

Physicochemical properties of irrigation water in western Himalayas, Pakistan

Haider Abbas, Muhammad Zafar Khan, Farida Begum, Nani Raut and Smriti Gurung

ABSTRACT

Appropriate irrigation water quality is essential for maintaining soil properties. This study investigates numerous physicochemical properties of irrigation water in three Himalayan valleys in northern Pakistan, receiving water from different sources. A total of 36 samples (3 replicates from four points at each site) were randomly collected and analyzed following standard laboratory techniques. The results revealed that most of the physicochemical parameters were within the permissible limits as specified by FAO, USEPA, and WWF for agriculture water. However, the total dissolved solids, potassium, mercury, nickel, and cadmium were found beyond the recommended ranges. Analysis of variance indicated that the mean values of various constituents differed significantly across the sources. Among the water sources, the mix of spring and glacial meltwater was found to contain maximum parameters within the permissible limits. The study recommends further investigating the implications of the existing water quality parameters on crop productivity and human health.

Key words | glacial meltwater, heavy metals, irrigation, nutrients, physicochemical properties, water quality

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HIGHLIGHTS

- Irrigated agriculture is an integral part of the agropastoral societies in the dry temperate region of the western Himalayas.
- The paper attempts to evaluate the irrigation water quality in the region, which is one of the least researched themes in the area.
- The paper concludes that the irrigation water in the study area greatly meets the quality standards, usually thought to be less suitable due to ruggedness, glaciation and geological processes. Few physicochemical properties were found to be beyond the permissible ranges.
- The paper makes interesting comparison between different water sources and finds the mix of spring and glacial meltwater to be more suitable in terms of quality standards.

INTRODUCTION

Water quality in general refers to the desired physical, chemical, and biological properties of water, defined in terms of human usage (Ritchie & Schiebe 2000; Haydar *et al.* 2016). Understanding water quality has become important in water resource planning and development for drinking, industrial and irrigation purposes (Shakoor 2015).

Irrigation water quality is becoming an important concern worldwide, owing to the challenges of agricultural intensification, climatic changes and excessive use of ground aquifers in arid and semi-arid conditions (Laze *et al.* 2016; Zaman *et al.* 2018). Irrigation depends not only on sufficient amounts of water, but also on its good quality, which is

essential for maintaining soil conditions, crop quality, and ecosystem health (Ayers & Westcot 1994).

Irrigation water, whether derived from surface or ground aquifers, contains substantial amounts of salts and chemical substances in solutions that may have an impact on crop yield and soil fertility (Phocaides 2007). The concentrations and composition of soluble salts in water determine its quality for irrigation (Zaman *et al.* 2018). The accumulation of salts in the root zone limits availability and uptake of water, causing plant stress and eventually decreasing crop yields (Shakoor 2015). A high concentration of salts can also change the plant nutrients balance in the soil, while some salts are toxic to certain plants (Irfan *et al.* 2014; Shakoor *et al.* 2015).

In addition to dissolved salts, which have been a major problem for centuries, irrigation water often contains substances derived from natural as well as anthropogenic sources (Ayers & Westcot 1994). The chemical constituents of irrigation water can affect plant growth directly through toxicity or deficiency, or indirectly by altering availability of nutrients (Ayers & Westcot 1994; Rowe & Abdel-Magid 1995). Similarly, the presence of certain metals in irrigation water also adversely affects crop production (Ali *et al.* 2003).

The characteristics of irrigation water vary with sources and locations (Zaman *et al.* 2018). There are regional differences in their characteristics, based mainly on geology and climate (Islam & Shamsad 2009). Several studies have been conducted throughout the world as well as in Pakistan to assess the irrigation water quality of different water sources (Mussarat *et al.* 2007; Ali *et al.* 2009; Verma *et al.* 2012).

The Himalayan mountains in northern Pakistan make one of the most rugged and glaciated landscapes on earth, constituted of diverse geological and topographic conditions. Only 2% of the land surface is cultivable, yet the majority of local populations depend upon agriculture for their livelihoods (Government of Pakistan & IUCN 2003). Irrigation water in northern Pakistan is derived from multiple water sources, i.e. springs, rivers, and glacier meltwater, depending upon the access to a source in the alluvial terraces located inside the remote valleys. However, knowledge of the irrigation water quality in the region is very limited, rather nonexistent. Data on the physicochemical properties of irrigation water and their

implications for agriculture and ecosystems is lacking. Therefore, the present study explores the irrigation water quality in the western Himalayan mountain region of Pakistan intending to investigate: (a) numerous physicochemical properties of irrigation water, (b) correlation between various physicochemical parameters, and (c) variation in the physicochemical parameters across different sources (river, glacial meltwater, the mix of spring and glacial meltwater). The broader aim of the study is to assess suitability of irrigation water for agricultural purposes in a mountainous landscape bearing fragile agroecosystems.

