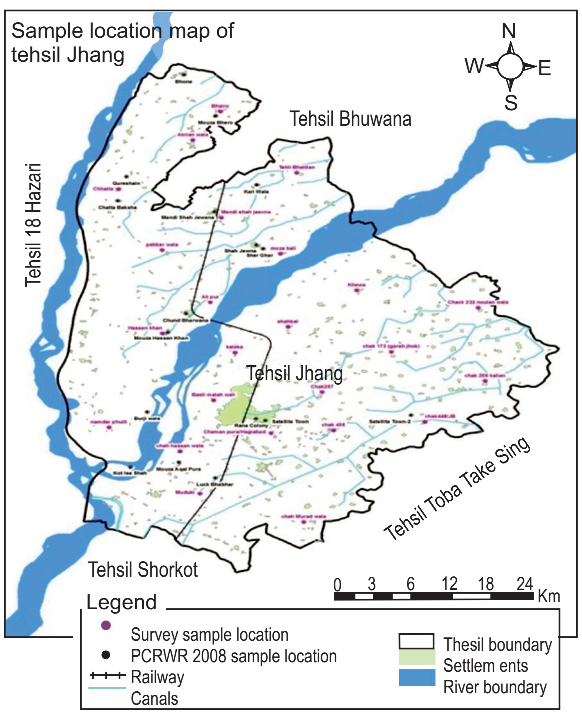

Fig. 3. Sample point locations map.

Fig. 4. Field kit testing.

Disease spread out associated with water quality parameters such as TDS, arsenic, fluoride and nitrate was determined using the list of diseases provided by health offices. Moreover, RHCs helped in collection of disease data for validation of water quality parameters.

PCRWR lab testing. In order to determine the accuracy of field data, water quality parameters were also analyzed by PCRWR lab Lahore. For this purpose, six different water samples were selected on random basis and sent to PCRWR lab Lahore for testing of water quality parameters. Results revealed that there were no major differences between field testing and lab testing. Arsenic contents were found higher on same points where primary data/field data exhibited higher values of arsenic. Similar results were recorded in case of Fluoride and TDS values. Although, minor differences in nitrate contents between primary data and lab tests were recorded but it was noteworthy that nitrate contents obtained by lab test were also higher than the standard permissible limits.

Inverse distance weighted (IDW). IDW is a well-known spatial interpolation method and widely used in environmental studies. IDW method is based on the assumption that near by points have higher correlation compared to distant points. IDW method gives best results with evenly distributed points in an area. However, mathematically it can be written as given below:

$$z_o = \frac{\sum_{i=1}^{s} z_i \frac{1}{d_i^k}}{\sum_{i=1}^{s} \frac{1}{d_i^k}}$$

where:

z_o = the estimated value at point o.
z_i = the value at known point i.
d_i = the distance between point i and point o.
s = the number of known point used in estimation.
k = the specified power.

Spatial auto correlation. Spatial correlation of data is the process of which involve validation of data by comparing direct parameters. For example, in order to analyze the water quality of an area, it is necessary to verify the public health data of that area. Therefore, in this study, a co-relational map was prepared using primary data and health data. For this purpose, layer of water quality map was merged with health data using Arc GIS 10.2. The data gathered during the field survey was validated using the generated maps. These prepared maps were found helpful in determining the link between water contamination and health risk. In this study, validation of data was carried out through the correlation of survey data with health data using GIS technology.

Results and Discussion

In this study, field survey and IDW analysis were applied on acquired data to obtain results regarding the groundwater quality of area under study. The maps of groundwater quality were prepared and compared with the health data for validation of results. Overall, it was observed that arsenic, fluoride and nitrate contents in groundwater were higher than the permissible limits. Higher values of these contaminants can be harmful for human health and other forms of life. People in the study area are on great threat. Surrounding urban areas there found high level of arsenic and nitrate which is causing many diseases in study area. Furthermore, results reveal that 67% of total samples were contaminated by arsenic 50% nitrate and 30% fluoride samples also showed high values than the WHO standards. Results depict that the majority of the population in the study area is consuming contaminated water which causes a severe threat to health (stomach ulcer, kidney and lungs cancers, teeth problems, weakened immune system). Detailed results are here as under:

