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Physiochemical Analysis of Fresh Water Sources in District Bhimber, Azad Jammu Kashmir

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Abstract: The present study investigates the physiochemical parameters of drinking water quality in district Bhimber of Azad Jammu and Kashmir. The drinking water supplies in the area come from four main sources, streams, springs, hand pumps and boreholes. A total of seventy one (71) samples from all four water sources were taken for determination of physiochemical parameters. The results show considerable variation in water quality parameters of different water sources. However, the data analyses indicate that physiochemical parameters of water samples are well within the permissible limits of drinking water quality. Stream water samples show slightly higher pH values, while two samples from hand-pump have shown marginally higher content of TDS. The mean values of dissolved oxygen in borehole and hand-pump water samples are also slightly below the water quality standard limits. The correlation studies show that pH has a strong negative correlation with calcium and positive relation with sodium in water samples of all four sources. Similarly, the dissolved oxygen has shown negative relationship with temperature and a weak to moderate positive relationship with pH of water. No evidence of pollution and industrial contamination of water was found. The study found that water from all four sources is safe for drinking purpose.

Keywords: Water quality analysis, physiochemical parameters, correlation studies, Azad Jammu Kashmir.

Introduction

Drinking water is a vital component for human beings and contamination of such a vital resource due to rapid population growth, industrialization and urbanization is a serious health concern (Velea et al., 2009). Clean and safe drinking water is the key to good health and it is being used for a variety of purposes such as household, industries, agriculture and for recreation purposes (Shirley et al., 2000). Household uses may include drinking, personal hygiene, cleaning and food production (Cahill, 2002; Rezaee et al., 2012). Drinking water can be contaminated from either geogenic (erosion, rocks weathering and ore deposits) or anthropogenic (wastewater, agricultural activities, mining and industries) sources.

The geology of the area and water-rock interaction has significant influence on the water quality. Previously, several studies have been conducted on water quality that showed well water in areas with specific geological feature did not meet the required drinking water standard without anthropogenic influence (Edmunds and Smedley, 1996). Agriculture effluents discharge into aquatic systems poses serious threats to the community that consume such contaminated water (Alkarkhi et al., 2008). For a safe and healthy life, drinking water must be free from pathogens and organic and inorganic pollutants and free from all those impurities which affect itscolor, taste and odor (Kraemer et al., 2001). The World Health Organization (WHO, 1998) has recommended general drinking water quality guidelines. However, the term maximum allowable concentration for heavy metals in drinking and spring water is still a subject of interest for scientists and researchers.

Trace elements concentration in ground water is also a subject of interest (Giammanco et al., 1998; Smith and Enger, 2015). Similarly, the shifting of interest towards the need for clean drinking water and prevention of environmental pollution for healthy life leads to establishment of drinking water quality guidelines (WHO, 1998).

The surface water is more easily accessible and at the same time, is more vulnerable to be contaminated by the microorganisms. Besides, it depends upon various other factors such as environmental conditions of that particular area, waste material mixed with water and discharge from the agricultural field and treatment plants (Greenstone and Hanna, 2014). Rainfall and topography of the specific region also play an important role in determining the water quality. On the other hand, ground water is more safe compared to surface water, because it is free from any dust particles and any other harmful materials. Springs, wells and tube wells are the common sources of ground water.

It should be kept in view that deep wells are less prone to contamination while shallow wells are more, which may cause numerous environmental and health problems (Abbas et al., 2014). The underground water is mostly comprised of chemical constituents, which are of different kinds. They depend on water movement, geo-chemical environment and the concentration of dissolved constituents, which are comparatively higher in underground water as compared to the surface water (Giammanco et al., 1998). Chemical contamination is one of the most serious matters that affect the underground water through infiltration, leaks in pipelines and cross contamination between aquifers that can transmit the pollutants among them (Rapant and Krcmova, 2007). Heavy metals are toxic in nature and impair the quality of water and food; therefore, they are of global concern among environmental contaminants (Shah et al., 2012a).

