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Water Quality Evaluation of Chapurson Valley in Hunza Nagar, Gilgit Baltistan, Pakistan, Based on Statistical Analysis and Water Quality Index

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Abstract

Water borne ailments are of serious public health concern in Gilgit Baltistan's (GB) region of Pakistan. The pollution load on the glacio-fluvial streams and surface water resources of the Chapurson Valley in the Hunza Nagar area of the GB is increasing as a result of anthropogenic activities and tourism. The present study focuses on the public health quality of drinking water of Chapurson valley. The study addressed the fundamental drinking water quality criteria in order to understand the state of the public health in the valley. To ascertain the current status of physico-chemical, metals, and bacteriological parameters, 25 water samples were collected through deterministic sampling strategy and examined accordingly. The physico-chemical parameters of the water samples collected from the valley were found to meet the World Health Organization (WHO) guidelines of drinking water. The water samples showed a pattern of mean metal concentrations in order of Arsenic (As) > Lead (Pb) > Iron (Fe) > Zinc (Zn) > Copper (Cu) > Magnesium (Mg) > Calcium (Ca). As, Cu, Zn, Ca and Mg concentration were under the WHO guidelines range. However, results showed that Pb and Fe are present at much higher concentrations than recommended WHO guidelines. Similarly, the results of the bacteriological analysis indicate that the water samples are heavily contaminated with the organisms of public health importance (including total coliforms (TCC), total faecal coliforms (TFC) and total fecal streptococci (TFS) are more than 3 MPN/100mL). Three principal components, accounting for 48.44% of the total variance, were revealed using principal component analysis (PCA). Bacteriological parameters were shown to be the main determinants of the water quality as depicted by the PCA analysis. The dendrogram of Cluster analysis using the Ward's method validated the same traits of the sampling locations that were found to be contaminated during geospatial analysis using the Inverse Distance Weight (IDW) method. Based on these findings, it is most likely that those anthropogenic activities and essentially the tourism results in pollution load from upstream channels. Metals may be released into surface and groundwater from a few underlying sources as a result of weathering and erosion. This study suggests that the valley water resources are more susceptible to bacteriological contamination and as such no water treatment facilities or protective measure have been taken to encounter the pollution load. People are drinking the contaminated water without questioning about the quality. It is recommended that the water resources of the valley should be monitored using standard protocol so as to protect not only the public health but to safe guard sustainable tourism in the valley.

Keywords

Chapurson Valley, Water Quality, Physico-Chemical, Principal Component Analysis (PCA), Inverse Distance Weight (IDW)

1. Introduction

Gilgit Baltistan (GB) region formerly known as northern areas is the water tower of Pakistan. Its glaciers supply the Indus River with 50.5 billion cubic meters of water yearly that accounts for 70% of the average annual flow. In GB, accessibility and availability of water is not a problem, but the quality of the water is an emerging problem having serious health implications. The primary causes of water quality deterioration in the region is mainly due to rapid population increase, economic advancements, human activities, lack of planning, capacity, paucity of financial resources, unsustainable tourism and overarching problem of climate change [1].

In GB, the main water sources are glaciers and snow melt. The melted snow joins streams, which in turn supply main waterways that deliver water into the human settlements for domestic and agricultural usages. The primary source of water for domestic consumption particularly in the rural areas is traditional irrigation channels. Water is also some time stored in manmade pits that is merely used for drinking and cooking. Even such types of pits are not protected by any means. Lesser snowfall and glacier melt which are not uncommon, not only restricted the water supply but also strongly influences the water quality. This situation is more pronounced during winter when the flow is drastically reduced from the upstream water channels. The water from the pit is supplied more often in the summer [2].

With a rich biodiversity made up of communities of a complex structure and high biological value, rivers and lakes are the ecosystems with tremendous ecological potential in the remote areas of GB. However, due to their unique typology, they are delicate and susceptible to environmental changes, particularly those brought by anthropogenic disturbances, which frequently indicate irreversible destruction of fragile ecosystem. The use of excessive amounts of fertilizers and pesticides in agriculture has also considerably contributed to the eutrophication and contamination of aquatic environments. Changes in the stream's watershed, brought on by agriculture, clear-cutting, wetlands degradation, and urbanization, have a significant impact on the quality of the stream water. These changes affect the stream physical properties, biota, and water chemistry. Frequent and ongoing monitoring is required to ascertain the impact of these changes on the water quality of a stream. Human activities that change the physical, chemical, and biological processes linked to water resources situate a lot of strain on freshwater ecosystems [3].

With this back drop, the purpose of this study is to examine the drinking water quality of the Chapurson Valley based on essential pollution indicators, such as physico-chemical, metals, and bacteriological parameters. The results are compared with the guidelines set by World Health Organization [4]. Water quality indices were also developed to have holistic picture of the current water quality in the valley. The findings of this study will aid the local water management authorities to make better decisions and maintain strict vigilance of the contrasting geospatial distribution of pollutants in the valley. It will also be easier to pinpoint the main sources of pollution entering in the river and surface water streams.

2. Materials and Methods

2.1. Study Area

Chapurson Valley is located in sub-district Gojal of district Hunza Nagar, Gilgit Baltistan, Pakistan (**Figure 1**). The is one of the most remote valley of Hunza districts that borders with Afghanistan at Wakhan corridor situated at 36˚45'N and 74˚20'E. The entire valley is about 70 km long. About 15% of the valley area is covered with great masses of glaciers [5]. The valley is home to eight dispersed settlements along either side of Chapurson River (Reshit, Yerzirich, Kirmin, Raminji, Kill, Zood Khon Ispanj, Sher-i-subz, and Shetmarj) and it is one of the remote places of GB region. The valley is geographically located at a height of 3000 meters above mean sea level as shown in the topographic map in **Figure 2**. The valley comprises of lofty mountains and multiple glacial and glacio-fluvial deposits. It is now one of the main tourist attractions of GB region owing to its scenic beauty, local hospitality and unique environmental features. The best time to visit the valley is from June to August. During this period the valley meadows are full of greenery with blossom of wild flowers. The temperature varies from 0˚C to 25˚C [5]. From November to February the temperature often varies between −7˚C to 8˚C. The rainfalls occur during the month of April. Snowfall occurs throughout the winter season.