MATERIAL AND METHODS

Description of the study area

The research was conducted at three different villages in northern Pakistan (Figure 1), each receiving irrigation water from a different source, mainly through gravity-fed irrigation channels. All the three study sites fall amidst the rugged mountains of Karakoram in the western Himalayas, predominantly in a dry temperate climatic zone. The mean monthly maximum temperature ranges between 9.5 and 36.2 °C, and the mean monthly minimum temperature ranges between -2.5 and 18.3 °C. The mean annual rainfall is about 134 mm, of which about 70% is usually received during the summer (Adnan *et al.* 2017).

Site A, namely Faizabad (35°58.964' N and 074°19.338' E at 1,482 m a.s.l.) is situated along the right bank of the Hunza River in District Gilgit. The village obtains irrigation water from the Hunza River through a 3.5 km long channel constructed in the 1970s. The area has a double-cropping system, where potatoes and wheat are grown in spring and maize in mid-summer. The village has relatively flat topography.

Site B, namely Sikandarabad (36°14.546' N and 074°22.641' E, at 1,860 m a.s.l.) is situated in District Nagir on the left bank of the Hunza River. The village receives irrigation water from Nilt Nallah (stream) which contains a mix of spring water, snow melt (from snow avalanche) and glacier meltwater. The area has a double cropping system, and the dominant crops are wheat and potatoes in spring and maize in summer. Apart from