Improper and inadequate sanitation, chlorination and sewage flooding may result in waterborne diseases in human beings (Amr and Yassin, 2008). Similarly, unhygienic living condition of poor societies can also cause water borne diseases (Lehloesa, 2000) in most of the developing countries. According to United Nations Environmental Program (UNEP), five to ten million deaths occur every year from the diseases caused by polluted water. A study carried out by the United Nations (UN) claimed that in 2025, most of the people will be suffering from shortage of fresh water (Seckler, 1998). Globally, environmental researchers have a prime focus on health risk assessment of humans through consumption of drinking water (Spayd et al., 2012).

Pakistan is a developing country, facing serious crisis in safe and clean potable water supply in urban and rural areas. In the northern region of Pakistan, only a few studies on the drinking water contamination have been reported in the past (Shah et al., 2012a; Muhammad et al., 2011). The aim of the study was to investigate the current status of quality of drinking water and to assess any health risks associated with drinking water. The research work will provide a base for the awareness campaign regarding the importance of pure and safe drinking water quality.

Location of Study Area

The study area lies in the Bhimber district of Azad Jammu & Kashmir (Fig. 1) and falls in the Survey of Pakistan topographic sheet Nos. 43-G/12, 43-G/16, 43-K/4, 43-L/1 and 43-L/5 with coordinates as Longitude: 73° 57 29 E to 74° 16 55 E, Latitude: 32° 57 86 N to 33° 09 41 N. The area is approximately 500 m above mean sea level and receives an average annual rainfall of 750 mm. The study area lies in the semi-arid zone. Temperature displays great seasonal and annual fluctuations and in the month of June it is over 40^{0}C. The area receives heavy monsoon rains during July to September. The winter rainfall is mainly caused by the movement of westerly winds.

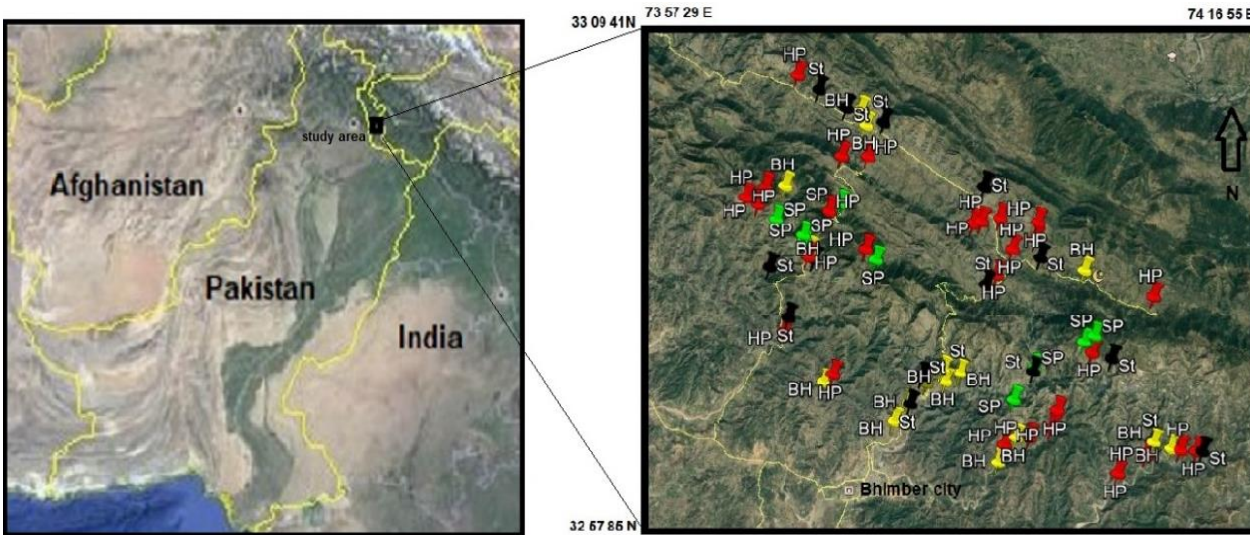

Fig. 1 Map of study area and location of sampling points where HP is sampling point of hand-pump water samples SP is spring water, ST is stream water and BH is borehole water sample point).