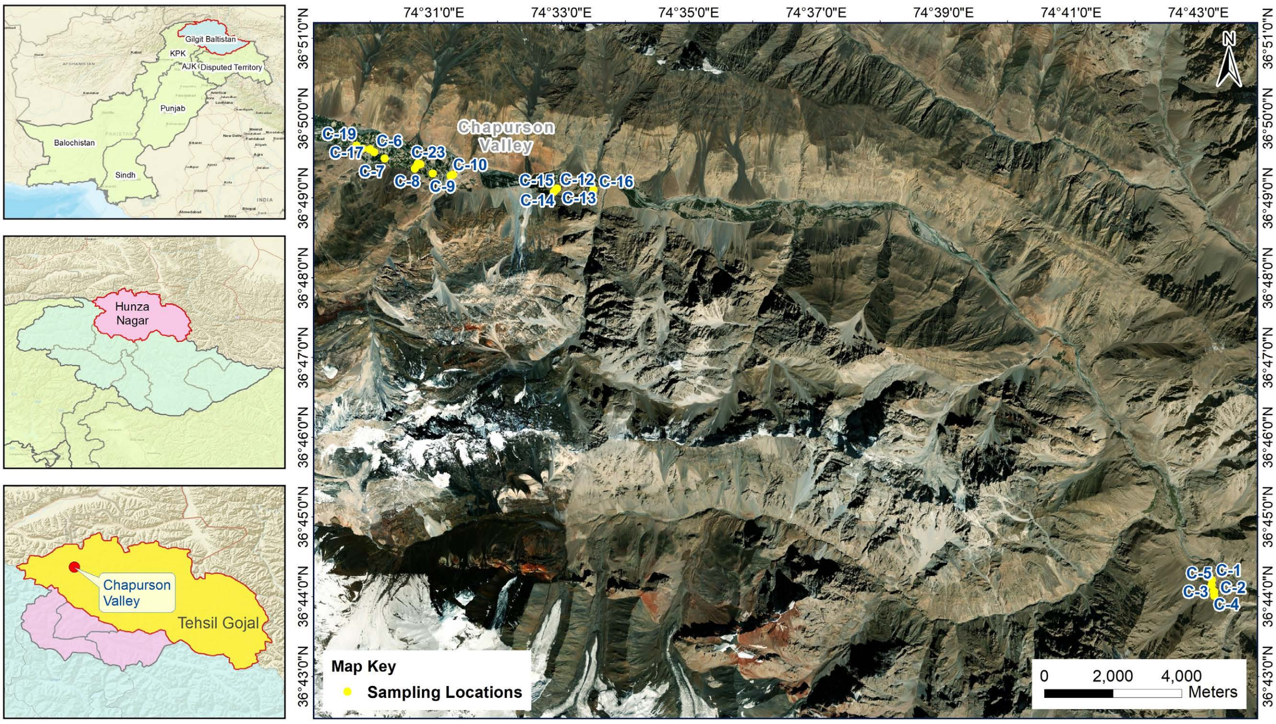

Figure 1. Study area and sampling location map of Chapurson valley.

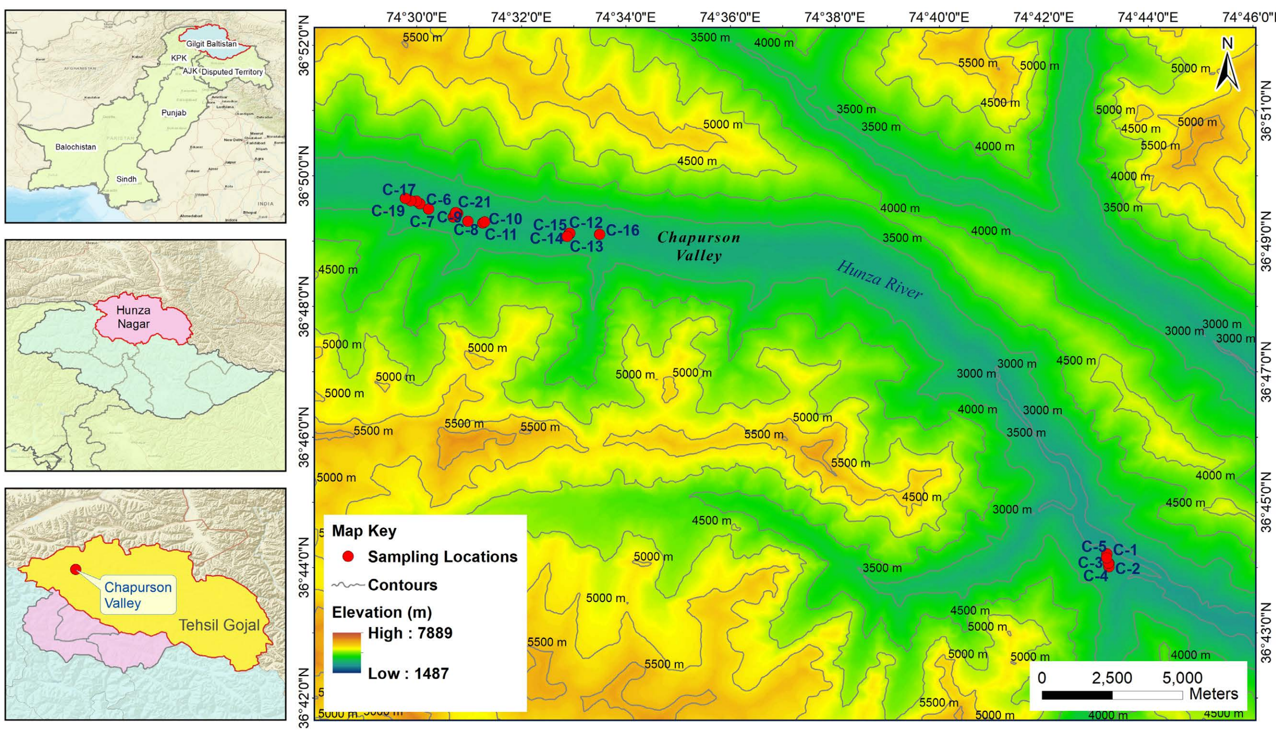

Figure 2. Topography and sampling location map of Chapurson valley.

