Impact Assessment of Groundwater Quality using WQI and Geospatial tools: A Case Study of Islamkot, Tharparkar, Pakistan

Natesh Kumar
Institute of Environmental Engineering and Management, Mehran University of Engineering and Technology
Jamshoro, Pakistan

Ali Asghar Mahessar
Sindh Barrages Improvement Project
Irrigation Department
Government of Sindh
Sindh, Pakistan

Sheeraz Ahmed Memon
Institute of Environmental Engineering and Management, Mehran University of Engineering and Technology
Jamshoro, Pakistan

Kamran Ansari
U.S.-Pakistan Centers for Advanced Studies in Water
Mehran University of Engineering and Technology
Jamshoro, Sindh Pakistan

Abdul Latif Qureshi
U.S.-Pakistan Centers for Advanced Studies in Water
Mehran University of Engineering and Technology
Jamshoro, Sindh Pakistan

Abstract–**Groundwater is the only source of fresh water in the Thar Desert which is located in an arid region of Pakistan with dense population and spreads over 19,638km^2. Low rainfall, low groundwater recharge, high evaporation and absence of perennial streams are the general reasons for water scarcity. Being the single water source for drinking, domestic and industrial uses, and livestock activities, this source is highly overexploited. Realizing the gravity of the situation, this paper presents a groundwater quality evaluation of Islamkot, Tharparkar, using Water Quality Index (WQI) and Geospatial tools. 40 samples were collected from dug wells. The TDS of 28 samples was found higher than 3000mg/L and 12 samples ranged from 1500 to 3000mg/L. Many (28) samples were not further analyzed due to their very high TDS which made the water unfit for drinking. Twelve samples with TDS ranging from 1500 to 3000 mg/L were further analyzed. The analyzed results revealed the average values of pH, EC, TDS, salinity, chloride, total alkalinity, fluoride, and arsenic. The results did not meet NEQS and WHO guidelines. Pearson correlation analysis was conducted among parameters. Further, groundwater quality was assessed by WQI and indicated that water quality varied from very poor to unsuitable for drinking. The consumption of polluted groundwater has been the main cause of prevalent waterborne diseases and poses a very high risk for public health.**

Keywords-statistics; physicochemical analysis; Islamkot; WQI; GIS models; public health

I. INTRODUCTION

Surface and ground water are the main resources of drinkable water, since the 97.5% of the total water on the globe is saline. The 68.9% of the drinkable water falls within glaciers and permanent snow at the poles, 29.9% is in groundwater, only 0.3% of the fresh water exists in rivers, and 0.9% is in soil moisture and swamp water from groundwater [1]. The surface and ground water are major water sources [2]. Groundwater is a significant natural resource particularly in rural areas [3]. Owing to the lack of surface water facilities, groundwater plays a pivotal part in overcoming drinking and agricultural needs in both arid and semi-arid areas [4]. Groundwater table is naturally recharged through rainfall, streams, lakes, rivers and swamp wetlands [5]. The groundwater becomes free from impurities of organic wastes by the filtration which occurs naturally through sediments and soil [6]. The quality of groundwater is an essential defining factor for its potentiality for drinking, agricultural and industrial usages [7].

The presence of some chemical elements in drinking water at concentrations above the standard levels can lead to health problems. Drinking water contains various elements essential for human health. However, high concentrations of these parameters (TDS, alkalinity, As, F, Cu, Zn, Fe, Cd, Ni, and hardness) might create severe health complications [8-9]. Contamination of groundwater by organic and inorganic material of anthropogenic origin poses a severe problem. Safe drinkable water plays a vital role in human health, while water unfit for drinking is known a major source of waterborne diseases [10]. About 1.8 million people in the world die from diarrhea related diseases annually, many of which have been interrelated to the consumption of contaminated water [11]. Globally, over 80% of people live with unimproved drinking water and 70% without improved sanitation. The adverse health effects of drinking water pose a serious problem in several parts of the world [11]. Severe problems have been reported even in Pakistan, especially in rural areas [12-17]. It is estimated that 30% of all diseases and 40% of all deaths are related to poor water quality. Water borne diseases are reported as a leading cause of death in infants and children in Pakistan while about 20% of the citizens suffer from polluted water related symptoms [18].

