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Journal of Natural and Applied Sciences Pakistan

Journal homepage: http://jnasp.kinnaird.edu.pk/

EVALUATING THE INFLUENCE OF CLIMATE VARIABILITY ON WATER QUALITY RESPONSE IN BASHO VALLEY SKARDU

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Article Info
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Keywords
TDS, TSS, GOLF, Physio-chemical, Basho valley, WHO, Glacier water, Spring water, Drinking water, Health, Climate change

Abstract
This study investigates the influence of climate variability on water quality in Basho Valley, Skardu, Pakistan—a region increasingly affected by environmental fluctuations due to its mountainous topography and proximity to glaciers. The research employed a combination of community-based surveys and laboratory analyses to assess both local perceptions and the physicochemical properties of water sources. A structured questionnaire and focus group discussions revealed that a significant portion of the population observed changes in water purity (22%) and soil fertility (33.9%) attributable to climate change. Physicochemical parameters of glacial and tap water samples—including color, odor, total suspended solids (TSS), total dissolved solids (TDS), electrical conductivity (EC), salinity, pH, turbidity, nitrite, and chloride levels—were examined. Results indicated that glacial water contained higher levels of suspended particles, turbidity, and distinct odor and taste, whereas tap water was comparatively clearer and odorless. The findings suggest that rising temperatures and erratic precipitation patterns are altering the physicochemical characteristics of water, thereby posing risks to public health, agricultural productivity, and overall environmental sustainability in the region. This study highlights the need for integrated water resource management strategies and climate-resilient infrastructure to safeguard water quality in vulnerable mountain ecosystems.

1. Introduction

Water is fundamental to human life, ecosystems, agriculture, and industry. However, its quality and availability are increasingly threatened by pollution, climate change, and unsustainable resource management (Sivakumar, 2011). Among these threats, agricultural water pollution (AWP) driven by intensified farming practices, livestock operations, and excessive agrochemical use has emerged as a significant global concern, especially as population growth continues to escalate food demand (Mateo-Sagasta et al., 2017). Despite regulatory measures, such as those implemented by the U.S. Environmental Protection Agency, water contamination remains a pressing issue, particularly in developing regions (Schnurr & Walker, 2019). In such areas, inadequate water, sanitation, and hygiene (WASH) infrastructure substantially contributes to the spread of waterborne diseases (Manetu & Karanja, 2021). According to the World Health Organization, nearly 80% of all human diseases are waterborne, highlighting the urgent need for improved water quality and sanitation systems (Forstinus et al., 2016). Water not only shapes Earth’s geography and climate but also underpins economic and social activities, including recreation, tourism, agriculture, and domestic use (Hall & Page, 2014). Nevertheless, rural populations in developing countries frequently lack access to safe drinking water, increasing their vulnerability to disease and emphasizing the critical role of WASH interventions (Okesanya et al., 2024). In South Asia particularly India and Pakistan—rapid industrialization and urban expansion have intensified environmental pollution, thereby increasing the risk of water-related health issues (Fida et al., 2023; Sarker et al., 2021). Groundwater, a key resource for agriculture, industry, and domestic use, is increasingly threatened by over-extraction and contamination. Climate change further exacerbates these challenges through more frequent extreme weather events such as floods and droughts, which degrade water quality and reduce availability, underscoring the necessity of integrated water management strategies (Delpla et al., 2024). In Pakistan, approximately 40% of deaths and 50% of waterborne diseases are linked to poor drinking water quality. Alarmingly, around 60 million people are at serious health risk due to elevated arsenic levels in drinking water, with pediatric mortality reaching critical levels in recent years (J. A. Baig et al., 2011). Additionally, anthropogenic and natural factors have disrupted river ecosystems, altering the biodiversity and ecological balance of lotic (flowing water) communities (Talukdar et al., 2023). The country's rapid population growth and industrial development have severely compromised surface water resources, posing substantial environmental and public health threats (Chowdhary et al., 2020; Myers & Patz, 2009). Gilgit-Baltistan (GB), often referred to as Pakistan’s “water tower,” contributes approximately 70% of the annual flow of the Indus River. Despite its abundance of freshwater resources, the region is increasingly facing water quality issues with significant public health implications (A. A. Khan et al., 2024; Myers & Patz, 2009). Glacial lakes in GB form through interactions between glacial melt, topography, and climate, with Glacial Lake Outburst Floods (GLOFs)—often triggered by climate-induced mass movement posing additional hazards (Sedai, 2021). The snowmelt and glacial runoff from GB feed surface water systems that supply freshwater for domestic, agricultural, and ecological needs. However, these high-altitude sources are highly susceptible to climate variability and pollution, and their chemical composition and safety remain critically understudied (Shahid, 2024). Located at the intersection of the Himalayan, Karakoram, and Hindu Kush (HKH) mountain ranges, GB plays a vital role in national projects such as the China-Pakistan Economic Corridor (CPEC) and harbors one of the world's most extensive glacial networks (S. S. Baig et al., 2023). While the glaciers of GB are the primary contributors to the Indus River’s flow supporting hydropower, agriculture, and drinking water supplies downstream, the water quality dynamics of these glacial-fed systems are poorly understood. This is particularly concerning in the context of accelerating climate change, which may significantly alter glacial behavior, meltwater composition, and the associated risks to downstream populations. Keeping in view the assessment of tap water and glacier water quality in climate affected Basho valley Skardu.

