WATER QUALITY ASSESSMENT USING WATER QUALITY INDEX: A CASE STUDY OF HIGH ALTITUDE AREA, GILGIT CITY, GILGIT BALTISTAN, PAKISTAN

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ABSTRACT: The research aimed to evaluate the surface water quality of Gilgit city by comparing the actual values of physio-chemical and microbiological parameters with that of the national standards for drinking water quality of Pakistan. A total of Sixteen surface water samples were gathered from the study area to analyze their quality. Multiple parameters including fluoride, hardness, pH, nitrite, nitrate, chloride, and TDS were mapped spatially using inverse distance weighting. To compute water quality index, ArcGIS Model Builder and ArcPy were employed. The key informants interviews and focus group discussions were also conducted to list the water-related problems. The findings of the water quality index ensured the good quality of collected surface water samples using physicochemical parameters but the occurrence of microbiological contamination in both rivers declared water unfit for drinking. It showed that the water of the city is being contaminated due to anthropogenic activities. The mixing of wastewater into drinking water sources was also reported by the respective authorities and community. The residents also suggested to repair filtration plants as well as cover the water storage structures on an urgent basis. The study will be helpful to concerned departments of the study area to plan their resources and provide their services to the residents efficiently.

Keywords: Water quality, Gilgit City, GIS, Water Quality Index, Focus Group Discussion, Key Informants Interviews

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INTRODUCTION

Water is an expensive and limited resource necessary for living organisms. As the population is rising (Ali *et al*., 2022), it is becoming difficult to get safe drinking water with time. In 2020, it is reported that every fourth person had unable to get safe water (WHO, 2021) and diarrhea is responsible for the death of every eight children in Africa, Asia and South America (Ugboko *et al.,* 2020). Pakistan is listed at 80 number out of 122 nations in terms of the quality of drinkable water (Shah *et al.,* 2021).

Drinking water quality is very important for the well-being of human beings and pollutant water is very dangerous for people. It is stated that 30% of mortality is because of contamination in water (Daud *et al.,* 2017). The insufficient management of liquid waste also results in the contamination of a large quantity of fresh or drinkable water. Another reason for water contamination could be inadequate treatment. About 2 billion people use polluted drinking water with fecal substances (Bogale, 2020). Clean water can be polluted at any stage so there is a dire need to take measures at all levels for the preservation of water from pollution.

Groundwater is considered a key source of drinking water. But, snow and glaciers are primary sources of providing water in GB (Unicef, 2019). That water moves into water channels which is stored and then supplied untreated water to the community for all purposes. With the passage of time, this water is being polluted due to the mixing of sewerage. Nevertheless, the occurrence of human activities nearby the water sources and the absence of water filtration plants are also accountable for the contamination in water. At a large scale, the sixth goal of sustainable development also emphasized on sustainable management of water and sanitation for all while, its 6.3 target states to improve the quality of wastewater treatment (Water, 2018). In such scenario, GIS technology aids not only in the mapping of physical, chemical and microbiological quality assessment parameters of water but also supports to analyze these parameters on a temporal basis.

Many studies have been conducted to evaluate the quality of water around the globe after considering its importance. A study was carried out in mountainous areas of India to assess water quality by computing water quality index at five different sites temporally (Chakravarty and Gupta 2021). Total coliform and chemical parameters were also observed exceeding tolerable limits by WHO in the Margala Hills of Islamabad (Batool *et al.,* 2018). In Kenya, groundwater quality was also assessed by taking samples from the three springs and outcomes revealed that very good quality water (Wekesa and Otieno, 2022). Similarly, for the Cau River, Vietnam, the computed indices displayed severe contamination in the downstream area (Son *et al.,* 2020). Likewise, a study in South Africa for the assessment of quality of water using water quality index stated poor water and suggested to filter the drinkable water (Madilonga *et al.*, 2021).

In Gilgit Baltistan (GB), already conducted studies also examined the quality of drinkable water in its different areas as well. PCRWR conducted a study in various villages of GB and stated that more than half (70%) of gathered samples from Gilgit were hazardous due to microbial contamination (Ahsan et al. 2021). Sample was taken from five districts of Gilgit Baltistan also displayed variation in computed WQI which may be due to anthropogenic activities (Sohail *et al.*, 2019). In district Ghizer, E.coli was also found to be exceeded the permissible limit of WHO (Ali and Hussain, 2018). The existence of Heavy metals in Gilgit declared water unhealthy for drinking (GB-EPA, 2019). Another study testified the existence of heavy metals in water sources of Gilgit (Hussain *et al.*, 2022). Similarly, the value of turbidity in Gilgit was also observed different from the limits of WHO in rivers (Din *et al.*, 2016). The Danyore village of GB also reported high contamination in water channels by E.coli (Shedayi *et al.*, 2015). Due to the contaminated water, an outbreak of typhoid was also witnessed in the study area (Wakhani, 2020). With the advancement in technology, GIS tools have also been used in the assessment of water quality in Gilgit. The variation in the concentration of E-coli was drawn spatially using GIS in the study area (Hussain *et al.*, 2014). E.Coli was also found in the household sampling of some areas of GB and sites of water samples were mapped using GIS (Abbas *et al.*, 2015). Water quality assessment of Chu Tran Valley, GB stated that drinkable water was unhealthy due to the presence of heavy metals using interpolation technique in GIS (Fatima *et al.*, 2022).