Corresponding author: Ali Asghar Mahessar (amahessar@yahoo.com)

Groundwater quality has received widespread attention since the demand of water of high quality is rising. Until recently, groundwater quality assessment has been based on laboratory investigation, but the emergence of satellite technologies such as Remote Sensing (RS) and Geographical Information System (GIS) has made it easy to integrate various databases for water quality assessment. RS has been used to land classification, land cover and land use changes [19]. GIS can be used as a powerful tool for finding water resource solutions, assessing water quality and availability, assisting in the prediction of local and regional floods, and understanding the natural environment. The WQI model is widely used worldwide for groundwater quality assessment, evaluation, and management [20]. Like many other countries, Pakistan also faces the problem of safe and clean drinking water availability. In the rural areas, the primary source of drinking water is groundwater. Poor water quality is a major health risk in Pakistan [21]. Fresh water resources in Thar region are scarce. Moreover, crops are totally dependent upon rainwater [22]. This study was conducted in order to evaluate groundwater quality by using WQI and GIS. In order to use these models for groundwater sustainably, groundwater resource monitoring and mapping are essential. Statistical analysis of groundwater quality data was performed using descriptive statistics and Pearson correlation.

II. STUDY AREA

Tharparkar district consists of seven Talukas. The total area of the district is 19,638km^2 mostly covered with sand dunes. The population is 1,649,661 (2017 census). Islamkot is a taluka of the Tharparkar District which is at a distance of 35km from Mithi City and around 450km from Karachi. Islamkot is geographically positioned between 24°42'4.9680"N and 70°10'41.9592"E with an altitude of 193 feet. The area selected for research is Islamkot city area including the villages falling within its vicinity. The map of the study area is shown in Figure1.

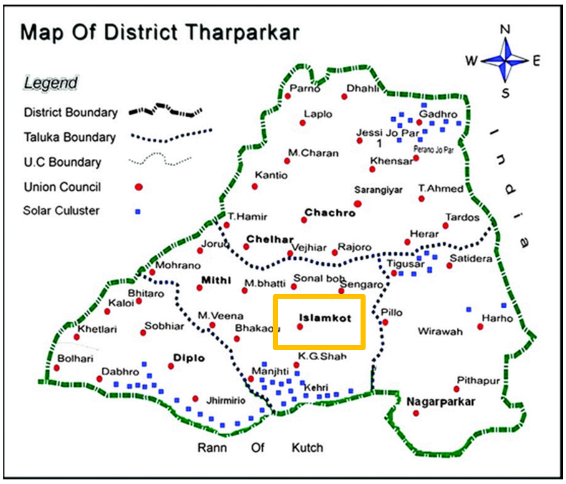

Fig. 1. Map of Tharparkar District, Sindh, Pakistan

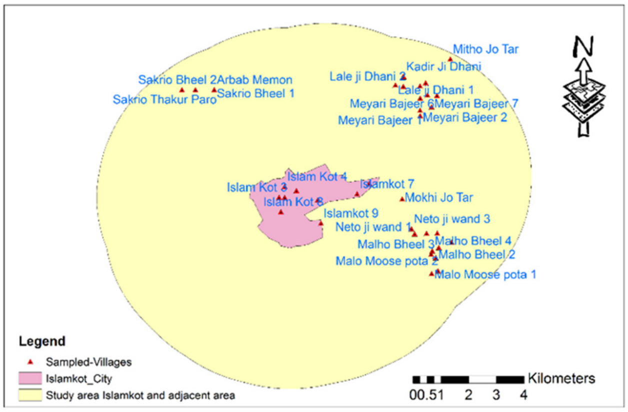

Fig. 2. Map of the study area

A. *Climate of the Study Area*

The climate of the studied area is dry with annual precipitation of 200–300mm whereas the temperature fluctuates between 9°C in winter to 48°C in summer. In summer, it is extremely hot during the day, but nights are remarkably cooler. April, May and June are the hottest months during the year, while December, January and February are the coldest. The inhabitants mostly rely on rainfall for agriculture and livelihood [23]. Agricultural practice depends upon the rainwater and is the major occupation of locals. The main sources of drinking water are dug wells and low-lying areas (Tarais) which recharge during rainfall.