The valley is only accessible through jeep or any other four wheelers. The valley is formerly inhabited by nomadic Khirgiz and Wakhis. The estimated population of the entire valley is around 3000 comprises of 500 households. The entire population is Wakhi and speaks Wakhi language. The people relies mostly on agriculture and livestock for their sustenance including sheep and yaks.

The main crops grown in the summer are wheat, maize, and barely. Due to the extremely low temperature in winter, the winter crops have minimal significance [6].

2.2. Water Sampling

A total of 25 water samples from the ChapursonValley were deterministically collected during day time in July to September 2021 using a random sampling strategy (**Figure 1**). According to site accessibility throughout the valley, spring and tap water samples were taken that are routinely used by the local community. Before being transported to the Institute of Environmental Studies at the University of Karachi for laboratory analysis, the samples were collected and kept in sanitized glass bottles in an icebox.

2.3. Physico-Chemical Analysis

On-site measurements were made for pH, turbidity, salinity, and total dissolved solids (TDS). A HACH Sension + MM156 Portable Multi-Parameter Meter (Model No. MM156) was used to measure pH and salinity, and EUTECH meter (Model No. TN-100) was used to measure turbidity in the water samples. For TDS and chloride, gravimetric and argentometric estimation techniques were used respectively. The gravimetric method was used to measure sulphate, and the Ethylenediaminetetraacetic acid (EDTA) titrimetric method was used to measure hardness. The brucine-reagent and ascorbic acid methods were used to measure nitrate and total phosphate, respectively. The above-mentioned parameters were analyzed using Standard Methods for the Examination of Water and Wastewater [7].

2.4. Metal Analysis

Arsenic (As), copper (Cu), lead (Pb), iron (Fe), zinc (Zn), calcium (Ca) and magnesium (Mg) were estimated using the appropriate standard Merck NOVA 60-Germany kits for metal analysis [7].

2.5. Bacteriological Analysis

The bacteriological parameters were examined in the water samples including total coliforms (TCC), total faecal coliforms (TFC) and total fecal streptococci (TFS). Single and double strength lactose broth (Merck, Germany) were used for TCC while EC medium (Merck, Germany) was used for the determination of TFC. TFS was estimated by using sodium azide broth [7]. The most probable number (MPN) technique was employed to determine the bacterial load in the water samples [7].

2.6. Statistical Analysis

Principal Component Analysis (PCA) is a thorough technique to comprehend the dynamics of all the variables in a system under observation [8]. By extracting the data as a small number of primary components, it aims to describe typical environmental characteristics while lowering the dimensionality of the multivariate dataset. The omission of information must be minimized in order to extract the primary principal elements that contain all relevant information [9]. In order to monitor the water quality of the Chapurson valley and pinpoint the key influencing factors, PCA is applied to the results of physico-chemical, metals, and bacteriological parameters. The following five primary operations [10] were employed using International Business Machines Corporation (IBM) Statistical Package for the Social Sciences (SPSS) v. 22 (SPSS Inc., Chicago, USA). The major resemblance function used for cluster analysis by unweighted pair group ordination was Euclidean distance [11].

1) Firstly, original data matrix was obtained as Equation (1):

$$X = \left(x_{ij}\right)_{n*p} = \begin{vmatrix} x_{11} & \cdots & x_{1p} \\ \vdots & \ddots & \vdots \\ x_{n1} & \cdots & x_{np} \end{vmatrix} \quad (1)$$

2) Equation (2) was used to normalize the original data and minimize its dimensionality:

$$x_{ij}^{*} = \frac{x_{ij} - \overline{x}_j}{s_j} \quad (2)$$

3) Correlation Coefficient Matric was obtained based on Equation (3):

$$R = \left(r_{ij}\right)_{p*p} = \frac{1}{n-1}\sum_{t=1}^{n} x_{ti}^{*} * x_{tj}^{*} \quad (3)$$

4) Eigenvalues and eigenvectors of the correlation coefficient matrix were obtained as Equation (4):

$$F_i = u_{i1}x_1^{*} + u_{i2}x_2^{*} + \cdots + u_{in}x_n^{*}\left(i = 1, 2, \cdots, n\right) \quad (4)$$

5) Principal components were obtained using Equation (5):

$$F = \frac{\lambda_1}{\lambda_1 + \lambda_2 + \cdots + \lambda_n}F_1 + \frac{\lambda_2}{\lambda_1 + \lambda_2 + \cdots + \lambda_n}F_2 + \cdots + \frac{\lambda_n}{\lambda_1 + \lambda_2 + \cdots + \lambda_n}F_n \quad (5)$$

where, n and p are number of sampling sites and water quality parameters, respectively; x_{ij} and x_{ij}^{*} are originally measured data and standardized variable, respectively; $\overline{x}_j$ is the average value for j^{th} indicator, s_j is standard deviation of j^{th} indicator, λ_i and u_i are eigenvalues and eigenvectors, respectively; and x_i^{*} is the standardized indicator variable.