Geological and Structural Setting of the Area

The Neogene Siwaliks Group rocks are exposed in the area. The older strata overlying the basement rocks are not exposed in the area. Most outcrops are incised by deep sewerage lines/*nalas* and characterized by rugged topography due to lithological variation along trend and show the development of dendritic drainage pattern including the BhundarKas, Bhimber and Sukatarnalas. These sewerage lines/nala systems originate from the northern peripheral outskirts of mountain belts and run across the strike of strata and ultimately drain into the Chenab river.

The strata exposed in Bhimber and its surrounding areas are mostly molasses. These horizons represent detritus mass derived from the sub-aerial waste of the Himalayan Mountains, swept down by the complex riverine system and streams. The deposition is predominantly bifacial with some conglomerates in the uppermost horizons. Dhok Pathan and Soan formations are exposed in Bhimber, Sangar, Babot and ChittiDheri areas. The detailed survey of these rock units indicates more or less continuous alternate beds of sandstone and shale with subordinate siltstone. The thicknesses of

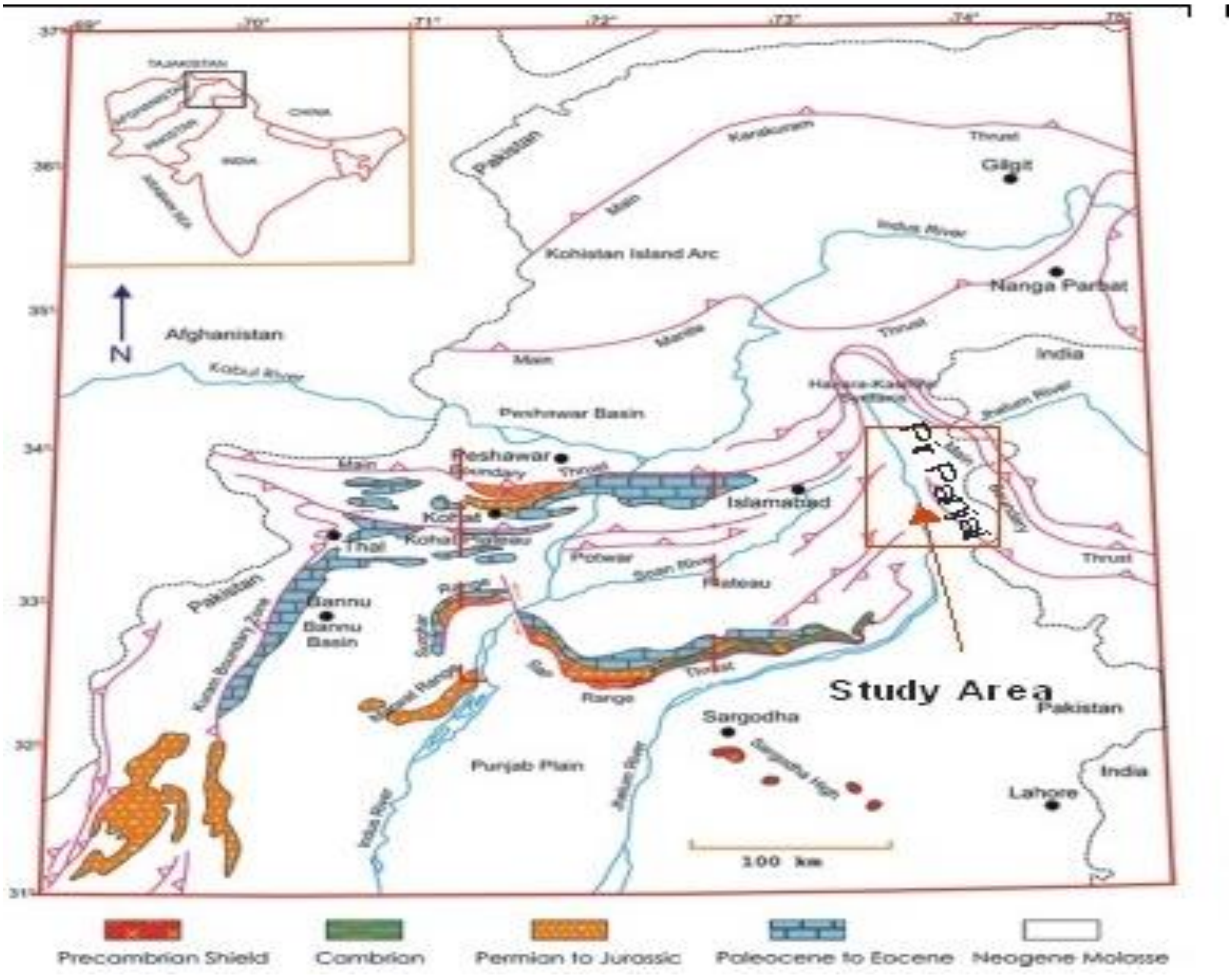

Fig. 2 Geological and tectonic map of northern Pakistan showing study area (Beck et al., 1995).

these alternate beds vary from place to place. The sandstones are generally light grey to brownish grey in color, medium to coarse grained, massive to thickly bedded, friable and micaceous, poorly to moderately sorted. Structurally, the Bhimber area lies along the southern most fringes of Pir Panjal Range forming the southern foot hill mountain belt of Himalayas (Fig. 2).