B. *Geology of the Study Area*

Tharparkar is the largest subtropical desert spread over 19,638km^2 and lies in Pakistan's southern Sindh province. Tharparkar district is specially named according to the geographical conditions, ie. Thar and Parkar. “Thar” means desert while Parkar refers to a rocky and hilly terrain.

III. MATERIALS AND METHODS

A. *Samples Collection*

Forty samples were collected in one-liter clean polyethylene bottles. At the time of sampling, the bottles were thoroughly rinsed with distilled water and labelled properly before transporting to laboratory and preserved with nitric acid. GPS coordinates were noted for sampling locations using handheld GPS (62s). The samples were collected from the study area and were sent to the Lab of Institute of Environment, Mehran University of Engineering and Technology, Jamshoro. The values of pH, TDS and salinity were taken in situ at samples' collection sites. The pH measurements were made with calibrated pH meter with glass electrode and reference internal electrode. Electrical Conductivity (EC), salinity and Total Dissolved Solids (TDS) were recorded with a calibrated salinity and conductivity meter (HACH 8163). Furthermore, physicochemical parameters have been measured in the Laboratory using standard analysis procedures. The locations of samples' collection, their latitudes and longitudes are listed in Table I.

TABLE I. SAMPLES' COLLECTION NUMBERS AND LOCATIONS

Locations of collected samples					
No.	**Latitude**	**Longitude**	**No.**	**Latitude**	**Longitude**
S1	24.701	70.217	S21	24.727	70.223
S2	24.736	70.156	S22	24.737	70.223
S3	24.703	70.183	S23	24.733	70.223
S4	24.701	70.179	S24	24.734	70.225
S5	24.701	70.177	S25	24.734	70.228
S6	24.705	70.179	S26	24.730	70.227
S7	24.700	70.190	S27	24.738	70.225
S8	24.689	70.221	S28	24.740	70.217
S9	24.706	70.206	S29	24.740	70.217
S10	24.702	70.202	S30	24.740	70.217
S11	24.690	70.228	S31	24.740	70.217
S12	24.691	70.220	S32	24.737	70.215
S13	24.687	70.233	S33	24.737	70.217
S14	24.682	70.228	S34	24.745	70.233
S15	24.683	70.226	S35	24.696	70.178
S16	24.684	70.227	S36	24.685	70.229
S17	24.751	70.150	S37	24.677	70.227
S18	24.754	70.150	S38	24.678	70.229
S19	24.758	70.146	S39	24.693	70.191
S20	24.729	70.223	S40	24.690	70.225

B. *Water Quality Index (WQI) Model*

WQI is an indicator of measuring water quality and suitability for drinking and surmises many parameters of water samples' results for understanding if the water is drinkable or not. The equation of WQI model is given:

$$QWI = \sum_{i=1}^{n} Wi*Qi \qquad (1)$$

where Qi is the i^{th} WQ parameter, Wi is the weight associated with the i^{th} WQ parameter, and n is the total number of WQ parameters.

TABLE II. WATER QULITY INDEX RATING

S. No.	QWI value	Rating
1	0-25	Excellent
2	25-50	Good
3	50-75	Poor
4	75-100	Very poor
5	>100	Unsuitable for drinking

C. *Karl Peason Correlation Matrix*

Karl Person linear correlation matrix [24] has been used to analyze the relationship among various physicochemical parameters (Table III).

D. *Gegrophical Information System Model*

RS has proved to be a beneficial and valuable tool in providing data for GIS in order to study various environmental aspects including groundwater. Various GIS techniques methods are used, such as Cokriging, Spilain, Natural Neighbors, Kriging and Inverse Distance Weight (IDW) for the spatial distribution of water quality parameters in the globe. IDW and Krinng techniques have been used for generating geospatial analysis in this study, which comprises of three distinct phases: (1) data acquisition, (2) data processing, and (3) data analysis.