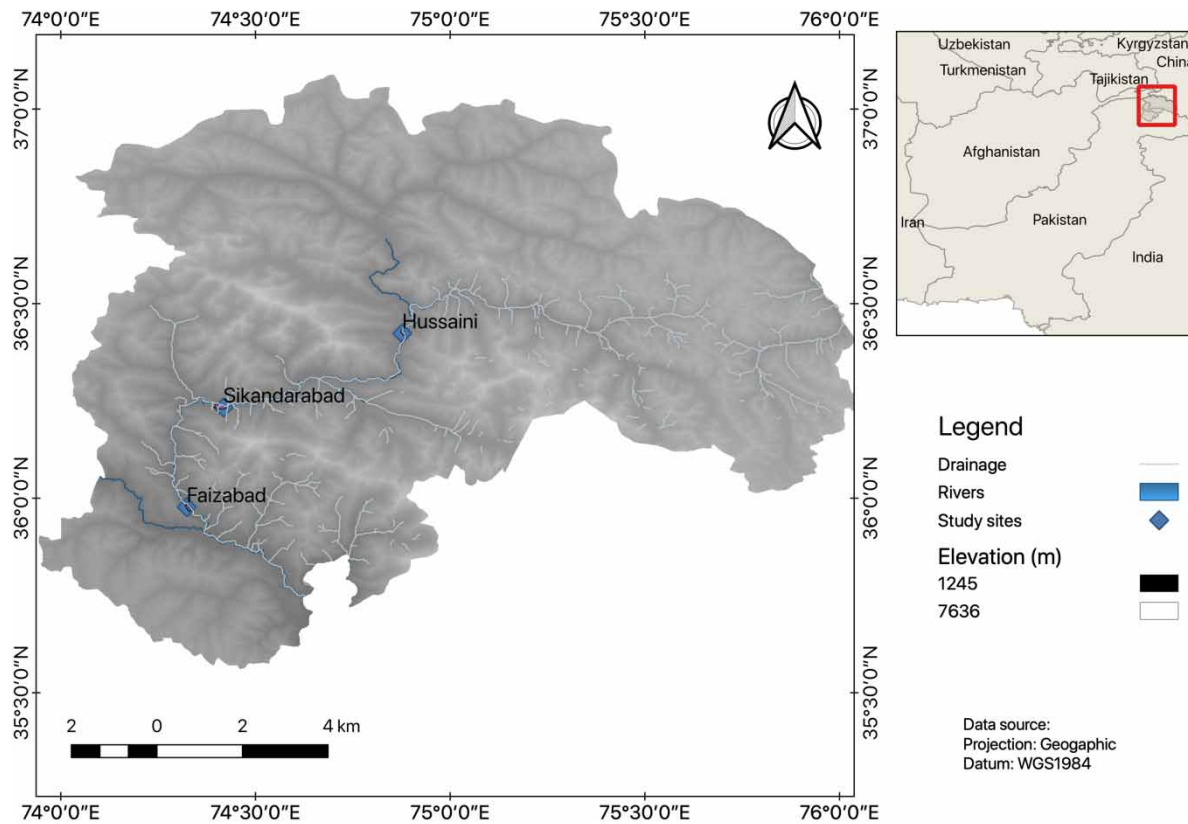


Figure 1 | Location map of the sampling sites.

crops, the cultivated land has fruit orchards such as apricots, apple, cherry, walnuts; firewood plantations, and fodder crops. Irrigation water from the source to the village is supplied with the help of a 7.5 km long primary irrigation channel, and 3.5 and 2 km long secondary irrigation channels. During rapid glacial melting in summer, the irrigation channels carry excessive sediments, which often becomes a problem by reducing the water holding capacity of the channels.

Site C, namely Hussaini ($36^{\circ}25.540' N$ and $74^{\circ}52.226' E$, at 2,546 m a.s.l) is situated in District Hunza, spanning both sites of the Hunza River. The village obtains irrigation water from the adjacent Hussaini-Ghulkin glacier directly through a pipe and earthen supply structures. The village lies along an elevational gradient (2,300–2,726 m) with terraced fields and cultivated lands that are dominated by crops, energy plantation, and fodder crops. The village has a single cropping system with potatoes and maize as the dominant crops.

Water sampling and analyses

Water samples were collected during the daytime from 1 to 3 September 2018. At each site, three replicate samples were collected from four sampling points: (a) primary channel head (connected with the source); (b) middle of the primary channel (between source and the village); (c) village inlet (channel entering into the cultivated lands of the site); and (d) middle of the village (any random location, approximately in the center of the village). The primary channel is the main channel supplying water to the village from a source, which may branch out into secondary and tertiary channels, depending upon cultivated area of a village. The sampling points were located $\approx 1,000$ – $3,700$ m apart depending upon the total area of a site and length of the channels. Thus, a total of 36 samples (12 from each site) were collected in one-liter bottles, properly capped and labeled.

Following Sabir *et al.* (2017) we investigated the different parameters by using standard methodologies. Among

various physicochemical parameters, the potential of Hydrogen (pH), Electrical Conductivity (EC) and Total Dissolved Solids (TDS) were analyzed instantly in the field, while for analyses of the remaining parameters the samples were brought to the laboratory and stored in a refrigerator at 4 °C. The other parameters were analyzed within one week and heavy metals within one month of the sample collection. TDS were determined by a Hanna Combo pH/TDS/Conductivity Tester model number HI98130, while pH and EC were determined by an Oakton pH/mV/Conductivity/C°/F° meter PC 700. For assessment of Calcium (Ca), Magnesium (Mg), Sodium (Na), Potassium (K), Iron (Fe), Mercury (Hg), Manganese (Mn), Nickel (Ni), Lead (Pb), Zinc (Zn), Cadmium (Cd) and Copper (Cu) we used the Perkin Elmer Analyst 700 model flame atomic absorption spectrometer equipped with deuterium background correction, hollow cathode lamps (HCL) and acetylene burner. For calibration of the instrument, we used a certified standard solution for each element. Before using standard solutions, blank solutions were also used for all the given parameters. Carbonates and bicarbonates were determined through the titration method by using a phenolphthalein indicator (Estefan *et al.* 2013). Nitrate nitrogen (N-NO₃⁻) and phosphorus (P) were determined following Estefan *et al.* (2013). Sodium Adsorption Ratio (SAR) was estimated following Richards (1954):

$$\text{SAR} = \frac{[\text{Na}^+]}{\sqrt{\frac{([\text{Ca}^{2+}] + [\text{Mg}^{2+}])}{2}}}$$

The concentrations of Na, Ca and Mg were converted to milliequivalent per liter.