Arsenic. Arsenic is a regular element of the earth's crust and commonly exists in the environment *i.e.*, "water and land". Higher contents of arsenic are very harmful and pose toxic effects on living organisms. Data analysis of present study revealed that 16 water samples out of 24 exhibited higher values of arsenic. It was recorded that 67% of total water samples used for drinking and irrigation purposes were contaminated with arsenic. Moreover, the comparison with lab results also validated the field results and showed high contents of arsenic on the same points (Fig. 5 and 6). Furthermore, the health data collected from the study area also confirmed that arsenic was present blood samples of almost 58% of total patients and caused skin problems, hearth damage, disturbed the liver functioning and yields negative impacts on proper functioning of brain also.

Nitrate. Nitrates are widely distributed in soil and anthropogenic activities such as use of chemical fertilizer and pesticides elevated the nitrate contents in soil. Nitrate is a compound that is formed naturally when

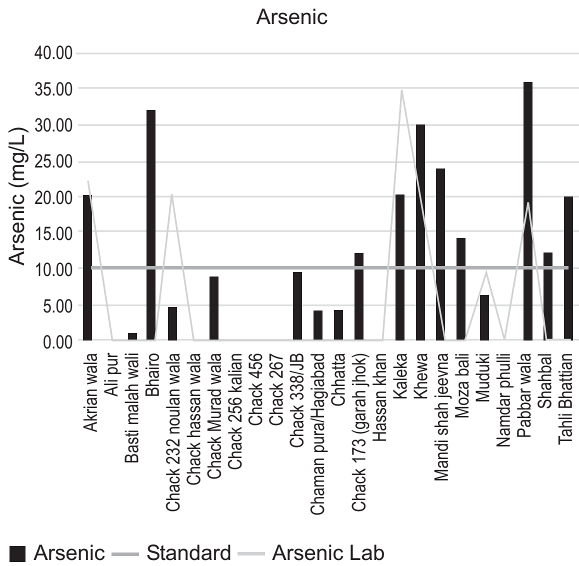

Fig. 5. Arsenic contamination results in the field.

nitrogen combines with oxygen or ozone. Nitrogen is essential for all living things but high levels of nitrate in drinking water can be dangerous to health, especially for infants and pregnant women. Nitrates are also made in large amounts by plants and animals and are released in smoke and industrial or automotive exhaust. Higher contents of nitrates in soil led towards leaching which cause contamination of groundwater resources. In this study, total 10 water samples showed higher nitrate contents as compared to the recommended values. It was recorded that about 40% of total water samples exhibited elevated levels of nitrates which can be lethal for living organisms. The highest value of nitrates was recorded in groundwater sample collected from Basti Malah Wali. However, 6 water samples exhibited nitrate contents below the permissible limits (Fig. 7 and 8). These results were validated by comparison with health data and it was noticed that about 23% of total patients were victims of higher contents of nitrates.

Fluoride. Fluoride is not among those chemicals which can cause noticeable negative impacts on human's health if used in drinking water. In groundwater, fluoride concentrations vary with the type of rock the water flows through but do not usually exceed 10 mg/L. Presence of lower contents of fluoride in drinking water cause negative effects on teeth. However, higher contents or repeated exposure of fluoride can give rise to a number of adverse effects ranging from mild dental fluorosis to crippling skeletal fluorosis depending on