IV. RESULTS AND DISCUSSION

A. *Geospatial Analysis of Collected Samples*

1) *pH*

According to National Environmental Quality Standards (NEQS) and WHO guidelines, water used for drinking should have a pH between 6.5 and 8.5. The pH values found in the study area's groundwater samples ranged from 7.6 to 8.7 as shown in the geospatial distribution of pH in Figure 3. All samples are within the range of WHO standard except of S9 and S10. The locations of these high samples' values are in Islamkot city. The pH is the primary parameter used to evaluate water quality and it has no immediate impact on health [25].

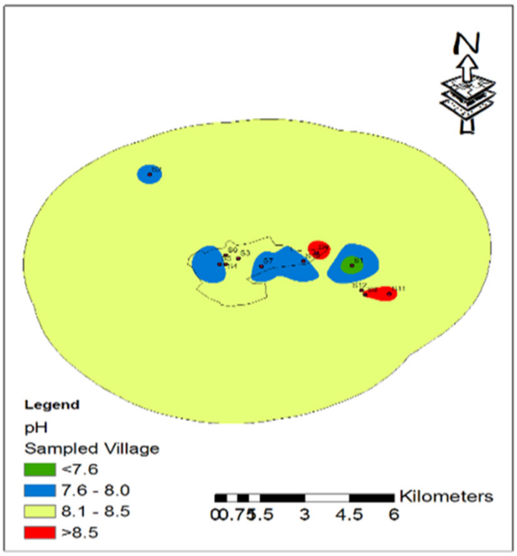

Fig. 3. Spatial distribution of pH using GIS

2) *TDS*

The analyzed levels of TDS ranged from 1900 to 2688mg/L with an average value of 2202mg/L. The TDS values of all samples are higher than 1500mg/L. In general, high TDS concentration is due to natural minerals in the rocks. The samples having TDS more than 3000mg/L were either brackish or saline in taste. A similar tendency of TDS concentration is reported in the groundwater of Thatta, Badin and Thar, the southern areas of Sindh province [17] and in Tharparkar district [23]. The high level of TDS impairs the study area's drinking water quality. Figure 4 shows the spatial distribution of TDS.

3) *Electrical Conductivity (EC)*

It is the main parameter used to evaluate drinking water quality. The EC in the sampled groundwater ranged from 2970 to 4200uS/cm with an average value of 3441uS/cm. The samples' conductivity is generally higher than the WHO standard. Higher dissolved salt concentration gives water mineral taste and generates aesthetic issues for consumers. The spatial distribution of EC is been shown in Figure 5.

4) *Total Hardness (TH)*

Water hardness is due to cations and anions like calcium and magnesium, sulphate, carbonate, bicarbonate and chloride.

In the sampled groundwater, TH ranged from 110 to 520mg/L. The acceptable limit for TH is 500mg/L as per WHO guidelines. Total water hardness levels higher than 500mg/L bring about scale formation in pipes, whereas total hardness concentrations lower than 100mg/L can reduce the pH of the water and render the water corrosive. The use of hard water may cause kidney or bladder diseases, stomach illnesses, and produce urinary concretions in the human body. The geospatial distribution of hardness is demonstrated in Figure 6.