In the recent years, number of studies have been published on water quality assessment of high altitude area (Gilgit) and reported water pollution which is affecting the health of the residents. Therefore, it is immensely needed to evaluate the quality of water sources on frequent basis in order to identify the problematic areas so that the preventive measures could be taken to save the natural finite resources in time. Elimination of pollutants in the sources of water would lead to better health of people. Although, quality of water sources of Gilgit City has already been assessed in different studies with selected number of parameters but no research described water quality assessment with the combination of testing of large number of parameters and computation of Water Quality Index (WQI) of this high altitude area. Thus, this paper not only focuses on the comparison of water quality parameters with drinking water quality standard values as well as their mapping and computes WQI of each sampling site to identify the status of quality of water at that source. It also incorporates the views of community and department officials regarding water related issues and their solutions which has not been addressed in previously conducted water quality assessment researches of the study area.

MATERIAL AND METHODS

Study Area: Gilgit city is an urban area and center place of the Gilgit District. It had a population of 79349 according to census carried out in 1998, whereas, its forecasted population is 330,724 for year 2025 including the rural population of Danyore and Sakwar (Annandale and Bailly, 2014). Gilgit City is positioned at 74.32 to 74.53 longitude and 35.83 to 35.98 latitude in the famous mountains of Karakoram. Hunza and Gilgit are the two rivers flowing in its neighborhood with major Nallahs including Kargah, Minawar, Jutial, Danyore and Sakwar. For the storage of water in the study area, five drinking water supply complexes were existed (Karrar and Iqbal, 2011). Figure 1 displayed the Gilgit City map.

Data Collection and Processing: The primary data was collected by conducting a field visit of the study area. In total, sixteen samples of surface water were collected from rivers and Nullahs with averagely three surface water samples from every water source (middle, downstream, upstream) within the boundary of Gilgit City shown in Figure 2.

The equipment and method adopted for collecting surface water sample were as per World Health Organization (WHO) standards. Samples were taken in two types of containers, plastic bottle was used to store 1.5 Liter water for physio-chemical testing whereas, for microbiological testing, sterilized glass bottle was used with storing 0.5 Liter water. Total 30 (26 physio-chemical and 4 microbiological) parameters were tested in a laboratory using standard methods for the assessment of water quality. The resulted values were compared with drinking water quality standards defined by Environmental Protection Agency, Pakistan displayed in table 1. Gilgit Baltistan also examined the water to check its quality (Ministry of Environment, 2010; GB-EPA, 2019). Inverse Distance Weighting (IDW) was performed on the results of chemical parameters (Shahid *et al.*, 2017), whereas, maps of microbiological contaminations were also developed to show the concentrations in the study area.

To probe the views of the community, five Focus Group Discussions (FGDs) were conducted by designing data collection instrument having questions about water storage, sewerage system, demography, water availability, public-private sharing models and quality of water, etc. Due to the Covid-19 situation, only five FGDs were arranged with minimum of 5 people in a group. Details of FGDs was given in table 2. The interviews were also conducted with the Deputy Directors of Gilgit Development Authority (GDA) and