Spatial Distribution by Inverse Distance Weight (IDW)

It is possible to infer the values of unknown points using weighted measurements and proximity-centered assumptions that close points are more comparable than the points positioned comparatively far apart. The inverse distance weighting and kriging geo-statistical interpolation techniques are the two most used (IDW). Data can be analyzed using a procedure known as kriging, which is further broken down into the categories of simple, ordinary, and universal kriging, by allocating weights to known or observed values based on the spatial orientation of the measured sites [12]. IDW is based on the idea that closer samples have a bigger impact on the unsampled position than kriging, hence it only considers the proximity of the known (sampled) points [13] [14]. The IDW method was employed in this analysis and was based on the strategy stated in a previous work [15]. Physico-chemical parameters, metals, microbiological parameters, and the projected WQI are all estimated geographically while combining Equations (6) and (7) using Esri's ArcMap 10.8.1 software.

$$Z(S_0)=\sum_i^n W_i Z(S_i) \tag{6}$$

$$W_i=\frac{\frac{1}{d_1^k}}{\sum_{i=1}^n \frac{1}{d_1^k}} \tag{7}$$

where, $Z(S_0)$ is unknown value for interpolation; $Z(S_i)$ is i^{th} data value of sampled location; n is the number of sampling points; W_i is the weight; d_i is horizontal distance between the observed and interpolation points; and k is the power of distance.

3. Results and Discussion

3.1. Descriptive Statistics

The results of descriptive statistics were obtained using OriginPro 2022 [16] in order to compute the mean, minimum, maximum and standard errors (**Table 1**).

3.2. Physico-Chemical Characteristics

The physico-chemical parameters of the water samples collected from the Chapurson Valley were all found to meet the set WHO guidelines set for drinking water quality.

3.2.1. pH

The pH of the water samples varied from 7 to 7.3 with 7.16 ± 0.10 as an average. Studies from other valleys in GB including Basho, Chu Tran, and Shigar have reported mean pH values as 7.22 [17], 7.17 [18], and 7.135 [15], respectively. However, the slightly alkaline pH (7.4) along Sultanabad Stream is consistent with the findings of the present study [3].

3.2.2. Turbidity

Turbidity was found to range from 0.41 to 0.89 Nephelometric Turbidity Unit (NTU) (0.66 ± 0.12 NTU), which is within the WHO-recommended limits (5 NTU), in water samples taken from the Chapurson Valley. Although the turbidity values are lower than those found in Basho valley of GB (0.480 ± 15) [17] and Chu Tran Valley (0.390 ± 03 NTU) [18] and are comparable to previous studies of the nearby areas [2] [15].

Table 1. Descriptive statistics of 25 water samples from Chapurson valley.

Parameters	Unit	Mean	Standard Deviation	Minimum	Maximum	Median	WHO Guideline 2011
Physico-chemical							
pH	-	7.16	0.10	7	7.3	7.1	6.5 - 8.5
Turbidity	NTU	0.66	0.12	0.41	0.89	0.67	<5
Salinity	‰	0.32	0.04	0.21	0.38	0.33	1.2
Total Dissolved Solids (TDS)	mg/L	378.30	7.00	365.46	388.28	379.36	<1000
Chloride		65.92	3.37	62	74	65	<250
Hardness		139.60	5.35	132	155	138	<500
Sulphate (SO_4^-)		78.24	3.38	72	86	78	250
Nitrate (NO_3^-)		0.09	0.01	0.054	0.099	0.089	12
Metals							
Arsenic (As)	mg/L	0.01	0.00	0	0.0094	0.0061	0.01
Copper (Cu)		0.75	0.07	0.64	0.85	0.75	0.2
Lead (Pb)		0.08*	0.01	0.045	0.099	0.085	<0.01
Iron (Fe)		0.32*	0.05	0.22	0.4	0.33	0.3
Zinc (Zn)		0.49	0.04	0.42	0.59	0.48	0.5
Calcium (Ca)		37.42	1.23	35.25	39.14	37.36	150
Magnesium (Mg)		10.76	0.81	9.33	12.36	10.69	100
Bacteriology							
Total Coliform Count (TCC)	MPN/100mL	24.16	91.93	3	460	3	0
Total Faecal Coliform (TFC)		12.88	41.84	3	210	3	0
Total Faecal Streptococci (TFS)		3.16	0.80	3	7	3	0

*Mean values are above WHO Guidelines (WHO, 2011).

3.2.3. Salinity

Salinity values of water samples from Chapurson Valley ranged from 0.21‰ - 0.38‰, with a mean of 0.32‰ and a standard deviation of 0.04. Although they are still below the WHO-recommended limits (for salinity: 1.2‰), the present salinity values are higher than the 0.015‰ - 0.025‰ estimated in a study to assess the drinking water quality status in the Gilgit city of GB region [2].

3.2.4. Total Dissolved Solids (TDS)

TDS concentration in water samples from Chapurson Valley ranged from 365.46 to 388.28 mg/L (378.30 ± 7.0 mg/L), which is higher than the TDS levels recorded in Nagar Valley of District Hunza in 2013 (175.7 - 233.67 mg/L) [19], but significantly lower than those recorded in Chu Tran Valley of District Skardu (440.76 mg/L) [18]. Other investigations have revealed mean TDS values of 280.4 mg/L

[17] 104.8 mg/L [20], and 284.4 mg/L [3] in water samples from the GB region, all of which are lower than the mean concentration obtained in the current study. However, each of these water sample concentration is substantially below the TDS threshold limit (1000 mg/L) established by the WHO.

3.2.5. Chloride

The chloride concentrations of the water samples from the valley ranged from 62 to 74 mg/L, with a mean value of 65.92 ± 3.37 mg/L. The results demonstrated that the chloride concentrations in water samples are well below the WHO guidelines of 250 mg/L. However, other studies found that the Basho Valley and Chu Tran Valley in GB, respectively, had chloride concentration between 58 and 106 mg/L [17] and 87 to 139 mg/L [18], respectively.