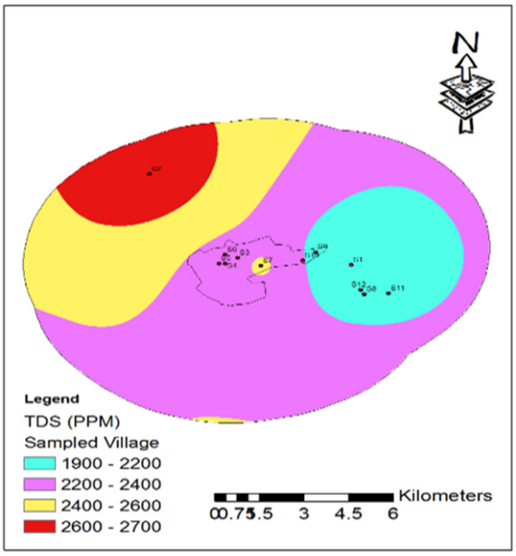

Fig. 4. Spatial distribution of TDS using GIS

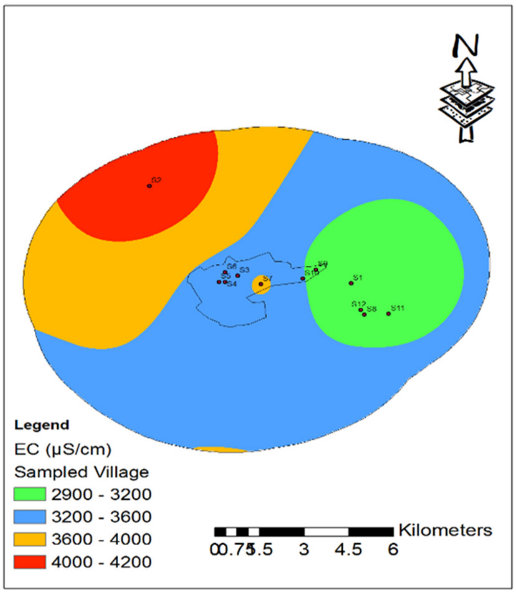

Fig. 5. Spatial distribution of EC using GIS

5) Chloride (Cl)

WHO has defined 250mg/l as the acceptable chloride limit. Natural water generally contains chloride, but its concentration depends on the region's geology. Chloride is completely soluble in water. In this study, chloride concentration in the sampled groundwater ranged from 319 to 968mg/L with an average value of 588mg/L. The values of all samples were found to be higher than the permissible limit. The highest concentration of chloride was recorded in sample S7 of Islamkot city. Indigestion and kidney disease patients should avoid drinking water with greater concentration of chloride [23-25]. Figure 7 represents the geospatial distribution of chloride in the study area.

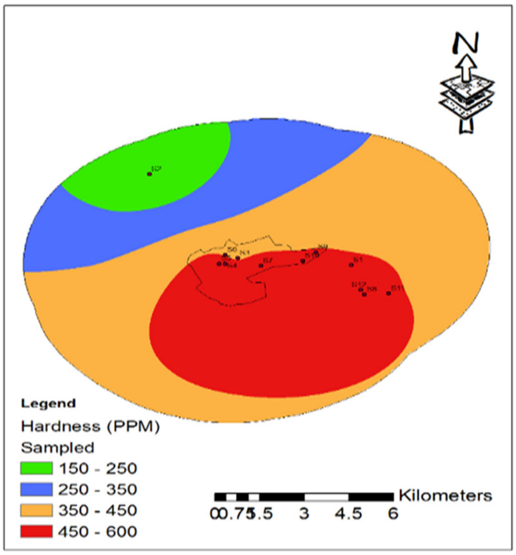

Fig. 6. Spatial distribution of hardness using GIS

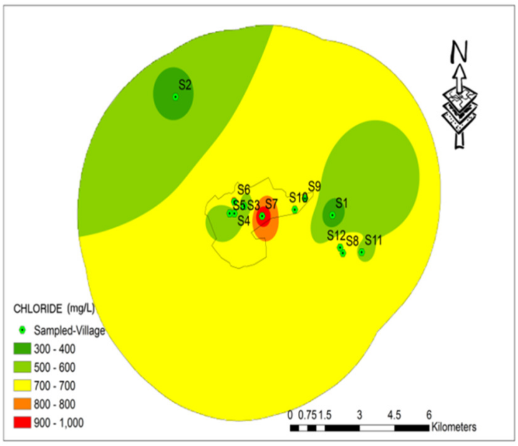

Fig. 7. Spatial distribution of chloride using GIS

6) Alkalinity (Alk)

The alkalinity value in the sampled groundwater ranged from 170 to 725mg/L and the average value was 403.3. The permissible limit of alkalinity according to WHO is 500mg/L. The alkalinity geospatial distribution is shown in Figure 8.

7) Fluoride (F)

Fluoride is an important micronutrient which reinforces skeleton tissues and teeth at concentrations below 1mg/L, whereas elevated concentrations, exceeding 1.5mg/L, result in dental and skeletal fluorosis, kidney and neuronal disorders.

According to WHO, the maximum allowable level of fluoride in drinking water is 1.5mg/L. The analyzed results show that fluoride average value is 1.36mg/L and ranging from 1.01 to 2.02mg/L as shown in Figure 9. The highest amount of fluoride was found in sample S2 (village Arbab Memon).