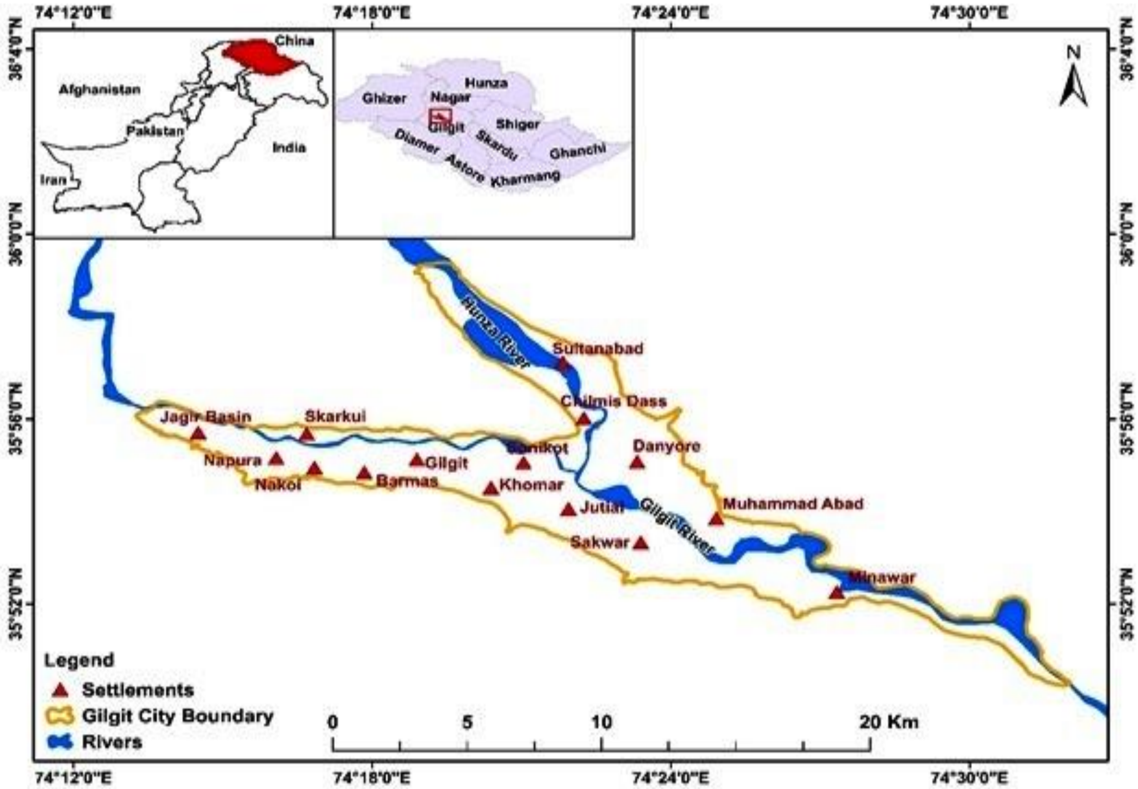

Figure 1: Gilgit City Jurisdiction Map

Environmental Protection Agency (EPA), Assistant Professor of Water Quality Lab of Karakoram International University (KIU) and Water Quality Manager of Agha Khan Development Network (AKDN) in the study area stated in table 4 to record their opinion regarding water issues. Moreover, Water Quality Index (WQI) was also calculated by measuring pH, TDS, Nitrate, Nitrite, Fluoride, Hardness, Chloride at each water sampling site using equation 1 (Garcia-Avila *et al.*, 2022; Adelagun *et al.*, 2021; Akter *et al.*, 2016) in ArcMap Model Builder using iteration function and ArcPy as well. Flow chart of the methodology is displayed in figure 3.

$$WQI = \frac{\sum_i^Q wi}{\sum_i^W} \dots\dots\dots\dots\dots\dots\dots.. (1)$$

The overall water quality index value was shown as WQI in equation 1. wi is relative weight computed using equation 2 and qi refers to water quality rating scale which can be determined by following equation 4 in which standard value was put as Si of ith parameter and actual value was assigned as Ci of ith parameter.

$$wi = \frac{k}{Si} \dots\dots\dots\dots\dots\dots\dots\dots\dots.. (2)$$

$$K = \frac{1}{\sum_{i=1}^{n} \frac{1}{Si}} \dots\dots\dots\dots\dots\dots\dots\dots (3)$$

$$qi = \left(\frac{Ci}{Si}\right) * 100 \dots\dots\dots\dots\dots\dots (4).$$

Table 1: Physiochemical and Microbiological Parameters with their thresholds and Methods

Sr. No	Parameters (Units)	NSDWQ with Standard Method
1.	pH	6.5-8.8, APHA-4500H+ B
2.	Color(pt-co Scale)	≤15, APHA-2120 B / C
3.	Odour	- , 2150 A
4.	Taste	- , APHA 2160 A
5.	Turbidity(NTU)	<5, APHA-2130 B
6.	TDS (mg/L)	<1000, APHA-2540C
7.	Cyanide (mg/L)	≤ 0.05, APHA-4500CN B
8.	Nitrate(mg/L)	≤50, APHA-4500 NO3 B

9.	Nitrite(mg/L)	≤ 3, APHA-4500 NO2 B
10.	Phenols(mg/L)	- , APHA-5530 D
11.	Free chlorine (mg/L)	0.2-0.5, APHA-4500Cl B+C
12.	Fluoride (mg/L)	≤ 1.5, APHA4500 F
13.	Hardness as CaCO3 (mg/L)	<500, APHA-2340 C / B
14.	Chloride (mg/L)	< 250, APHA-4500 Cl-
15.	Cadmium(mg/L)	0.01, APHA- 3111B
16.	Chromium(mg/L)	≤0.05, APHA- 3111B
17.	Copper(mg/L)	2, APHA- 3111B
18.	Iron(mg/L)	- , APHA- 3111B
19.	Lead(mg/L)	≤ 0.05, APHA- 3111B
20.	Manganese(mg/L)	≤ 0.5, APHA- 3111B
21.	Nickel(mg/L)	≤ 0.02, APHA- 3111B
22.	Silver(mg/L)	- , APHA- 3111B
23.	Arsenic(mg/L)	≤ 0.05, APHA- 3120B
24.	Barium(mg/L)	0.7, APHA- 3120B
25.	Boron(mg/L)	0.3, APHA- 3120B
26.	Mercury(mg/L)	≤0.001, APHA- 3120B
27.	Tc (CFU/100mL)	0, APHA-9222B
28.	Fc (CFU/100mL)	0, APHA-9222D
29.	FS (CFU/100mL)	0, APHA-9230C
30.	TPC (CFU/mL)	- , 9215B