2. Materials and Methods

2.1 Research Area

Basho Valley is located in Baltistan region in the Northern Areas of Pakistan (Fig-1). The valley ascends from the southern side of the Indus River at an altitude of approximately 2150 m above sea level to the Banak La Mountain at 5520 m. Because of the altitude, the area has a marked seasonal climate comparable to that of the temperate zone. The mean maximum temperature during summer is around 30–35 °C, while temperatures may drop to −25 °C in winter. The lush green Basho Valley is located in the Baltistan region in the NAs of Pakistan at 75°15′ E, 35°25′ N. The valley ascends from the southern side of the Indus river at an altitude of approximately 2150 m above sea level to the peak of Banak La (5520 m). Ascending from the southwestern side of the Indus River from top to bottom (west to east), the valley is present at an altitude ranging from 2055 to 3568 m above mean sea level.

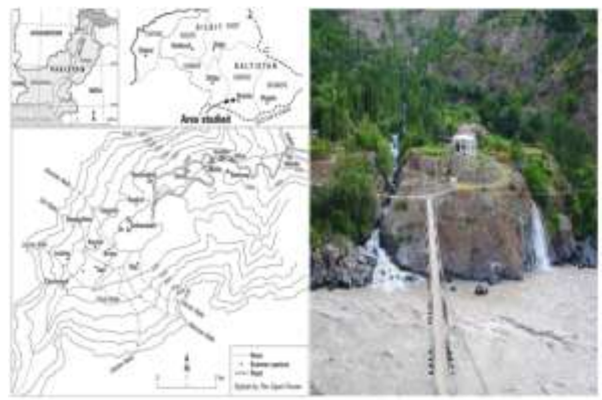

Figure 1 Study area Basho Valley

2.2 Climate Effect

Because of the nearby mountain ranges' sharp variations in weather, Gilgit-Baltistan's climate varies from region to region. The eastern region contains the western Himalayas' moist zone, but toward the Karakoram and Hindu Kush, the climate becomes noticeably drier. The weather at Basho Valley, Pakistan is pleasant ranging from warm enjoyable days to cool evenings and nights. Ideal attire to pack for during the day is light and comfortable clothing and during the night a thick jacket with pants is perfectly suitable. In the chance of rain, the temperature can drop as fast as the rain falls. Staying updated on weather conditions can be helpful in determining whether or not to bring a rain jacket. Enhanced levels of suspended material, organic matter, nutrients, inorganic chemicals, and pathogenic organisms in source waters are just a few of the ways that extreme weather events can affect drinking water sources and influence water quality (A. Khan et al., 2015). The quality of drinking water will be threatened by microorganisms within any severe weather scenario. First, it will alter the water's physicochemical characteristics. Extreme precipitation affects water sources indirectly as well. In addition to altering microbial activity and ability to break down organic matter, precipitation additionally influences soil porosity. (Whitehead et al., 2009). Inadequate water management, inadequate sanitation, and a shortage of healthcare assets, climate change raises the risk of water-related illnesses in impoverished nations like Pakistan. The shortage and contaminated water exposure increase diseases like cholera, diarrhea, and typhoid, which are caused by pathogens like E. coli and Salmonella. (Noureen et al., 2022). The survey and collected data shows in bar graph state that 22 % people opinion about water purity change due to climate change, 33.9% people commented decrease soil fertility and 25.4% people said no changing observed due to climate change, 18.6% people said both water purity and soil fertility decrease due to climate change Keeping in view the leading results by questionnaire based and Focused group discussion (FDGs) were carried (Noureen et al., 2022) extensive analysis of water conducted.