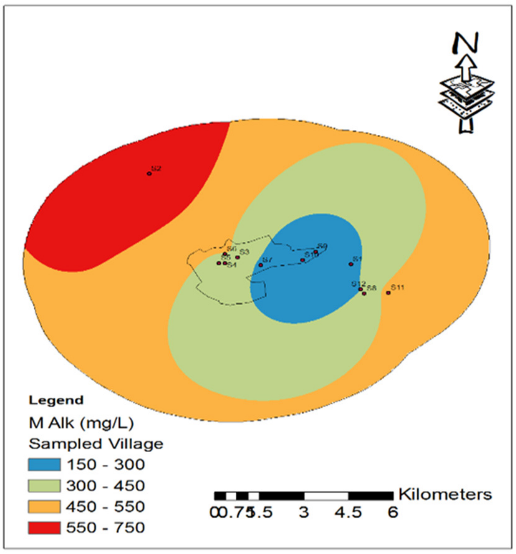

Fig. 8. Spatial distribution of alkalinity using GIS

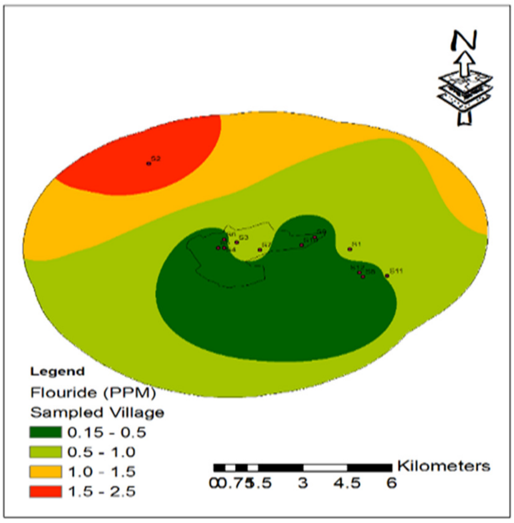

Fig. 9. Spatial distribution of fluoride using GIS

8) Arsenic (As)

The highest permissible amount of arsenic in drinking water is 0.01mg/L according to WHO. In the study area, it ranged from 0.0007 to 0.019mg/L with an average value of 0.0097mg/L (Figure 10). High-arsenic groundwater shows an alarming condition for individuals who use this water for drinking. The arsenic contaminated groundwater causes diseases of gastroenteritis, skin pigmentation changes, skin, dental, skeletal fluorosis, liver, cardiovascular problems, and even cancer.

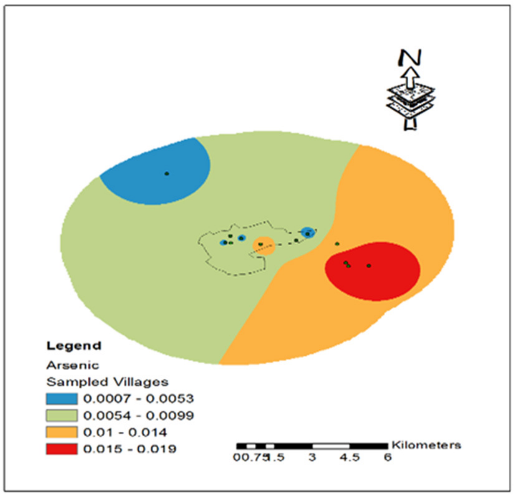

Fig. 10. Spatial distribution of arsenic using GIS

B. Pearson Linear Correlation Model

Karl Person linear correlation matrix [26] was used to analyze the relationship among the physicochemical parameters. The correlation computation matrix is shown in Table III. The correlation of EC with TDS and salinity is strong with positive and weak correlation with alkalinity, hardness, chloride, arsenic and fluoride. The pH has weak negative relation with EC, TDS, and hardness.

C. WQI Analysis

The groundwater quality of the study area calculated by WQI indicates that the water lies in the unsuitable for drinking category while only one sample (S9) lies under the very poor category having satisfactory result with WQI below 100. In this study, the computed WQI values range from 98 to 153. The overall view of the WQI of the study area signifies its deteriorated water quality.