APHA=American Public Health Association, pt-co Scale= Platinum- Cobalt Scale, NSDWQ=National Standards for Drinking Water Quality, mg/L= Milligram Per Liter, NTU= Nephelometric Turbidity Unit, CFU/mL= Colony Forming Unit/milliliter, TPC= Total Plate Count, Tc= Total Coliform, Fs= Feacal Streptococci Enterococci, Fc= Feacal Coliform

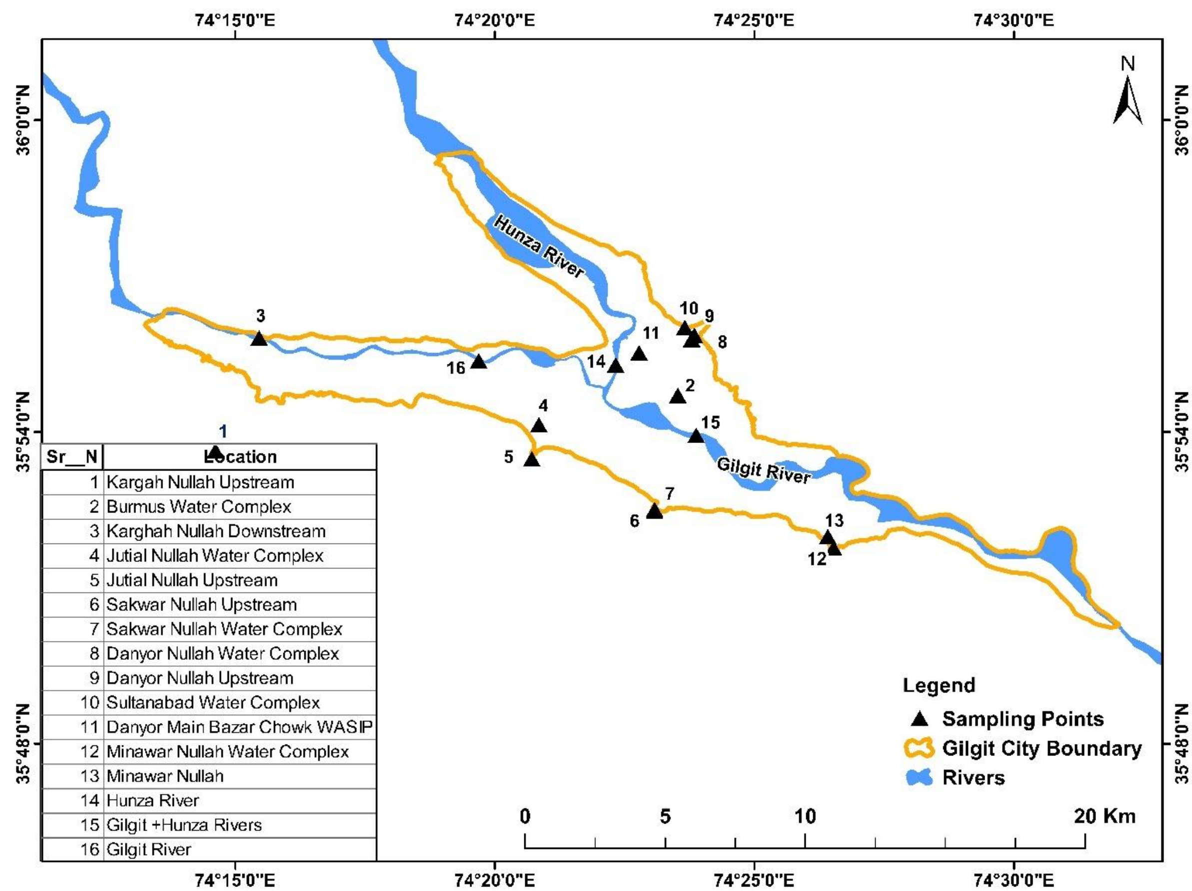

Figure 2: Geographical Location Map of Gilgit City Water Samples

Table 2: Details of FGDs.

FGD No	Nullah Name	Settlement Name	Total Houses	Number of Contributors
1.	Kargah Nullah	Yadgar Muhallah, Kashroat, Sonikot, Main City	11475	6
2.	Jutial Nullah	Khomar, Jutial,	9000	5
3.	Sakwar Nullah	Sakwar	1100	7
4.	Minawar Nullah	Minawar	600	5
5.	Danyore Nullah	Danyore, Muhamadabad, Sultanabad	10800	5