3.2.6. Hardness

With a mean concentration of 139.60 ± 5.35 mg/L, the hardness as $CaCO_3$ concentration was below the WHO guidelines of 500 mg/L, ranging from 132 to 155 mg/L. The presence of hardness in water samples was also noted in studies conducted in other valleys of GB, with the concentration of 4.66 ± 16.66 mg/L in Nagar Valley [19], 160 ± 190 mg/L in Danyore Valley [2], 130.54 ± 76.75 mg/L in Chu Tran Valley [18] and 102.9 ± 10.44 mg/L in Basho valley [17].

3.2.7. Sulphate

Sulphate concentration of water samples fluctuated in a narrow range, from 132 to 135 mg/L, with a mean value of 78.24 ± 3.38 mg/L. Sulphate concentration in the water samples in general are significantly well below the WHO guidelines (250 mg/L). Sulphate concentrations of the water samples valley are is consistent with those found in Basho valley (89.5 ± 9.86 mg/L) [17] and in Chu Tran Valley (130.54 ± 12.88 mg/L) of GB region [18].

3.2.8. Nitrate

The results showed that the average nitrate (NO_3) concentration in the water samples from Chapurson Valley is 0.09 ± 0.01 mg/L, with a range of 0.054 to 0.099 mg/L. Sultanabad stream in GB has a somewhat higher nitrate concentration (8.8 mg/L) [3]. The study conducted for Shigar Valley had a nitrate concentration of 0.188 ± 0.024 mg/L [15], Chu Tran Valley had a nitrate concentration of 0.23 ± 0.14 mg/L [18], and Basho Valley had a nitrate concentration of 0.25 ± 0.08 mg/L [17]. Results from this study are somewhat inferior to those from other valleys in Skardu.

3.3. Heavy Metals in Water Samples

Chapurson Valley water samples showed a pattern of mean metal concentrations that went as follows: As > Pb > Fe > Zn > Cu > Mg > Ca. Arsenic, copper, zinc, calcium, and magnesium were found in amounts that were within the WHO guidelines (**Table 1**). However, results showed that lead and iron are present at much higher concentrations than recommended by the WHO. Continuous ingestion of these heavy metals through drinking water poses a serious risk to the public health [17].

3.4. Bacteriological Quality of Water

The findings revealed that the water samples from springs and taps in Chapurson Valley were contaminated with the organisms of public health importance therefore render unfit for human consumption. The bacteriological contamination (**Table 1**) is mainly due the indiscriminate disposal of human and animal waste. It is pertinent to mention that as such water and sewage infrastructures are hardly available in the valley. The human and animal wastes ultimately find its way to the nearby water channels. Moreover, water treatment facility particularly water disinfection is absolutely not available in the valley. Although, general health of the local people is good and the average life span is much higher than the rest of the country but still water borne diseases are common in the valley. No productive efforts have been made from the governmental side to provide safe water to the community. Few initiatives, however taken by the NGOs in particular Aga Khan Rural Support programme to develop water infrastructure in the valley but it is only restricted to the water supply and not related to the water treatment. Toilet facilities are available in almost all the residential units but the safe disposal of human waste is still a big challenge in the valley. Local livestock is yet another source of water contamination in the valley. As such solid waste disposal system is also not available, therefore the chances of water contamination are much more than expected.

3.5. Multivariate Analysis

3.5.1. Principal Component Analysis (PCA)

PCA was used to examine the effects of physico-chemical, metal, and microbiological characteristics on the water quality in Chapurson Valley using normalised data. **Table 2** displays the first three fundamental components, their eigenvalues, variance in percentage, and cumulative percentages. Three dimensional (3D) ordination for PCA analysis of physico-chemical, metals, and microbial parameters in the water samples of Chapurson Valley is also provided in **Figure 3**.

48.44% of the overall variation was found to be accounted for by the first three factors. The first component, which made up 20.75% of the total variation, was mainly explained by high concentrations of microbiological parameters. Additional evidence that the first component has higher concentrations at the bulk of the sampling locations comes from the monitoring findings exceeding WHO limits. Previous study pertains to the GB regions showed that sediments along the Indus River were contaminated with physico-chemical substances [21].

Chemical parameters including as sulphate, calcium, chloride as well as high levels of salinity are closely associated to the second component, which accounts for 14.489% of the overall variation. Metals make up the majority of the connected features, similar to how they do for the first principal component. Lead,

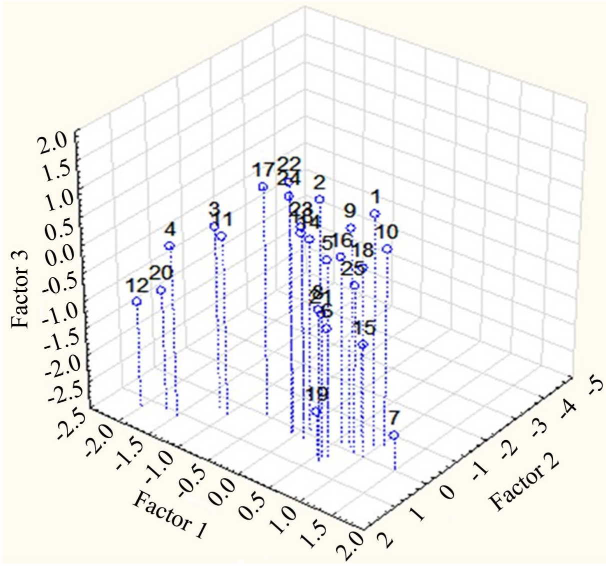

Figure 3. Principal component analysis ordination (3D) of physico-chemical, metal and bacteriological analysis of Chapurson valley.

Table 2. Results of Principal Component Analysis (PCA).