The strata of the Siwalik Group having monotonous southern dips follow the general strike direction (NW-SE). The northern flank of this belt has a faulted contact with a large elongated anticline comprised of the rocks of Eocene on both sides and a breached core of Mesozoic-Paleozoic rocks. Finally, a major thrust is marking the contact between predominantly sedimentary sequence towards south and metamorphic-igneous rocks towards north (Beck et.al., 1995).

Materials and Methods

A total of 71 water samples were collected to determine the drinking water quality parameters of the area. Water samples from four sources, streams (sixteen samples), boreholes (seventeen samples), hand pumps (twenty-eight samples) and springs (ten samples) were taken in clean plastic bottles following the standard procedure. All the protocols for sample analysis were followed as per specifications outlined in standard method of water testing (APHA, AWWA and WEF 1998). The parameters such as pH, dissolved oxygen (DO) and temperature were measured in the field using Hanna Instrument HI 9829 potable meter. The chemical parameters of water quality, total dissolved solids (TDS) and concentrations of Sodium (Na^+), Calcium (Ca^{2+}), Magnesium (Mg^{2+}) and Sulfate (SO_4^{2-}) were determined in the environmental lab of Bahria University Islamabad.

Results and Discussion

Physiochemical characteristics of different water sources such as stream, spring, borehole and hand pumps give a clear picture of the water quality. Drinking water quality has been affected by a number of physiochemical factors causing different environmental problems and health hazards (Mora et al., 2009). The values of measured physiochemical parameters of selected water samples are shown in Table 1. The results of physiochemical parameters show considerable variation in water quality of different water sources. The pH values of water

Table 1. Range and mean (standard deviation) concentrations (mg/L) of physiochemical parameters in drinking water samples of stream, borehole, handpump and spring in the study area.