Statistical analyses

The data were entered into Excel and exported to Statistical Package for Social Sciences (SPSS v. 20, IBM Corp. 2011). Mean and standard deviation for each parameter were computed to compare with permissible limits of agriculture water quality parameters specified by FAO, USEPA, WWF, and others (Ayers & Westcot 1994; Jena *et al.* 2012; Mezgebe *et al.* 2015; Jeong *et al.* 2016; Laze *et al.* 2016). One-way analysis of variance (ANOVA) was used to determine the

significant differences in the water quality across water sources and Pearson correlation was used to determine correlations between different parameters.

RESULTS AND DISCUSSION

Physicochemical properties of irrigation water and their implications for irrigation

The various physicochemical parameters assessed in the current study and their permissibility concerning the water quality parameters recommended by various organizations such as FAO, USEPA, and WWF are summarized in Table 1. The permissible concentrations of certain parameters of irrigation water quality are highly variable by location and vegetation types (see e.g. Ayers & Westcot 1994; WWF Pakistan 2007; Jena *et al.* 2012; Mezgebe *et al.* 2015; Jeong *et al.* 2016; Laze *et al.* 2016).

Most of the physicochemical parameters in our study were noted to be within the recommended limits, indicating good quality irrigation water. However, TDS was found to be much below the permissible limits, while K, Hg, Ni, and Cd were found exceeding the permissible limits. P and Mn exceeded their limits in the river water of Faizabad and glacial meltwater of Hussaini (Table 1). It is important to understand the implications of the parameters that are not within the permissible ranges, because the irrigation water quality is crucial for soil properties, plant growth and productivity and thus becomes pertinent for human and ecosystem health (Sanchez & Silvertooth 1996).

TDS measures concentration of salts that have been dissolved in water (USEPA 1986), and there is strong empirical evidence that soluble salts affect plant growth by making it more difficult for the plants to absorb water from the soil (Blaylock 1994). Salts can also affect soil structure and decrease its aeration and water holding capacity. Ideally, farmers should use freshwater to irrigate fields in arid regions (Yadav *et al.* 2011).

Exceeding limits of heavy metals in agriculture water is a serious concern that deteriorates not only the soil quality but also increases toxicity in crops (Asano *et al.* 2007). Certain metals such as Fe, Mn, Cu, Zn, and Ni have a role in plant growth, as plants fail to grow and reproduce normally

Table 1 | Mean values and concentrations of various physicochemical parameters in irrigation water at the three study sites in northern Pakistan

Parameters	Present study			Permissible limits (Recommended by)	References
	Sikandarabad	Hussaini	Faizabad		
Physical parameters					
pH	7.92	7.13	7.65	6.5–8.5 (FAO, WWF)	Ayers & Westcot (1994); WWF (2007)
EC ($\mu\text{S}/\text{m}$)	622.5	113.5	659.5	3000 (FAO)	Mezgebe <i>et al.</i> (2015)
TDS (mg/l)	98.42	20.75	102.5	500–2000 (FAO)	Ayers & Westcot (1994)
Soluble anions and cations					
P (mg/l)	1.94	2.11	2.69	0–2 (FAO)	Ayers & Westcot (1994)
K (mg/l)	4.37	10.55	4.7	0–2 (FAO)	Ayers & Westcot (1994)
Ca (mg/l)	53.06	8.78	43.63	800 (FAO)	Mezgebe <i>et al.</i> (2015)
Na (mg/l)	0.6	0.64	1.88	200 (WHO)	WHO (2006)
Mg (mg/l)	5.51	1.92	9.4	120 (FAO)	Mezgebe <i>et al.</i> (2015)
(N- NO_3^-) (mg/l)	1.02	1.77	0.76	0–10 (FAO)	Ayers & Westcot (1994)
HCO_3^- (me/l)	5.78	3.64	4.27	0–10 (FAO)	Ayers & Westcot (1994)
SAR (me/l)	0.02	0.4	0.05	0–15 (FAO)	Ayers & Westcot (1994)
Heavy metals					
Fe (mg/l)	0.12	4.44	0.27	5.0 (FAO, USEPA)	Jeong <i>et al.</i> (2016)
Hg (mg/l)	0.68	0.58	0.86	0.01 (WWF)	WWF (2007)
Mn (mg/l)	0.1	0.24	0.22	0.2 (FAO, USEPA)	Jeong <i>et al.</i> (2016)
Ni (mg/l)	8.46	24.73	30.14	0.2 (FAO, USEPA)	Jeong <i>et al.</i> (2016)
Pb (mg/l)	1.09	2.17	2.89	5.0 (FAO, USEPA)	Jeong <i>et al.</i> (2016)
Zn (mg/l)	-0.7	-0.76	-0.82	2.0 (FAO, USEPA)	Jeong <i>et al.</i> (2016)
Cu (mg/l)	0	-0.01	-0.01	0.2 (FAO, USEPA)	Jeong <i>et al.</i> (2016)
Cd (mg/l)	0.24	0.64	1.00	0.01 (FAO, USEPA and WWF)	Jeong <i>et al.</i> (2016), WWF (2007)