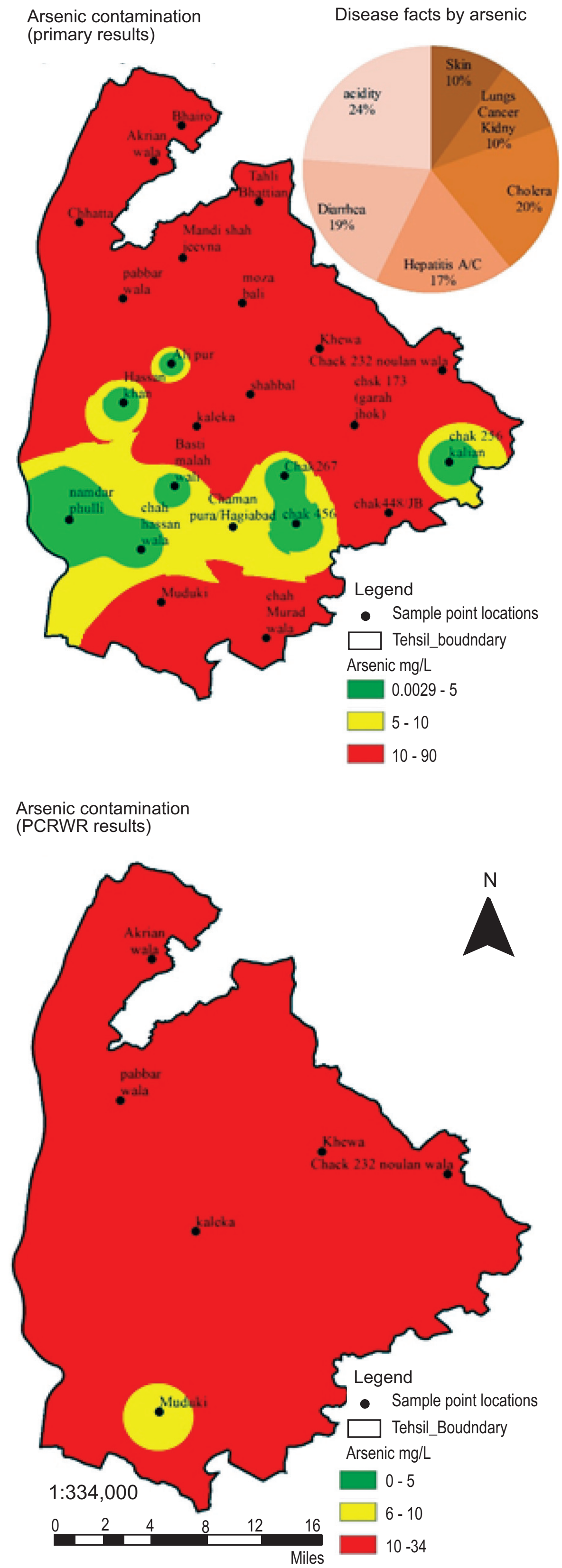

Fig. 6. Arsenic contamination map.

the level and period of exposure. In this study, only 3 water samples showed higher contents of fluoride and reaming all the water samples exhibited fluoride contents below the permissible limits. Moreover, health data showed that only 4% of total patients were found victim of Fluoride in the study area (Fig. 9 and 10). Furthermore, Fluoride prevents tooth decay by making teeth stronger and more resistant to acid attacks. It also helps with slowing down or stopping the decay process. When fluoride levels in water are at optimal levels, it helps to protect teeth against cavities.

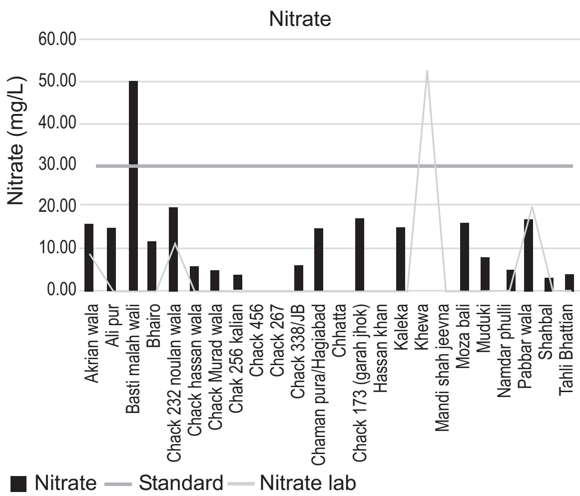

Fig. 7. Nitrate contamination results in the field.

Total dissolved solids (TDS). Total dissolved solids (TDS) represent the presence of inorganic salts and minor contents of organic matter in water solution. Total dissolved solids (TDS) is the term used to describe the inorganic salts and small amounts of organic matter present in solution in water. The principal constituents are usually calcium, magnesium, sodium and potassium cations and carbonate, hydrogen carbonate, chloride, sulphate and nitrate anions. However, the principal components are calcium, magnesium, sodium and potassium cations and carbonate, hydrogen carbonate, chloride, sulphate and nitrate anions. Although, TDS