Component	Eigenvalue	Percentage variance	Cumulative percentage variance	First 4 eigenvector coefficients	Associated variables
1	3.736600	20.75889	20.75889	−0.877176	TCC
				−0.876495	TFC
				−0.866995	TFS
				−0.540642	pH
2	2.608091	14.48939	35.24828	0.665031	SO_4
				0.499548	Ca
				−0.494256	Chloride
				0.480129	Salinity
3	2.374754	13.19308	48.44136	0.655017	Pb
				−0.642994	Hardness
				−0.632820	Cu
				−0.566887	SO_4

hardness, copper, as well as elevated concentrations of sulphate have an impact on the third principal component, which makes up 13.193% of the total variance.

3.5.2. Cluster Analysis

Using physicochemical, metal, and microbiological data, cluster analysis and the dendrogram created using the Ward's technique showed that the sampling locations could be divided into two main groups (**Figure 4**). Group 1, which consists of 24 samples shows that all sampling locations have similar characteristics. In contrast, Group 2 has just one sample. Group 1 further divided into multiple sub-groups. The results revealed that the water quality of Chapursonvalley is likely to be affected by essentially by human activities.

3.5.3. Box and Whisker Plot

Box & Whisker plots are also developed to visualize the results summary (**Figures 5-7**). It does not provide as much detail as a histogram, but it is particularly useful for indicating whether a distribution is skewed and whether there are any potentially unusual observations (outliers) in the data set. A box plot is ideal for comparing distributions because it shows the center, spread, and overall range right quite apparently [22].

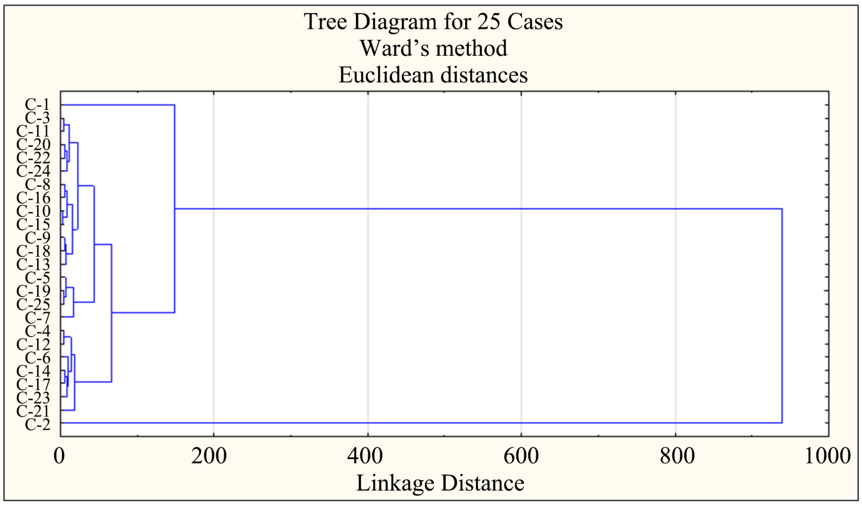

Figure 4. Dendogram derived using Ward's method at 25 sites of Chapurson valley based on physico-chemical, metals and microbial parameters.

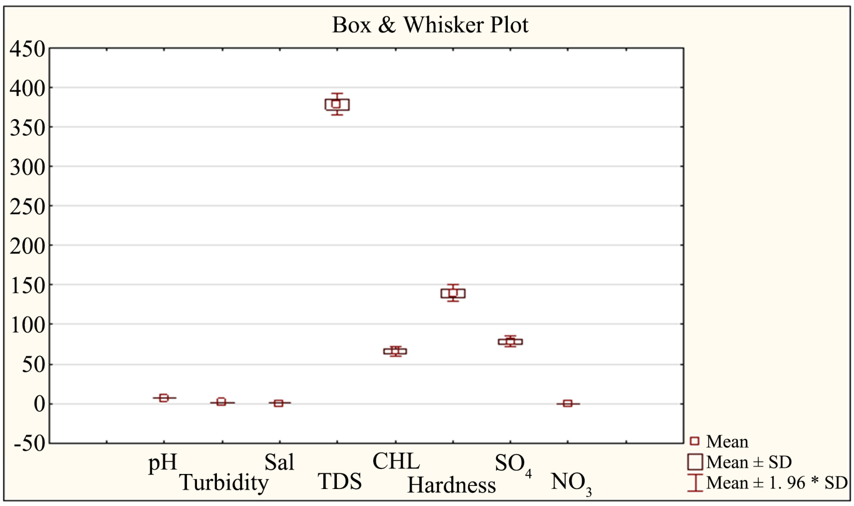

Figure 5. Box & whisker plot based on physico-chemical analysis of Chapurson valley water samples.

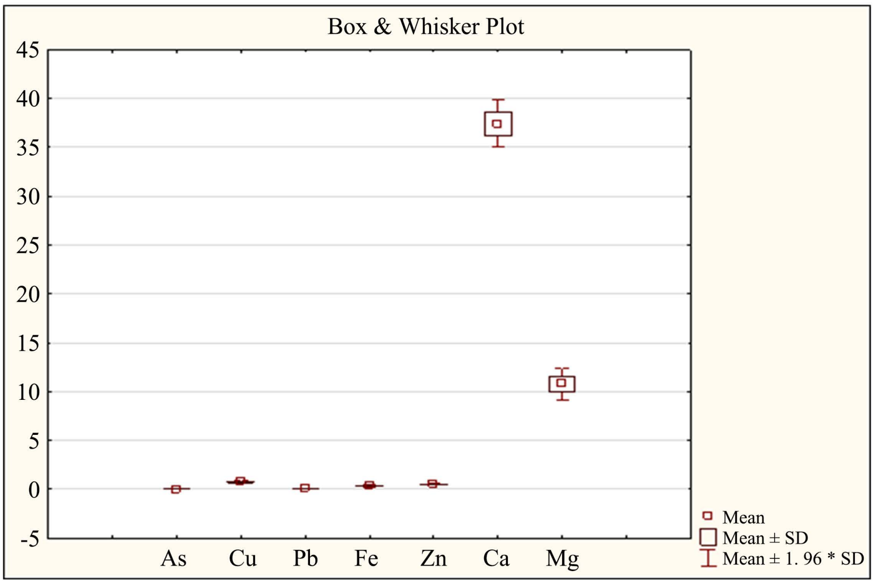

Figure 6. Box & whisker plot based on heavy metals analysis of Chapurson valley water samples.