in the absence of those elements (Emamverdian *et al.* 2015). However, high concentrations of these metals can disrupt critical physiological processes and result in toxicity (Peralta-Videa *et al.* 2009).

According to Peralta-Videa *et al.* (2009) plants can accumulate heavy metals such as Cd, Ar, Cr, Hg, and Pb at toxic levels without known biological functions. In Tamil Nadu, India, Kumar *et al.* (2017) attributed the increasing trends of Fe and Mn in agriculture water to the chemical weathering dissolution and the process of ferromagnetism. Hg has no known essential or beneficial role in human or animal nutrition (USEPA 1994). Liquid metallic mercury and elemental mercury dissolved in water are comparatively non-toxic, but some mercury compounds, such as mercuric chloride and alkyl mercury, are considered very toxic. Elemental mercury is readily alkylated, particularly to methyl mercury, and concentrated by biological activity. Potential health effects of exposure to some mercury compounds in water include severe disorders of the kidneys and nervous system (USEPA 1994).

Cd and Pb are non-essential elements for plant metabolism (Alves *et al.* 2016), though they may affect photosynthesis, seed germination, and plant growth (Lee *et al.* 2003; Sharma & Dubey 2005; Peralta-Videa *et al.* 2009). Exceeding concentrations of Ni and Cd in irrigation water make it very toxic to some plants and animals (USEPA 1994). Cd is normally strictly restricted since, when dissolved in water or soil, it can be accumulated in the crop and in turn be harmful to the human body (Gupta & Gupta 1998). In our study, concentrations of Zn and Cu were found to be below detection limits across the three sites, although Zn, Cu and Ni are considered to be beneficial within permissible limits (Alves *et al.* 2016). Cu activates various enzymes helping in chlorophyll production, Zn plays an important role in the synthesis of proteins while Ni is involved in Nitrogen (N) metabolism and biological Nitrogen fixation (Tisdale *et al.* 1997). However, excessive concentrations of Cu and Zn can cause leaf chlorosis as well as the suppression of root growth (Asano *et al.* 2007).

For the healthy growth and development of agricultural crops, nutrient levels in irrigation water should also be within safe limits. N and P are the major nutrients for crop growth but when applied excessively, these nutrients can

exert a negative effect (Setter *et al.* 1997). The concentration of P in agricultural water in Sikandarabad was within a good range (Table 1), while in Hussaini and Faizabad it exceeded acceptable limits. The level of K is of concern across the study sites as the mean concentration was higher than standard safe values for agriculture water. It might be an indication of the presence of potash silicate minerals and its weathering in the catchment of water sources (Hamid *et al.* 2020). The concentration of N-NO_3^- across Sikandarabad, Hussaini, and Faizabad were within the recommended limits of irrigation water quality standards.

The salt concentration in irrigation water is the primary factor that affects crop growth; water quality deteriorates as the salt concentration increases. Water quality impacts on soil permeability are more complicated. Two opposing factors need to be considered: salt concentration, as estimated conventionally by EC, and sodicity hazard, as reflected by SAR. The effects of EC and SAR on soil permeability are opposite to one another: permeability increases with increasing EC, whereas permeability decreases with increasing SAR. Consequently, soil permeability is maintained by an optimal combination of high EC and low SAR (Oster *et al.* 2016).

Correlation between various physicochemical parameters

Table 2 shows the correlation of various physicochemical parameters. Pearson correlation revealed that pH was significantly correlated with EC, TDS, HCO_3^- , Ca, Mg, Mn, K, and Fe. Similarly, EC was significantly correlated with TDS, Mg, Ca, HCO_3^- , Fe, and K. TDS was correlated with Mg, Ca, HCO_3^- , Fe and K, while HCO_3^- was significantly correlated with Ca, Mn, SAR, Fe and Ni. SAR was correlated with Na, Mn, Ni, Pb, and Cd. Mg was significantly positively correlated with Ca and Na. The level of Ca in irrigation water was significantly correlated with Cu while Na was correlated with Pb and Cd.