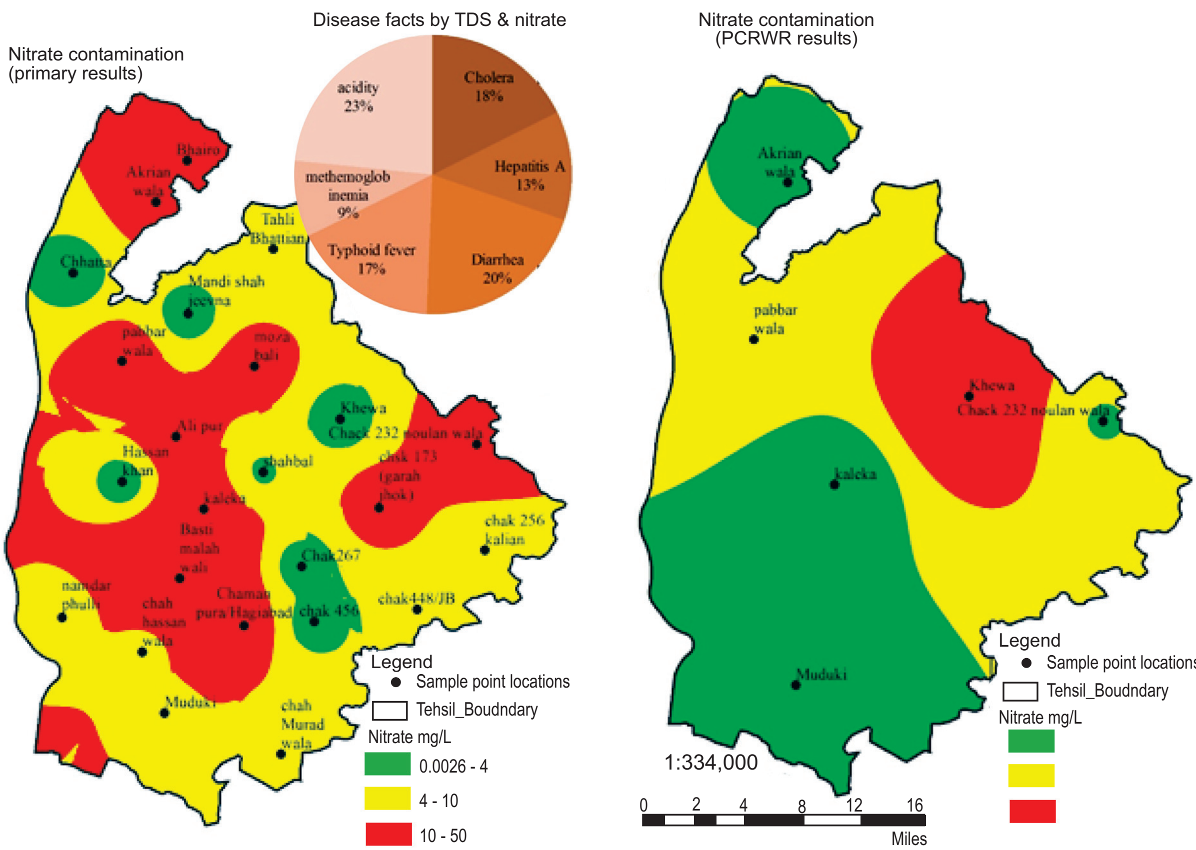

Fig. 8. Nitrate contamination map.

are naturally present in drinking water but urban runoff, sewage water, industrial wastewater and use of chemical during water treatment increased the values of TDS in drinking water above the recommended levels. In this study, only two water samples collected from Chaman Pura and Muduki exhibited higher values of TDS. However, the remaining 22 water samples showed TDS values below the permissible limits (Fig. 11 and 12).

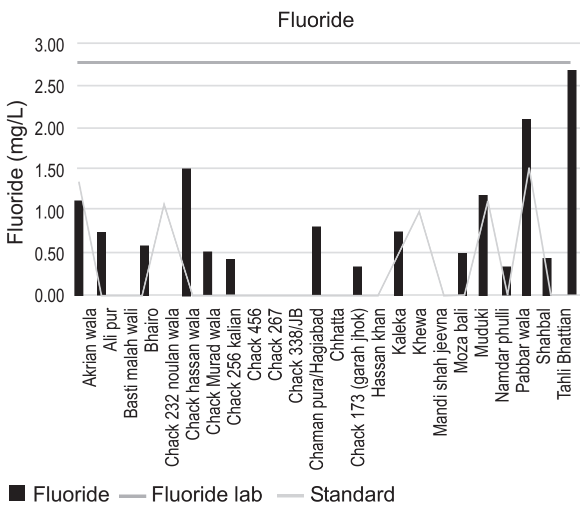

Fig. 9. Fluoride contamination results in the field.