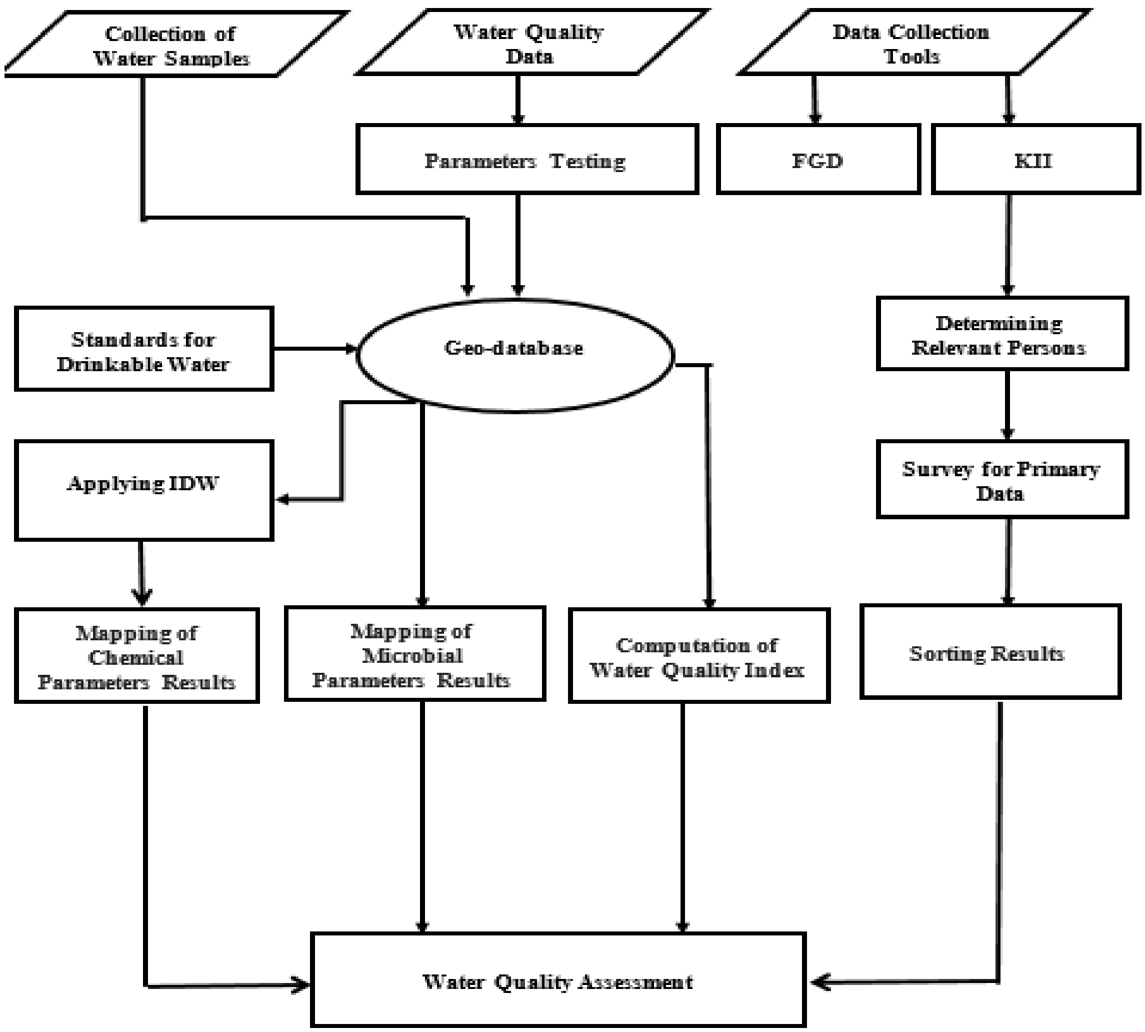

Figure 3: Methodology for Water Quality Assessment.

RESULTS AND DISCUSSION

The outcomes of physio-chemical parameters showed the selected parameters within the defined limits of national drinking water quality standards (Ministry of Environment, 2010) and the concerned province of study area (GB-EPA, 2019) stated in table 3. Table 4 displayed the root mean square error using multiple powers of Inverse Distance weighting. The determined value of pH showed minimum value (6.6) in Gilgit river and maximum (7.81) in Hunza river which is allowable for drinking water. No color, odour, cyanide, turbidity, taste, phenols and free chlorine were observed whereas, TDS was found <1000 mg/L, lowest in sample 1 and highest in Gilgit River and. Similarly, mercury, copper, arsenic, cadmium, chromium, iron, lead, silver, barium, boron, manganese and nickel were examined within the specified limits. Some parameters including nitrate, fluoride and nitrite were observed < 1(mg/L) value in the study area. The results of calcium carbonate and chloride were also within the range. Moreover, the developed maps of selected physio-chemical parameters results using IDW technique were displayed in figure 4. Taneez *et al.,* (2021) also found minimum presence of some heavy metals in his study area.

WQI analysis showed excellent water quality as per the recent conducted studies (Garcia-Avila et al., 2022; Shahid *et al.*, 2014; Akter *et al.*, 2016; Shahid *et al.*, 2017) because the calculated value at each sampling sites was less than 12. Garcia-Avila *et al*., (2022) also computed Good to Excellent WQI. In Nepal, WQI was determined using eight parameters and showed high quality water (Singh *et al.,* 2021). Another study conducted in Hemkund Lake of India also displayed excellent quality of water (Deep *et al.*, 2020).