	Stream samples		Borehole samples		Hand Pump samples		Springs samples		
Parameters	**Range**	**Mean ± SD**	**Range**	**Mean ± SD**	**Range**	**Mean ± SD**	**Range**	**Mean ± SD**	**WHO**
Temp ^{0}C	9.5 - 31.7	17±7.5	13.1- 26.4	21.58±3.27	17.3-26.8	22.4±2.4	14.4-21	17.09±2.2	-
pH	8.11 - 8.84	8.5±0.2	6.91- 8.7	7.66±0.59	6.8-8.44	7.26±0.32	7.0-8.3	7.42±0.43	6.5-8.5
TDS mg/L	185 - 279	237.8±25.83	112 - 603	352±106	205-690	378±109	220-468	331.1±68	500
DO mg/L	4.26-7.6	6.09±0.84	1.01-5.02	2.47±1.30	1.02-4.29	2.28±0.81	1.9-6.7	3.95±1.59	3
Ca mg/L	3 - 68	41.13±18.46	3.0-130	65.06±47	5.0-167	98.5±36.54	46-125	85.4±25	200
Mg mg/L	5- 24	16.19±4.92	0.6-36	14.64±11	1.0-33.0	18.64±7.54	16-42	25.4±8	150
Na mg/L	22 - 101	49.25±21.51	12.0-272	74.88±71	15.0-280	52.5±54	14 - 170	50.0±46	200
Cl mg/L	4 - 10	6.88±1.8	3.0-71	74.88±71	3.0-51	20±14.87	3 - 17	6.2±4.9	200
SO4 mg/L	8-37	17±8.4	5-56	74.88±71	1-83	26.9±22.3	1-31	12.9±11	400

Table 2. Pearson correlation matrix for water quality parameters of stream samples.

Parameters	**Temp.**	**pH**	**TDS**	**DO**	**Ca^{+2}**	**Mg+2**	**Na^{+1}**	**Cl^{-1}**	**$SO4^{-2}$**
Temp.	1								
pH	-0.568	1							
TDS	-0.389	0.180	1						
DO	-0.778	0.541	0.201	1					
Ca^{+2}	-0.294	-0.289	0.222	0.325	1				
Mg^{+2}	0.241	-0.465	-0.149	0.085	0.274	1			
Na^{+1}	-0.259	0.570	0.555	0.090	-0.456	-0.470	1		
Cl^{-1}	-0.060	0.337	0.259	0.175	-0.301	-0.131	0.503	1	
$SO4^{-2}$	-0.039	0.326	0.299	0.117	-0.129	0.127	0.295	0.521	1

samples from hand pumps and springs ranged from 6.8 to 8.44 and 7.0 to 8.31 respectively and fall within the permissible limits of WHO. However, pH values of twelve water samples obtained from stream and two samples of borehole water fall above the WHO permissible limit.

The higher pH values indicate alkaline nature of water which may be caused by carbonate rocks in the stream catchment. Similarly, it is the indication of presence of trace metals in the study area, which affect the pH (Giammanco et al., 1998). It is assumed that these contaminants may be geogenic in nature, as the area is less affected by anthropogenic activities. Among different physiochemical parameters, pH is considered as the basic indicator for determining water quality and has an indirect effect on human health, as it provides an ideal condition for microorganisms to survive in and spread fatal diseases (Ho et al., 2003).

The DO values shown in Table 1 indicate that DO is significantly low in some samples of bore hole, hand pumps and spring water, whereas the stream water contains DO amount as per WHO standards. The mixing of running water and direct contact with atmosphere allow stream water to absorb sufficient oxygen. The low values of DO in underground water sources may be caused by oxidation of organic matter in the subsurface. DO is a key component in determining the degree of freshness of an aquatic system (Fakayode, 2005).

The concentration of chemical parameters determined in the drinking water, as shown in Table 1 mainly falls within the permissible limits of water quality standards. Calcium (Ca^{2+}) ranges from 3.0 to 167.0 mg/L with comparatively higher mean value of 98.5 mg/L in water samples from hand pumps. The results of sodium (Na^{1+}) ranges from 12.0 to 272.0 mg/L. One sample each from bore hole and hand pump source contains higher than permissible concentration of sodium. However, the mean values of sodium in bore hole and hand pump samples are 74.88 and 52.25 mg/L respectively, which is safe for drinking purpose. Similarly, TDS value ranges between 112 to 690 mg/L. The maximum value of 690 mg/L was observed in water sample, which comes from hand pumps. Most of the samples have TDS values within the permissible limit, with few exceptions, where the TDS exceeds the permissible limit. Higher concentration of TDS is harmful for aquatic biota and human beings and excessive use of such contaminated water can cause kidney disease. TDS in drinking water originates from natural sources, sewage, urban run-off, industrial wastewater and chemicals used in the water treatment process (Jain, 1998).