Water quality. Polluted water cause several negative effects on human's health. Water is among the basic needs of all living organisms on earth including human beings. Therefore, it is a matter of great concern to maintain the quality of drinking water for better health. According to the data given in Table 1, it can be observed that water samples collected from Chak 456, Chak 267, Kalian, Hassan Khan and Namdarpulli exhibited excellent water quality. However, water samples collected from Chatta, Kaleka, Khewa, Muradwala, Shahbal and Chak 44/JB exhibited poor water quality. According to the health data provided by BHUs and RHCs suggested that following health effects were observed in the area under study due to poor water quality:

- Skin rashes
- Upset stomachs and ulcers

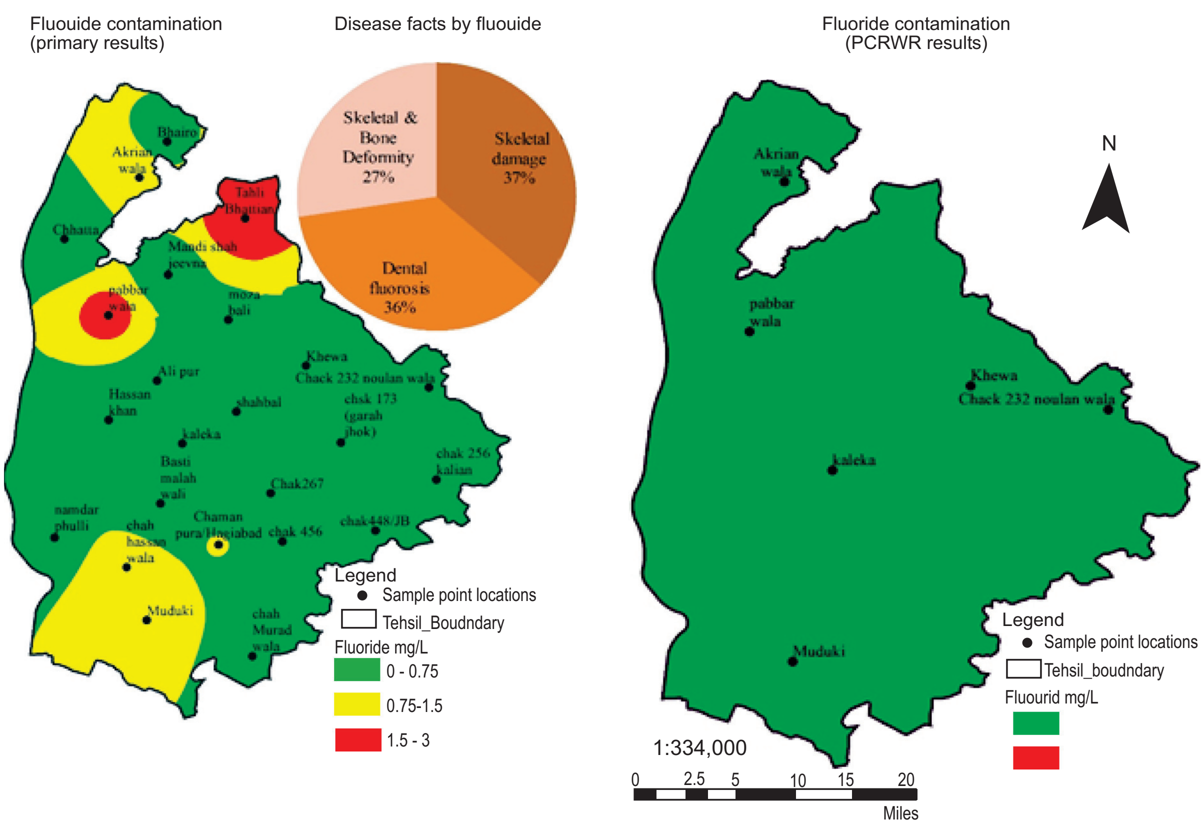

Fig. 10. Fluoride contamination map.