There were four parameters including Fc, Tc, Fs and TPC were chosen for microbiological investigation in Gilgit City. The findings showed the presence of both Tc & Fc in the rivers and Fs in Hunza river only. In India, total coliform was also detected in the lake (Kumar and Sharma, 2019). The presence of microbiological pollutants proved the occurrence of human involved activities near water sources. In Danyore, the waste of existed slaughter house was also thrown into the river. Figure 4 represented the maximum value of observed TPC 29200 and minimum 15. Water was obtained directly from rivers for distribution to Gilgit City's people, with no further treatment. However, existed open water storage structures with various capacities were also employed to store water and their results were cleared during testing.

During investigation from the community, all the residents confirmed the use of untreated water for their requirements. Between June to September, water sources are full and minimum water availability was observed in December and January. There was no evidence of rainwater conservation practices. The present network of water supply was constructed more than 30 years ago by respective authority in the study area thus, rusted at most of the places. The availability of water in these lines was only for two to three hours usually. Agha Khan Development Network (AKDN) worked hard in the Gilgit City for the provision of drinkable water by replicating the public private sharing models such as the construction of a lengthy line for the distribution of clean drinkable water to the residents of three settlements in Danyore. The NGO also conducted testing in its programs for keeping its quality better. As, area of interest is deprived of the sewerage network so they are compelled to throw their waste into the rivers. The community raised a several issues relating to water including absence of water treatment plants, deficiency of knowledge, little pressure in supply lines, etc. They also recommended that all stakeholders should collaborate to solve these highlighted problems.

During discussion, EPA representative clarified the systematic testing of the sources for the water quality evaluation and recommended to separate waste water from the drinkable water. Assistant Professor at KIU also ensured the waste water was primary source of contamination in water sources. The plan of constructing sewerage in the study area was in the process informed by the respective official at Gilgit Development Authority but will be executed in sections due to budget constraints. He also emphasized to keep existing storage structure clean as the KIU concerned person. The EPA also advised developing an integrated watershed management plan as well as conducting sessions among the community for water. Both GDA and EPA are using GIS technology to some extent for the development and optimal resource allocation.

Table 3: Laboratory Results of Parameters.

Sr. NO	Parameters (Units)	WS1	WS2	WS3	WS4	WS5	WS6	WS7	WS8	WS9	WS10	WS11	WS12	WS13	WS14	WS15	WS16
1	pH	7.11	7.21	6.53	6.92	6.84	7.31	6.72	7.38	7.59	7.61	7.17	7.15	7.16	7.81	7.58	6.65
2	Color(pt-co)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	Odour	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
4	Taste	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5	Turbidity(NTU)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	TDS (mg/L)	68.82	201	71.1	157	105	189	118	313	311	309	254.11	131	136.21	212.76	235	327.23
7	Cyanide (mg/L)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
8	Nitrate(mg/L)	0.001	0.029	0	0.041	0.015	0.031	0.021	0.231	0.201	0.129	0.021	0.119	0.0.004	0.023	0.112	0.0029
9	Nitrite(mg/L)	0	.001	.001	.001	0	.002	.001	.012	0.031	0.027	0.015	0	0.006	0.0004	0.011	0.01
10	Phenols(mg/L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	Free chlorine (mg/L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	Fluoride (mg/L)	.002	.03	.001	.046	.003	.02	0.051	0.02	0.014	0.007	0.005	0.01	0.04	0.071	0.009	0.024
13	Hardness as CaCO3 (mg/L)	52	76	56	55	56	99	60	104	112	100	112	64	84	92	72	144
14	Chloride (mg/L)	23.48	52.1	25.44	45.02	41.09	78.05	43.05	58.71	62.61	52.83	46.96	46.96	31.31	43.05	52.83	72.41
15	Cadmium(mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
16	Chromium(mg/L)	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
17	Copper(mg/L)	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
18	Iron(mg/L)	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
19	Lead(mg/L)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
20	Manganese(mg/L)	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
21	Nickel(mg/L)	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
22	Silver(mg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
23	Arsenic(mg/L)	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
24	Barium(mg/L)	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
25	Boron(mg/L)	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
26	Mercury(mg/L)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
27	Tc (CFU/100mL)	0	0	0	0	0	0	0	0	0	0	0	0	0	19	14	5
28	Fc (CFU/100mL)	0	0	0	0	0	0	0	0	0	0	0	0	0	8	8	0
29	FS (CFU/100mL)	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0
30	TPC (CFU/mL)	315	90	1110	2970	14200	670	11500	2180	225	121	14200	15	115	1112	29200	920

WS=Water Sample, NO= Not Observed, ND= Not Detected, Tc= Total Coliform, Fc= Feacal Coliform, Fs= Feacal Streptococci Enterococci, TPC= Total Plate Count

Table 4: Root Mean Square Error of Selected Parameters using Multiple powers of Inverse Distance Weighting.