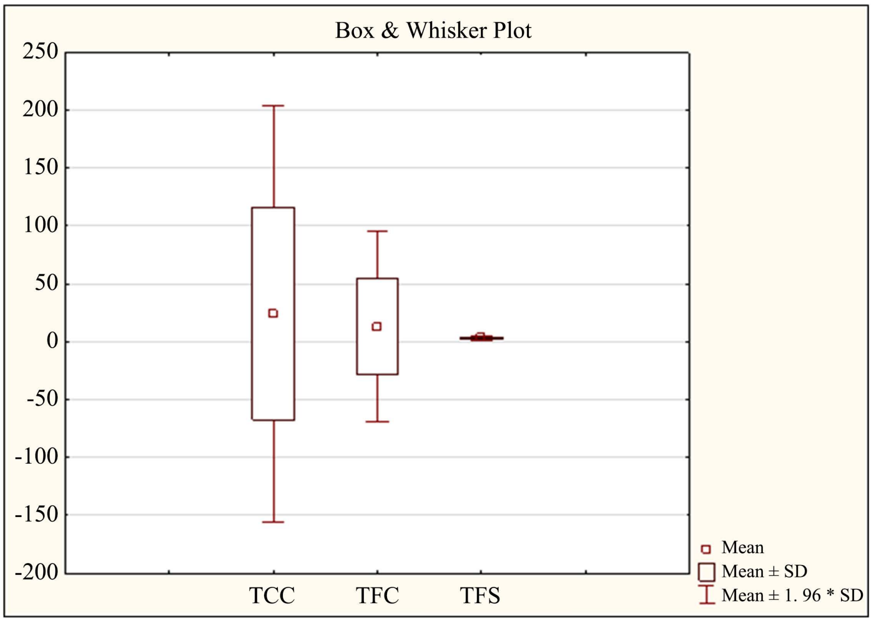

Figure 7. Box & whisker plot based on microbiological analysis of Chapurson valley water samples.

3.5.4. Correlation Matrix

For the information on water quality, a correlation coefficient matrix was also created to examine the relationships between the variables, as shown in **Table 3**. The method adopted was the examination of the positive and negative correlation for trends in concentration among water quality measures in the Chapurson Valley that were either significant or not [23]. Only few physico-chemical parameters were found to have a significant positive correlation ($r > 0.5$) such as pH, Hardness, and Turbidity. These water quality indicators primarily show the

Table 3. Correlation coefficient matrix.

	pH	TBD	SLN	TDS	CHL	HRD	SLP	NIT	As	Cu	Pb	Fe	Zn	Ca	Mg	TCC	TFC	TFS
pH	1																	
TBD	−0.153	1																
SLN	0.294	**−0.456***	1															
TDS	0.193	−0.218	**0.398***	1														
CHL	**−0.556**	0.263	−0.366	−0.227	1													
HRD	0.124	0.231	0.005	0.054	−0.178	1												
SLP	0.173	−0.160	0.366	0.112	−0.383	**0.604***	1											
NIT	0.182	0.065	0.157	0.052	0.188	0.247	0.347	1										
As	0.207	0.135	−0.068	0.161	−0.261	−0.128	−0.107	−0.255	1									
Cu	−0.188	**0.424**	−0.236	−0.120	0.119	0.281	0.199	−0.266	−0.113	1								
Pb	0.120	−0.227	−0.193	−0.265	0.039	−0.178	−0.366	−0.024	0.073	**−0.440***	1							
Fe	−0.206	**0.529***	0.104	−0.374	0.119	0.164	0.033	0.037	−0.049	0.249	−0.272	1						
Zn	−0.209	0.258	−0.013	0.081	**0.397***	0.036	−0.150	0.071	0.043	0.234	−0.015	0.104	1					
Ca	−0.053	−0.037	−0.079	0.081	−0.091	0.082	0.231	0.142	−0.381	−0.077	0.079	−0.151	−0.054	1				
Mg	0.115	−0.099	0.027	−0.029	0.121	−0.229	0.114	0.059	−0.111	0.128	−0.142	−0.178	0.266	0.252	1			
TCC	0.268	−0.119	0.185	0.134	−0.221	−0.084	0.012	0.042	0.168	−0.080	0.033	−0.129	0.158	−0.320	−0.082	1		
TFC	0.263	−0.129	0.182	0.142	−0.216	−0.088	0.018	0.046	0.165	−0.086	0.036	−0.144	0.150	−0.308	−0.079	**0.999***	1	
TFS	0.287	−0.070	0.195	0.094	−0.243	−0.062	−0.015	0.026	0.179	−0.052	0.019	−0.064	0.188	−0.367	−0.095	**0.988***	**0.982***	1

Bold typeface: Strong correlation coefficient.

physical and chemical properties of the surface water in the Chapurson Valley, which may be used to gauge the effects of human activity and provide further information about how PCA can be used to analyze the monitoring data [24]. Strong positive relationships were also seen for Cu and Pb and among microbial parameters TCC and TFC also showed positive correlation with TFS.