Most of the trace elements were not significantly correlated with physicochemical parameters such as NPK and N-NO_3^- . However, the results indicated that Fe was significantly correlated with K; Mn with Ni, Pb, Cd, Zn, and K; Ni with Pb, Cd, Zn, and P; and Pb with Cd, Zn and P. Zn was negatively significantly correlated with Cd, P and Cu.

Table 2 | Correlation of various physicochemical parameters of irrigation water in northern Pakistan

	pH	EC	TDS	HCO ₃ ⁻	SAR	Mg	Ca	Na	Fe	Hg	Mn	Ni	Pd	Zn	Cu	Cd	P	K
pH	1																	
EC	.865**	1																
TDS	.876**	.988**	1															
HCO ₃ ⁻	.766**	.619*	.662*	1														
SAR	-.398	-.079	-.093	-.683*	1													
Mg	.599*	.904**	.860**	.273	.292	1												
Ca	.954**	.954**	.960**	.789**	-.333	.735**	1											
Na	.198	.569	.548	-.155	.751**	.823**	.320	1										
Fe	-.607*	-.754**	-.735**	-.600*	.363	-.637*	-.751**	-.273	1									
Hg	.144	.298	.200	-.007	.021	.423	.195	.273	-.479	1								
Mn	-.808**	-.508	-.515	-.805**	.794**	-.131	-.723**	.357	.511	-.120	1							
Ni	-.534	-.169	-.218	-.695*	.735**	.223	-.422	.569	.106	.253	.841**	1						
Pb	-.426	.032	-.009	-.561	.826**	.428	-.254	.759**	.004	.193	.816**	.923**	1					
Zn	.294	-.042	-.027	.451	-.516	-.295	.156	-.514	.098	-.061	-.624*	-.811**	-.766**	1				
Cu	.466	.570	.599*	.555	-.146	.453	.581*	.234	-.518	.227	-.383	-.396	-.137	.284	1			
Cd	-.296	.129	.117	-.432	.869**	.486	-.146	.848**	.006	.160	.742**	.812**	.942**	-.628*	-.038	1		
P	-.117	.314	.266	-.150	.282	.547	.115	.506	-.469	.264	.387	.611*	.701*	-.624*	.218	.538	1	
K	-.750**	-.770**	-.701*	-.551	.382	-.660*	-.778**	-.228	.821**	-.579*	.649*	.185	.144	-.146	-.311	.145	-.248	1
N-NO ₃ ⁻	-.447	-.401	-.319	-.016	-.001	-.398	-.367	-.224	.149	-.075	.303	.033	.024	.036	.328	.063	.066	.534

**Correlation is significant at the 0.01 level (2-tailed) *Correlation is significant at the 0.05 level (2-tailed).

Our findings correspond with [Emurotu & Onianwa \(2017\)](#) regarding no significant correlation of pH with Hg, Ni, Zn, Cu, Pb and Cd. Regarding correlation of EC with other parameters, our results are in line with [Kumar *et al.* \(2017\)](#) who also observed positive correlation of EC with HCO_3^- , Ca, Mg, and Na, whilst contradicting their observation regarding positive correlation of EC with K. The positive correlation of EC with TDS, Ca, and Mg has also been observed in other studies (*e.g.* [Shrestha & Basnet 2018](#)). These parameters strongly contribute to change the electrical conductivity of water ([Shrestha & Basnet 2018](#)). We noticed positive correlation of SAR with Na, which has also been observed elsewhere (*e.g.* [Sadick *et al.* 2017](#)).

The high values of SAR have been associated with decreases in Ca, Mg, HCO_3^- and CO_3^{2-} and vice versa ([Sadick *et al.* 2017](#)). This means higher concentrations of Ca and Mg are related to decrease in SAR values for the irrigation water. Water rich in HCO_3^- tends to precipitate insoluble Ca and Mg in the soil which ultimately leaves a higher proportion of Na to be available in solution and increases the SAR value ([Singh *et al.* 2004](#)). According to [Ayers & Westcott \(1994\)](#), although ordinary HCO_3^- is not toxic it can cause Zn deficiency. [Emurotu & Onianwa \(2017\)](#) observed that the synergistic effects were significant between Fe and K, while there was no significant relation with other heavy metals. Correlation of K with pH, EC, TDS, Ca and Fe was observed to be negatively significant, so the increasing values of these parameters would result in decreasing values of K ([Bhandari & Nayal 2008](#)). P was observed to have strong negative correlation with pH ([Cerozi & Fitzsimmons 2016](#)).