- Respiratory problems
- Kidney and liver damage
- Lungs cancer
- Teeth problem
- Weakened immune system

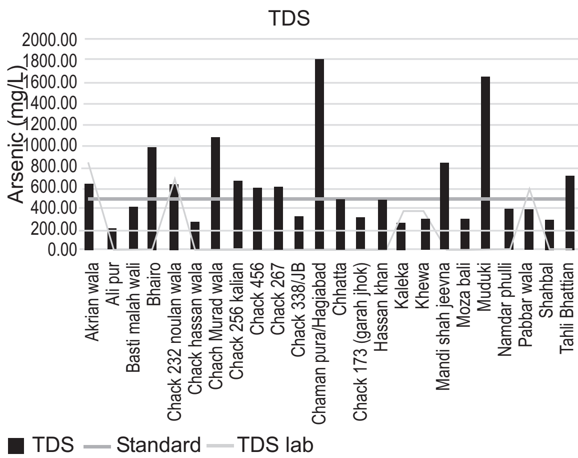

Fig. 11. TDS contamination results in the field.

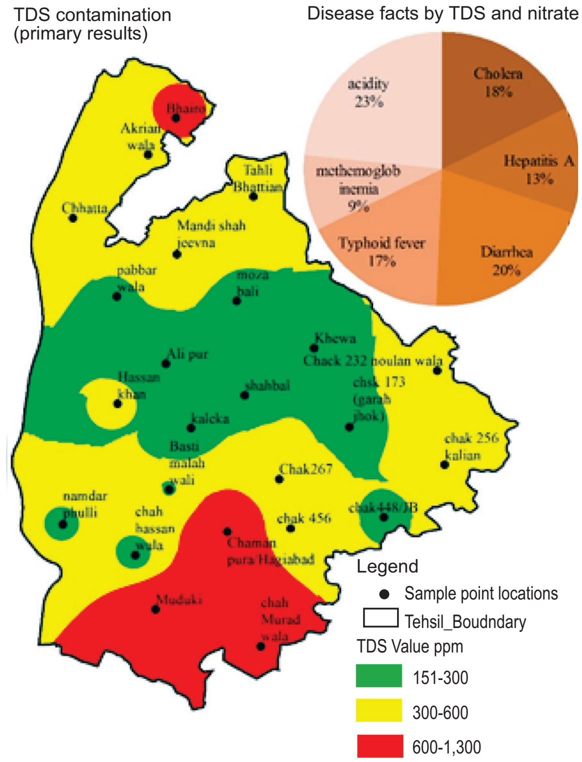

Table 1. Sample location wise water quality data

Villages name	Arsenic	Fluoride	Nitrate	TDS	Quality
Akrianwala	50	1.10	16	435	UFD
Noulanwala	11.0	0.00	20	479	UFD
Hassanwala	2.0	1.50	6	200	Good
Chak 456	0.0	0.00	0	411	Excellent
Chak 267	0.0	0.00	0	430	Excellent
Chatta	10.0	0.00	0	331	Poor
Kaleka	50.0	0.10	15	180	Very poor
Khewa	75.0	0.00	0	192	Poor
Bali	35.0	0.50	16	217	UFD
Alipur	0.0	0.40	15	151	Good
Malahwali	2.0	0.00	50	291	Good
Muradwala	22.0	0.50	5	751	Poor
Kalian	0.0	0.40	4	460	Excellent
Chamanpura	10.0	0.80	15	1270	UFD
Chak 173	30.0	0.30	17	210	UFD
Hassan khan	0.1	0.1	2	339	Excellent
Pabbarwala	90.0	2.10	17	270	UFD
Shahbal	30.0	0.40	3	210	Very poor
Tahli Bhattian	50.0	2.70	4	487	UFD
Bhairo	80.0	0.49	12	677	UFD
Chak 448/JB	25.0	0.1	6	228	Poor
Shah Jewena	60.0	0.4	0	2576	UFD
Muduki	16.0	1.20	8	1172	UFD
Namdarpulli	0.1	0.30	5	280	Excellent