TABLE III. PEARSON CORRELATION MATRIX

Parameter	pH	EC	TDS	Salinity	Chloride	Hardness	Alkalinity	Arsenic	Fluoride
pH	1								
EC	-0.041	1							
TDS	-0.041	1.000	1						
Salinity	-0.071	0.976	0.976	1					
Chloride	0.266	0.495	0.495	0.320	1				
Hardness	-0.154	-0.108	-0.108	-0.153	0.277	1			
Alkalinity	0.126	0.062	0.063	0.154	-0.421	-0.44	1		
Arsenic	0.111	-0.193	-0.193	-0.288	0.276	0.03	-0.190	1	
Fluoride	-0.133	0.254	0.254	0.396	-0.484	-0.65	0.672	-0.317	1

D. Health Assessement

Figure 11 shows the frequent occurrence of various diseases. Kidney problems, hepatitis, gastroenteritis, blood pressure and heart problems, cancer, bone pain and skin problems are common among the residents in the study area. The consumption of polluted groundwater is a high risk for locals.

TABLE IV. WQI RATINGS

Sample Location	WQI	Type	Sample Location	WQI	Type
70° 13' 01.4916" E 24° 42' 02.1384" N	115	US	70° 11' 23.1432" E 24° 42' 01.2420" N	153	US
70° 09' 22.1760" E 24° 44' 08.3040" N	142	US	70° 13' 16.0248" E 24° 41' 21.7500" N	139	US
70° 10' 58.0548" E 24° 42' 11.8368" N	123	US	70° 12' 23.0976" E 24° 42' 19.9476" N	98	VP
70° 10' 44.3964" E 24° 42' 03.8988" N	124	US	70° 12' 08.8632" E 24° 42' 08.0352" N	117	US
70° 10' 37.8156" E 24° 42' 04.0320" N	119	US	70° 13' 42.3156" E 24° 41' 22.6500" N	147	US
70° 10' 44.2596" E 24° 42' 16.3872" N	140	US	70° 13' 12.1800" E 24° 41' 27.6432" N	128	US

US: unsuitable, VP: Very poo

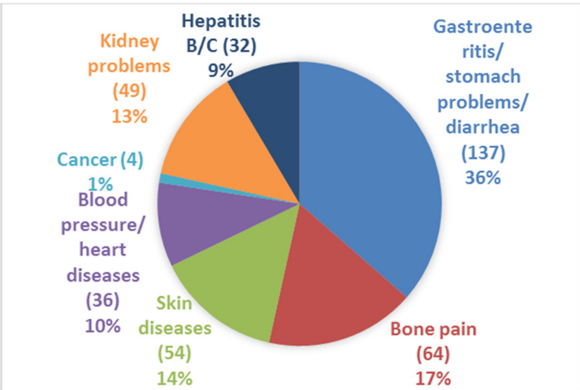

Fig. 11. Reported health issues in the study area

V. CONCLUSIONS

After physicochemical analysis of the collected 40 samples from dug wells, it was shown that the TDS of 28 samples was found higher than 3000mg/L which indicates that water consumption poses a direct health threat on locals. Hence, 28 samples were not further analyzed due to their very high TDS values. Twelve samples with TDS ranging from 1500 to 3000mg/L were further analyzed. The 12 analyzed samples had average pH, EC, TDS, salinity, chloride, alkalinity, fluoride and arsenic values of 8.158, 3441.66, 2202.4, 1.83, 588, 265.4, 403.3, 1.366, and 0.093 respectively. The resultantly parameters did not meet NEQS and WHO guidelines. The geospatial distribution of all physicochemical parameters shows the real groundwater picture. Pearson correlation analysis shows weak, moderate and strong correlation among physicochemical parameters. Groundwater quality was assessed by WQI which indicates that the water quality of the 12 collected groundwater samples varies from very poor to unsuitable. The consumption of polluted groundwater is related to waterborne diseases and poses very high risk for public health. It is also concluded, from the health impact assessment survey, that the occurrence of various waterborne and water-related diseases is common among the residents of the study area. Consequently, the use of degraded groundwater should instantaneously be stopped and new techniques should be adopted such as rainwater harvesting and storage/tarais, irrigation network expanse, manufacturing of reverse osmosis, de-arsenic and fluorination plants, and also freshwater supply schemes should be introduced in Thar. Water quality monitoring and health impact assessment must be conducted constantly.

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