Variation of physicochemical parameters across different water sources

Numerous studies have shown varying quality of irrigation water across sources and locations ([Ayers & Westcott 1994](#); [WWF Pakistan 2007](#); [Jena *et al.* 2012](#); [Mezgebe *et al.* 2015](#); [Jeong *et al.* 2016](#); [Laze *et al.* 2016](#)). Our findings also confirm a variation in the different physicochemical properties across the study sites and sources. Water pH, EC, TDS, Ca, Mg, and Na significantly varied across the sites ($p < 0.001$), HCO_3^- and SAR also varied ($p < 0.01$). While Na did not vary significantly between Sikandarabad (mix of spring and glacial meltwater) and Hussaini (glacial meltwater), EC and TDS did not differ significantly between Sikandarabad and

Faizabad (river water) and the same trend was observed for HCO_3^- and SAR between Hussaini and Faizabad.

The mean values of nutrient concentration in irrigation water did not differ significantly across the sites except for K. The concentration of certain heavy metals in irrigation water was significantly varied across the study sites ($p < 0.001$ for Mn, Ni, Pb, and Cd) and ($p < 0.01$ for Fe). The same trend was shown to be significant between Sikandarabad and Hussaini, however, between Hussaini and Faizabad the concentration of Ni, Hg, Zn, and Cu did not vary significantly. Similarly, between Sikandarabad and Faizabad the concentration of Fe, Hg, and Cu did not differ significantly.

River water quality

The present study revealed that the river water quality was suitable for agricultural use. The dominance pattern of trace elements was in the order of $\text{Ni} > \text{Pb} > \text{Cd} > \text{Hg} > \text{Fe} > \text{Mn} > \text{Cu}$ ([Table 1](#)). The mean values of EC, TDS, Mg and Na of river water were higher than glacial melt and the mix of spring and glacier meltwater. This might be due to the high level of weathering process and suspended solids in the river water. The level of TDS was observed below the recommended range; however, among trace elements, Hg, Mn, Ni, and Cd values were above permissible limits. Globally, many rivers are experiencing declining water quality, with altered levels of sediments, salts, and nutrients ([Lintern *et al.* 2018](#)). High pollution levels not only threaten the use of rivers as a source of potable water for humans ([Jiang 2009](#)) but can also contribute to the degradation of rivers.

In our study P and K were observed exceeding the recommended range ([Table 1](#)). The likely source of K in the watershed would be the weathering of potash silicate minerals and agrochemicals (potash fertilizers) ([Hamid *et al.* 2020](#)). In river water, dissolved nutrient species can be mobilized by the mineralization of organic matter or desorption from particulates ([Vidon *et al.* 2010](#)). Salts are generally in the dissolved form, and as such are mobilized by weathering and dissolution from soils and parent rocks as well as dryland and irrigation salinity processes ([Lintern *et al.* 2018](#)). The sediments, nutrient species, and salt concentrations ([Corsi *et al.* 2010](#)) change seasonally also due to seasonal changes in mobilization and transportation processes ([Lintern *et al.* 2018](#)). All of the constituents of river water originate from

the dissolution of the earth's rocks. The dissolution of rocks in the catchment area is a major determinant of river water chemistry locally as well, but this varies with geology and with the magnitude of inputs through the amount, type, and distribution of precipitation, surrounding vegetation, catchment hydrology, and land use (Hynes 1975).