The chloride concentration varies from 3.0 to 71.0 mg/L with minimum mean value of 6.2 mg/L in spring water and maximum average value of 17.59 mg/L in samples from borehole source. The obtained results were all within the limits set by WHO (200 mg/L). Similarly, the values of sulfate show the result in a range of 1.0 to 81.0 mg/L. The maximum value of 81.0 mg/L was observed for hand pump water sample and results are within permissible limits.

The water samples taken from stream show strong negative correlation between temperature and dissolved oxygen (r = -0.778), while similar relationship is also found between temperature and pH (r = -0.568) given in Table 2. The sodium ion has significantly positive correlation with pH (r = 0.570) and chloride ion (r = 0.503) in water samples of stream source. The Pearson correlation coefficients of water quality parameters of borehole samples are shown in Table 3. The pH of borehole samples show very strong negative correlation with calcium(r = -0.908) and magnesium (r = -0.625) while positive relation with sodium (r = 0.601) was observed. The TDS values have positive correlation with sodium (r = 0.538), chloride (r = 0.652) and sulfate (r = 0.664) in the bore hole water. The results also show strong positive relationship between sulfate and chloride (r = 0.82).

The results of Pearson correlation of water quality parameters of hand pump samples are similar with those of bore hole and stream water samples (Table 4). The pH values have strong negative correlation with calcium (r = -0.883), magnesium (r = -0.548) and positive relation with sodium (r = 0.762). Similarly, strong positive relationship of TDS was found with chloride (r = 0.666) and sulfate (r = 0.647). The results of correlation analysis of spring samples yield comparable values (Table 5). The dissolved oxygen displays strong positive association with pH (r = 0.908), chloride (r =0.846) and sodium (r =0.687). TDS results expectedly show strong relation with magnesium (r = 0.951) and sodium (r = 0.729). Calcium demonstrates strong negative relationship with sodium (r = -0.603), chloride (r = -0.620) and sulfate (r = -0.558). The physiochemical parameters analyzed to determine the water quality of the study area mostly fall within the permissible limits set by WHO for drinking water. The range of temperature values is comparable with other studies of similar water sources ((Fakayode, 2005; Mustapha, 2008).

The dissolved oxygen content of water is a key parameter for assessing the ecological health and quality of water. The higher values of dissolved oxygen in stream water is probably caused by mixing of running river water and low temperature as shown in Table 2 by its strong negative correlation coefficient value (r = -0.778). The

Table 3. Pearson correlation matrix for water quality parameters of borehole samples.

Parameters	Temp.	pH	TDS	DO	Ca+2	Mg+2	Na+1	Cl-1	SO4-2
Temp.	1								
pH	-0.368	1							
TDS	0.121	-0.123	1						
DO	-0.531	0.076	-0.246	1					
Ca+2	0.136	-0.908	0.229	-0.018	1				
Mg+2	0.002	-0.625	0.164	0.464	0.699	1			
Na+1	0.085	0.601	0.538	-0.283	-0.605	-0.483	1		
Cl-1	0.002	-0.253	0.652	-0.184	0.355	0.154	0.262	1	
SO4-2	0.017	-0.123	0.664	-0.040	0.223	0.216	0.305	0.825	1

Table 4. Pearson correlation matrix for water quality parameters of hand pump samples.

Parameters	Temp.	pH	TDS	DO	Ca+2	Mg+2	Na+1	Cl-1	SO4-2
Temp.	1								
pH	-0.435	1							
TDS	0.161	-0.057	1						
DO	-0.178	0.067	-0.102	1					
Ca+2	0.510	-0.883	0.391	-0.021	1				
Mg+2	-0.024	-0.548	0.259	0.043	0.557	1			
Na+1	-0.255	0.762	0.494	-0.074	-0.558	-0.483	1		
Cl-1	0.046	-0.052	0.666	0.014	0.300	0.130	0.304	1	
SO4-2	0.305	-0.172	0.647	-0.302	0.435	0.164	0.144	0.667	1