Parameters (Units)	1	2	3	4	5	(Optimal Power) with RMSE
pH	0.361559	0.3704674	0.383954	0.394127	0.399434	(1) 0.361559
TDS (mg/L)	60.67385	54.9396763	54.10561	55.4111	56.61241	(2.703) 53.9827
Nitrate (mg/L)	0.054105	0.05614439	0.056446	0.056688	0.056949	(1.001) 0.054104
Nitrite (mg/L)	0.007742	0.00848456	0.009048	0.009431	0.00965	(1) 0.007742
Fluoride (mg/L)	0.024866	0.02755807	0.029741	0.031196	0.032025	(1) 0.024866
Hardness as CaCO3 (mg/L)	26.42448	26.0020988	26.14341	26.73806	27.2781	(2.316) 25.9520
Chloride (mg/L)	16.58738	16.1512489	15.69367	15.57761	15.57753	(4.4109)15.572478

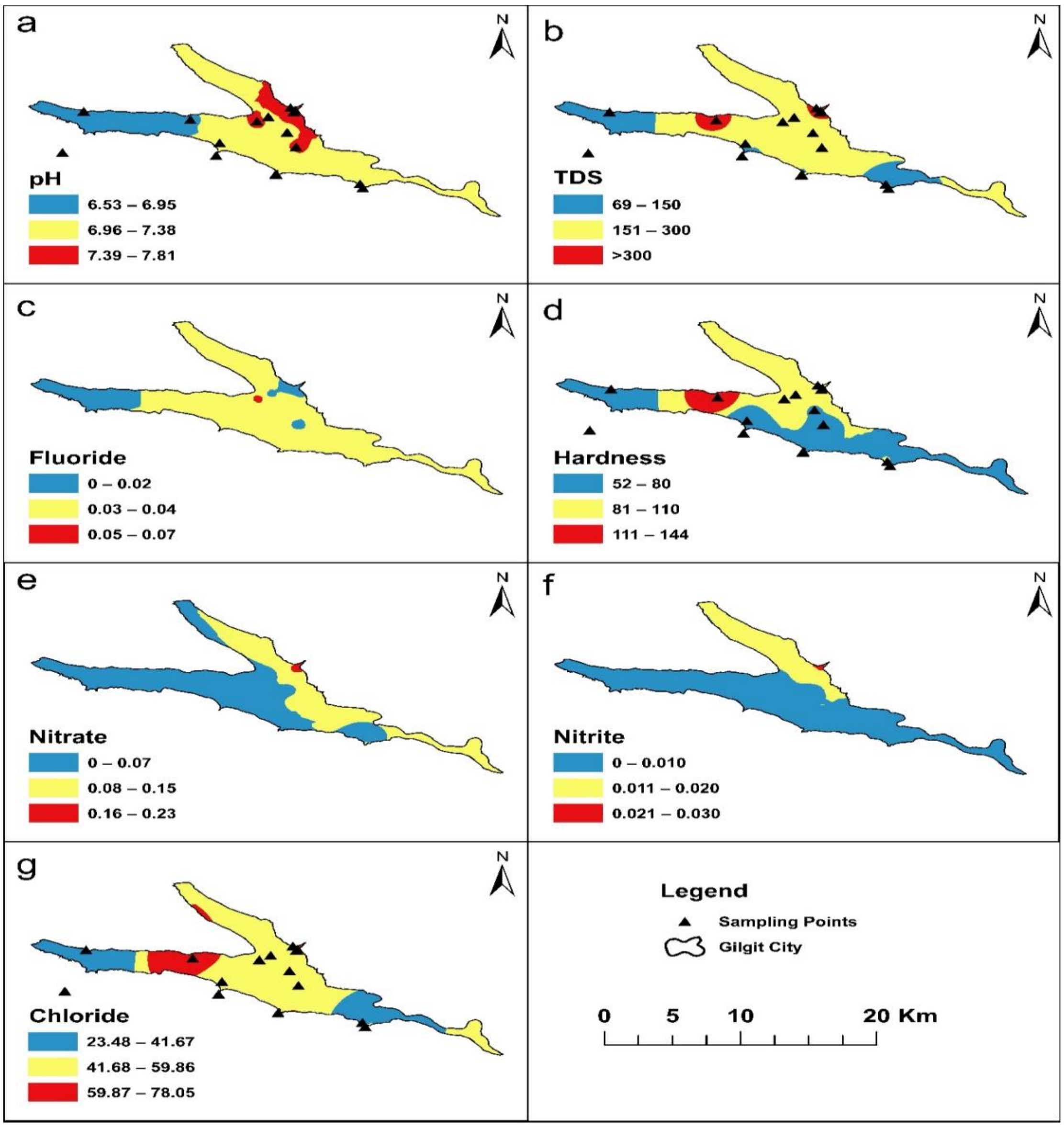

Figure 4: Chemical Concentration in Gilgit City

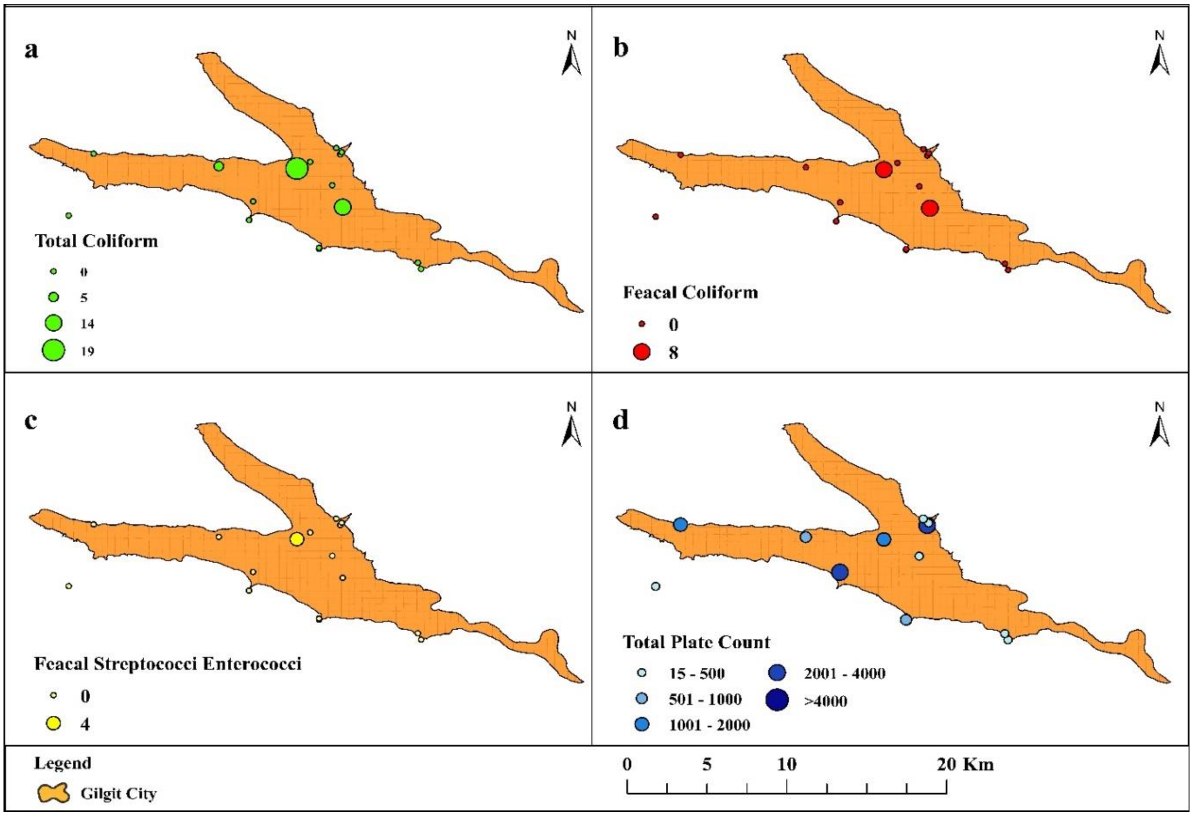

Figure 5: Microbiological Concentration in Gilgit City

Conclusion: Gilgit Baltistan is a region with high elevation and beautiful scenic views. In the last years, literature reported contamination in the surface water of Gilgit City. Therefore, this study was an effort to evaluate the quality of the water sources of Gilgit City in combination by analyzing its physio-chemical and microbiological parameters with drinking water quality standards and calculating the water quality index at each sampling site. Furthermore, the community of the study area was also probed to record their views regarding water quality issues and their solutions as an imperative objective.

The results of the study revealed that all physio-chemical parameters of water samples were within the tolerable range of prescribed standards however, both rivers observed microbiological pollution due to the mixing of liquid waste. The residents nearby these rivers were also performing anthropogenic activities. The installed filtration plants in the city were abandoned and existing water complexes were also uncovered. The concerned persons of EPA and KIU also emphasized to separate the fecal waste from natural water sources to reduce contamination in water. The officials of GDA clarified that the designed sewerage system plan will be implemented in phases due to budget constraints. The community also encouraged public-private projects for the development of their city. Both, EPA and GDA departments are using GIS technology in mapping, development and organizing their resources after realizing its importance.

In such a scenario, Gilgit's respective authority should work on filtration plants for supplying treated water to the residents as well as to protect the water storing structures with regular cleaning. The network of sewerage should be developed at the earliest for the preservation of water channels. Public Private partnership model should be operated for the development of the area as WASEP in the study area and the Component Sharing Model (CSM) in Karachi with many other districts of Punjab. An awareness campaign should be conducted for the preservation of water and the current issues in the city. GIS technology can plan an important role in resolving the highlighted issues. The maps developed using GIS technology can assist concerned authorities in solving their water-related issues. It would guide them to plan and manage their resources in a dexterous way as well.

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