3.6. Geospatial Distribution

Geospatial distribution of physico-chemical parameters and metals is illustrated in the **Figure 8** and **Figure 9**, respectively. The regional distribution demonstrates that Pb, Fe and Ca are just a few of the few metals and physico-chemical characteristics that have significantly impacted the quality of the water in the central and eastern regions. However, the pollutant levels in these valley areas suggested that human activity, notably domestic and agricultural runoff are significant contributor to surface water contamination along Chapurson Valley. Spatial distribution of physico-chemical (**Figure 8**) shows that turbidity and salinity levels are increased towards eastern and western parts of the valley whereas TDS is also found in higher concentrations at intermittent locations towards

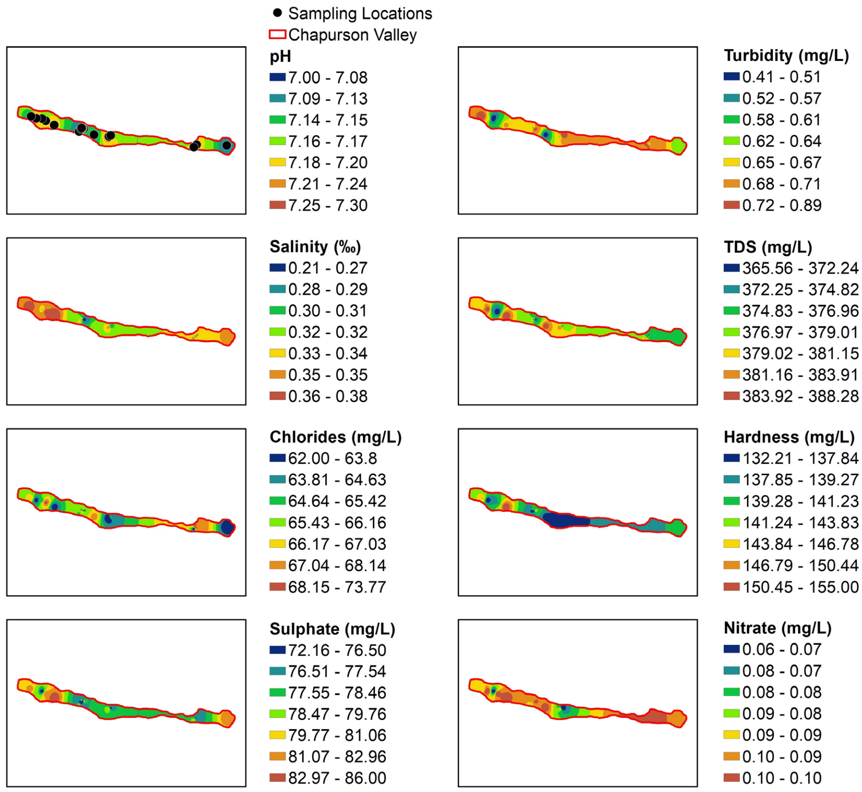

Figure 8. Geospatial distribution of physico-chemical water quality in Chapurson valley.

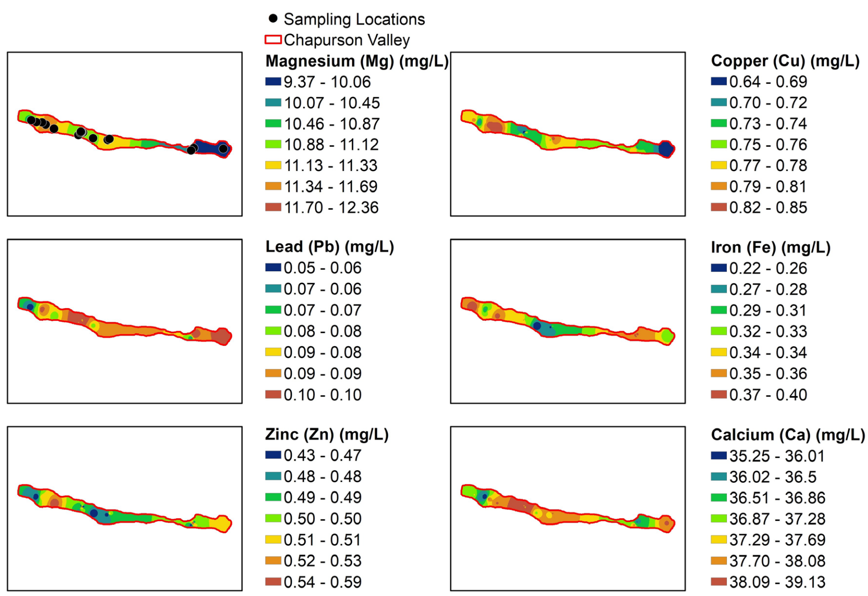

Figure 9. Geospatial distribution of metals in Chapurson valley.

west. Among all samples, those obtained from extreme eastern and western locations of the valley, tend to have higher concentrations of sulphate. However, nitrate is also found in concentrations throughout the valley except few sampling locations. As illustrated in Figure 9, Mg and Cu are found in higher concentrations at western and central parts of the valley, whereas, Pb and Ca are robustly found the water samples throughout the valley. Few locations at eastern and western ends of the valley shows that Fe is found in the water samples at elevated levels. Zn is only shown in increased level at few locations at western parts of the valley.

4. Conclusion

This study comes to the conclusion that the majority of drinking water sources in the valley are contaminated primarily with the organisms of public health importance. Except for Pb and Fe the metals concentration is well within the limits. These metals and bacteriological pollution sources are potential environmental contaminants and hazardous to human health, thus there is a pressing need to limit the risk of exposure. Water borne ailments prevailing in the valley are mainly due to the consumption of water directly from the channels. Elderly people and children are mostly suffering from water borne diseases. There is a dire need to establish water quality surveillance programme and establish water treatment facility in the valley. What is more strongly needed is to have water disinfection system to ensure potable water supply to the community. Future water quality monitoring research studies should be piloted to conduct more systematic efforts to identify contaminants important to impaired water quality, as well as enhanced quantification of chemicals with high biological activity.

Authors Contribution

All authors of the paper have actively contributed to the scientific study reported in the paper and to the preparation of the manuscript.

Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest

The authors declare that they have no competing interests.

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