Table 5. Pearson correlation matrix for water quality parameters of spring samples

Parameters	Temp.	pH	TDS	DO	Ca+2	Mg+2	Na+1	Cl-1	SO4-2
Temp.	1								
pH	-0.466	1							
TDS	0.096	0.205	1						
DO	-0.634	0.908	0.252	1					
Ca+2	-0.020	-0.810	0.002	-0.606	1				
Mg+2	0.227	0.252	0.951	0.297	-0.145	1			
Na+1	-0.157	0.757	0.729	0.687	-0.603	0.737	1		
Cl-1	-0.232	0.816	0.455	0.846	-0.620	0.578	0.785	1	
SO4-2	0.278	0.496	0.462	0.430	-0.558	0.674	0.603	0.779	1

low values of dissolved oxygen in some samples of bore hole and hand pump sources may be caused by high temperature and decomposition.

Like other fresh water sources, the dominant cation in water samples is calcium and magnesium. Both calcium and magnesium show strong negative relationship with sodium. The occurrence of calcium and magnesium in water sources can be attributed to catchment geology and rock weathering (Lesack and Melack, 1991). The pH values of majority water samples tend to indicate alkaline environment with some values even higher than the maximum permissible limit of 8.5. These high pH values are most likely caused by natural geological conditions of the area, as there are no obvious pollution sources except for surface runoff for agriculture land.

Conclusion

The results of physiochemical parameters analyzed in the present study indicate that physiochemical characteristics of water samples taken from four water sources i.e. stream, borehole, hand pumps and spring in Bhimber district of AJK largely fall within permissible limits. The 60% samples of stream water were found to have higher than desirable pH values. However, the use of stream water for drinking purpose is negligible in the area as most people rely on water from borehole and hand pump sources. The quality of drinking water from spring, borehole and hand pump sources is well within the WHO standards. Only two samples, one each from borehole and hand pump source, contains higher than permissible concentration of sodium ion.

The correlation studies show that pH has a strong negative correlation with calcium and positive relation with sodium in water samples of all four sources. Similarly, dissolved oxygen has negative relation with temperature and a weak to moderate positive relationship with pH of water. The results of correlation coefficients will help in picking the suitable treatments to reduce the contamination of water. There is need for awareness among the people to preserve and maintain the water sources at their highest quality and purity levels and the present research work in the area may prove useful in achieving it.

References

Alkarkhi, A. F., Ahmad, A., Ismail, N.,Easa, A.M. (2008). Multivariate analysis of heavy metals concentrations in river estuary. *Environmental Monitoring and Assessment*, **143** (1), 179-186.

Amr, S.A.,Yassin, M.M. (2008). Microbial contamination of the drinking water distribution system and its impact on human health in Khan Yunis Governorate, Gaza Strip: seven years of monitoring (2000–2006).*Public health*, **122**(11), 1275-1283.

Abbas, N., Deeba, F., Irfan, M., Butt, M.T., Jamil, N., Khan, A. (2014). Treatability study of arsenic, fluoride and nitrate from drinking water by adsorption process. *Journal of the Chemical Society of Pakistan*, **36** (5), 837-840.

APhA, A.W.W.A. (1998). WEF (American Public Health Association, American Water Works Association, and Water Environment Federation). Standard methods for the examination of water and wastewater, 19.

Beck, R.A., Burbank, D.W., Sercombe, W.J., Riley, G.W., Barndt, J.K., Berry, J.R., Afzal, J., Khan, A.M., Jurgen, H., Metje, J.,Cheema, A. (1995). Stratigraphic evidence for an early collision between northwest India and Asia. *Nature*, **373**(6509), 55-59.

Cahill, A.T. (2002). Determination of changes in streamflow variance by means of a wavelet-based test. *Water Resources Research*, **38**(6), 262-271.

Edmunds, W. M., Smedley, P. L. (1996). Groundwater geochemistry and health: an overview. *Geological Society, London, Special Publications*, **113**(1), 91-105.