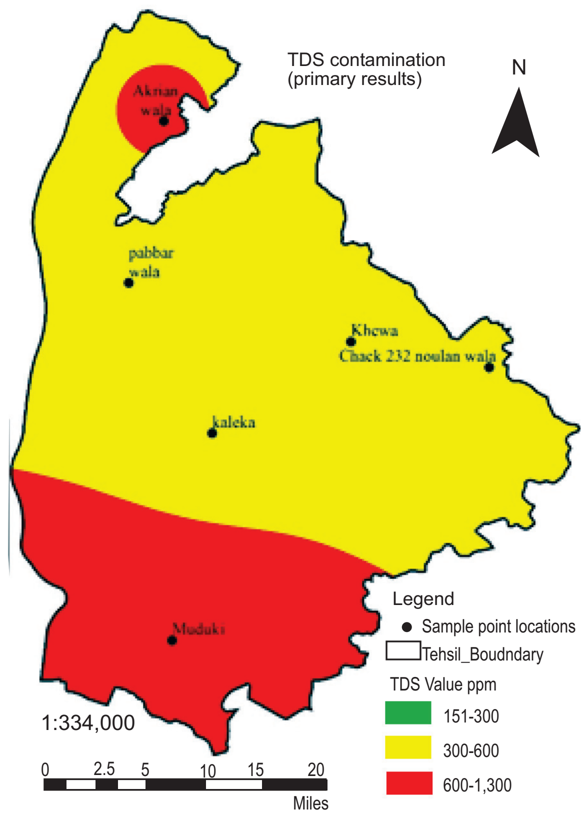

Fig. 12. TDS contamination map.

Conclusion

In this study, groundwater quality of area under study was assessed by on spot water testing during filed survey. Moreover, these results were compared with permissible limits recommended by World Health Organization (WHO). Based on the results of the present study, it can be concluded that pH values of all the collected water samples were found normal and fit to be used for drinking purpose. However, arsenic contents were recorded higher in 67% of total water samples, nitrate contents were found higher in 13 water samples collected from different locations in tehsil Jhang. Five other water samples showed marginal values for nitrate contents and highest value of nitrate contents were recorded in water samples collected from Basti Malah Wali. In case of floride, out of 24 samples, only three water samples exhibited higher contents of floride compared to the permissible limits. Furthermore, it was recorded that TDS values were found higher than the permissible limits only in water samples collected from Chaman Pura and Muduki. So, based on results, it can be concluded that about 50% of total water samples (12 water samples) collected from different locations in tehsil Jhang exhibited groundwater quality which was not suitable for drinking purpose. Total five water samples exhibited poor to very poor water quality, however, eight different sites exhibited good to excellent water quality for drinking purposes. Hence, the results of the present study suggested that most of the groundwater resources in tehsil Jhang have been contaminated with arsenic and nitrates. Moreover, majority of the population in study area use poor quality water which led towards serious health risks in human beings.

Recommendation

Based on the findings of the present study, practical recommendations for assessment and management of poor water quality are follows:

- The government should take immediate steps for the provision of good quality water for drinking purpose by devising a concrete policy to cope with the existing challenges across the region.
- The experts should be engaged to assess the quality of drinking water and indicate the reasons of the water contamination with counter instructions on periodic basis. If there is any possibility to install any treatment plants in the rural or urban areas, then it should be properly monitored and treated water should be analyzed as per standards of "PSQCA".
- As the industrial wastewater is a major source of water contamination, therefore, there is a need to conduct Environment Impact Assessment (EIA) study of industry in order to mitigate the contamination caused by this source.
- The use of elevated level of chemical fertilizers and pesticides must be restricted to ensure the safety of groundwater aquifer.
- Other way to ensure the health safety of the community is the installation of water treatment plants as per the "Pakistan Standards Quality Control Authority (PSQCA)."
- Moreover, awareness campaigns regarding safety of water quality and its remediation at community and regional level should be initiated.
- This study can be used on commercial scale. GIS make easy to assess the water quality of large area with limited resources. This study can be helpful for the professionals to better understand the water quality of Jhang and can be used in future to devise management strategies on sustainable basis.

Conflict of Interest. The authors declare they have no conflict of interest.

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