Glacier meltwater quality

The dominance pattern of trace elements was in the order of $\text{Ni} > \text{Fe} > \text{Pb} > \text{Cd} > \text{Hg} > \text{Mn} > \text{Cu} > \text{Zn}$ and that of nutrients was $\text{K} > \text{P}$ and N-NO_3^- in this water source (Table 1). Among physicochemical parameters, the level of SAR was greater than for river and spring water. Among heavy metals Hg and Mn levels were higher than in the other two water sources. The low level of physicochemical parameters and trace elements compared to other water sources could be due to the low weathering process of rocks because of the short distance between the glacier body and village arable land. The levels of P and N-NO_3^- were also observed with similar trends. The mean concentrations of Hg, Ni, Mn, Cd, P and K were observed above permissible limits while TDS was below the recommended range. The contamination of water by these metals might be due to glaciers being the reservoirs of atmospherically deposited trace elements that are released during melt (Hong *et al.* 2004). Weathering in glacial environments also contributes solutes to proglacial streams (Carling *et al.* 2017). Trace metals are deposited in alpine environments via wet and dry atmospheric deposition, with important contributions from windblown dust (Reynolds *et al.* 2010). As the rate of glacier melt continues to accelerate, trace metal concentrations in melt water will increase (Carling *et al.* 2017). As observed by Huang *et al.* (2012) glaciers on the Tibetan Plateau are currently an important sink in the global Hg cycle, but with a warming climate, they may become the source of Hg that could endanger ecosystems and human health in the region. The high ion concentrations of Hg in streams emerging from rock glaciers are attributed to a seasonally increasing release of meltwaters from active rock glaciers (Thies *et al.* 2013).

The mix of spring and glacier meltwater

The composition of surface and underground waters is dependent on natural factors such as geological,

topographical, meteorological, hydrological and biological factors in the drainage basins and varies with seasonal differences in runoff volumes, weather conditions, and water levels (Bartram & Balance 1996). The dominance pattern of heavy metals of combined spring and glacial meltwater was in the order of $\text{Ni} > \text{Pb} > \text{Hg} > \text{Cd} > \text{Fe} > \text{Mn} > \text{Cu} > \text{Zn}$ and that of nutrients was $\text{K} > \text{P}$ and N-NO_3^- (Table 1). The level of TDS was observed below the recommended range while Hg, Ni, Cd, and K levels exceeded permissible limits. The results of the study indicate that the mix of spring and glacier meltwater was most suitable for irrigation as compared to river water and glacier melt irrigation water.

The quality of groundwater depends on the composition of the recharge water, the interactions between the water and the soil, soil-gas and rocks with which it comes into contact in the unsaturated zone, and the residence time and reactions that take place within the aquifer (Bartram & Balance 1996). In addition, seasons and climatic factors affect the quality and quantity of groundwater (Idoko 2010). Changes in groundwater recharge rate caused by seasonal variation affect the concentration of a range of water parameters (Makwe & Chup 2013). The degree of groundwater contamination is also affected by soil porosity. For instance, sandy soils (defined as porous) may hinder the spread of microorganisms, while karst soils (nonporous) are known to be more vulnerable (Goepfert & Goldscheider 2011) and most influenced by agricultural activities and wastewater emissions. Groundwater quality also varies as a function of its chemical composition, influenced by the solubility of the soil it passes through and by aquifer depth (Sonkamble *et al.* 2012).

CONCLUSION

Irrigation water in western Himalayan (Karakoram) mountainous landscapes in Pakistan meets the standard as most of the analyzed physicochemical properties were found within the permissible ranges specified by FAO, WHO, WWF and USEPA for irrigation water quality. The concentrations of Hg, Ni, Cd and K were above permissible ranges in all the study sites, which might be due to weathering of underlying rocks, as the study sites fall within extensive rocky landscapes. The mean concentration of Mn and P were also found above permissible limits in Hussaini and

Faizabad. The high P level may cause a nutrient imbalance in the soil and affect plant growth. The impacts of metals can be minimized by reducing the amount of irrigation water through irrigation efficiency and avoiding the commonly used flood irrigation practices. The impacts of K and P can also be reduced by minimizing the use of chemical fertilizers containing K and P and promoting the application of organic manure.

Among the three sources, *i.e.* glacial melt, river and the mix of spring and glacial melt, the mix of spring and glacial meltwater was found to contain the maximum number of parameters within permissible limits. Regarding irrigation water quality, the findings of our study largely corresponded with the spring water quality assessment conducted in western Nepal (Bhusal & Prakash 2015), indicating an appropriate quality of surface irrigation water across Himalayan landscapes. In contrast, groundwater in the lower plains of Pakistan have been observed to be less appropriate for irrigation purposes, indicating groundwater contamination (Ali *et al.* 2009).

The study could not find any evidence of water contamination due to anthropogenic activities across the study sites. Further research is needed to evaluate the sources of the trace elements in irrigation water. Moreover, we recommend future research to study the implication of varying ranges of physicochemical parameters on soil properties, agriculture produce, and corresponding impacts on human and ecosystem health.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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