Fakayode, S. O. (2005). Impact of industrial effluents on water quality of the receiving Alaro river in Ibadan, Nigeria.

Giammanco, S., Ottaviani, M., Valenza, M., Veschetti, E., Principio, E., Giammanco, G., Pignato, S. (1998). Major and trace elements geochemistry in the ground waters of a volcanic area: Mount Etna (Sicily, Italy). *Water Research*, **32** (1), 19-30.

Greenstone, M., Hanna, R. (2014). Environmental regulations, air and water pollution and infant mortality in India. *The American Economic Review*, **104**(10), 3038-3072.

Ho, K.C., Chow, Y. L., Yau, J.T.S. (2003). Chemical and microbiological qualities of The East River (Dongjiang) water, with particular reference to drinking water supply in Hong Kong. *Chemosphere*, **52** (9), 1441-1450.

Jain, P.K. (1998). Hydrogeology and quality of ground water around Hirapur, district sagar (mp) (a case study of Proterozoic rocks). *Pollution Research*, **17**, 91-94.

Kraemer, A. (2001). Protecting water resources: pollution prevention. Thematic background paper. In International Conference on Freshwater. BMU.

Lehloesa, N.Y.O. (2000). Evaluation of the impact of household treatment procedures on the quality of groundwater supplies in the rural community of the Victoria district, Eastern Cape. *Water SA*, **26**(2), 285-290.

Lesack, L. F.,Melack, J.M. (1991). The deposition, composition, and potential sources of major ionic solutes in rain of the central Amazon basin. *Water Resources Research*, **27**(11), 2953-2977.

Mora, A., Mac-Quhae, C., Calzadilla, M., Sánchez, L. (2009). Survey of trace metals in drinking water supplied to rural populations in the eastern Llanos of Venezuela. *Journal of Environmental Management*, **90** (2), 752-759.

Muhammad, S., Shah, M.T., Khan, S. (2011). Health risk assessment of heavy metals and their source apportionment in drinking water of Kohistan region, northern Pakistan. *Microchemical Journal*, **98**(2), 334-343.

Mustapha, M.K. (2008). Assessment of the water quality of Oyun reservoir, Offa, Nigeria, using selected physico-chemical parameters. *Turkish Journal of Fisheries and Aquatic Sciences*,**8** (2), 309-319.

Rapant, S., Krčmová, K. (2007). Health risk assessment maps for arsenic groundwater content: application of national geochemical databases. *Environmental Geochemistry and Health*, **29**(2), 131-141.

Rezaee, R., Hassanzadeh-Khayyat, M., Mehri, F., Khashyarmanesh, Z., Moallemzadeh, H., Karimi, G. (2012). Determination of parathion, aldicarb, and thiobencarb in tap water and bottled mineral water in Mashhad, Iran. *Drug and Chemical Toxicology*, **35** (2), 192-198.

Seckler, D.W. (1998). World water demand and supply, 1990 to 2025: Scenarios and issues.**19**. Iwmi.

Shirley, M.M., Xu, L. C., Zuluaga, A.M. (2000). Reforming the urban water system in Santiago, Chile.

Smith, B., Enger, E. (2015). Environmental Science. McGraw-Hill higher education.

Spayd, S. E., Robson, M.G., Xie, R., Buckley, B.T. (2012). Importance of arsenic speciation in populations exposed to arsenic in drinking water. *Human and Ecological Risk Assessment: An International Journal*, **18**(6), 1271-1291.

Shah, M.T., Ara, J., Muhammad, S., Khan, S., Tariq, S. (2012). Health risk assessment via surface water and sub-surface water consumption in the mafic and ultramafic terrain, Mohmand agency, northern Pakistan. *Journal of Geochemical Exploration*, **118**, 60-67.

Velea, T., Gherghe, L., Predica, V., Krebs, R. (2009). Heavy metal contamination in the vicinity of an industrial area near Bucharest. *Environmental Science and Pollution Research*, **16** (1), 27-32.

World Health Organization. (1998). Guidelines for drinking-water quality**. 2,** Health criteria and other supporting information: addendum.