Represent the impact of climate change on waer and soil fertility.

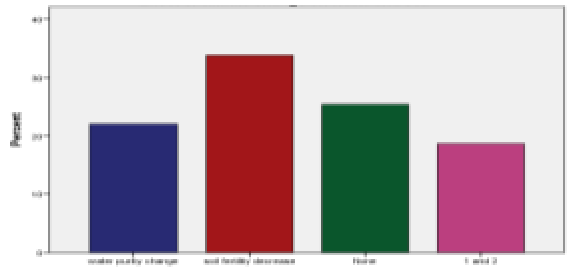

Figure 2 Represent the impact of climate change on waer and soil fertility

2.3 Physio-Chemical Assessment

Two sample (one glacier and one tap) water were collected from Strangbut (Basho) valley in August 2024. 500 ml of each sample was collected in pre-sterilized bottle with proper labeling. The physiochemical analysis of water samples was assessed in Karakorum International University laboratory. Compare the features of glacial and tap water in order to evaluate how the climate affects the health of water and impact on agriculture and health. Basho Valley's residents use both tap water and glacial water for irrigation and drinking. The following parameters were investigated using a chemical and physical test to evaluate the quality of glacial and tap water of the Valley.

Figure 3 Represent the tap water of Basho valley and glacier water of Skardu valley Skardu

2.1.1. Color and order test

The color of tap water is clear, while the color of glacial water is muddy and opaque, containing many suspended particles. There is no smell in tap water, but glacial water has a muddy smell. There is no taste in tap water, but glacial water has a muddy taste.

2.1.2. TSS test water

Total Suspended Solids (TSS) test measures the concentration of suspended particles in water. For TSS of both tap water and glacial water we use filter paper to separate suspended particle from samples. Muirhead (1998) developed an analytical method for measuring the reflectance and color of TSS. The method minimized color contributions from background filter media by calculating the "ultimate reflectance" of an infinite layer of TSS. (Sutherland, 2006). To conduct a Total Suspended Solids (TSS) test, we took 40 ml from both water sample in clean 100 ml beaker. Weigh a clean, dry filter paper, then filter the water sample through it using a filtration apparatus to capture the suspended solids. Rinse the filter with distilled water to remove water soluble compounds, then dry the filter paper with the collected solids in an oven at 103-105 °C for 1-2 hours. After drying, cool the filter in a desiccator to prevent moisture absorption, and then weigh it again to determine the final weight. Repeat the test of each sample 3 times to minimize the error. Subtract the initial weight of the filter paper from the final weight to find the weight of the suspended solids, and calculate the TSS concentration using the formula: TSS (mg/) = Weight of solids (mg) / Volume of sample (L). Adhered to safety guidelines and ensured all equipment was clean to avoid contamination.

2.1.3 TDS test of sample water

Total Dissolved Solids (TDS) is a measure of all the tiny particles, like salts and minerals that are dissolved in water. It's usually shown in milligrams per liter (mg/L) or parts per million (ppm). To measure Total Dissolved Solids (TDS) using an EC /TDS / Salinity Pocket Tracer. Initially calibrate the device according standard SOP, making sure it's clean and free of any residues. Then, collected a water sample of both tap and glacial water in a clean container, ideally at room temperature. Turn on the Pocket Tracer and immerse the probe in the water, to keep ensuring it's fully submerged but not touching the bottom. Wait few seconds for the reading to stabilize, and then noted the displayed TDS value, typically shown in parts per million (ppm) or milligrams per liter (mg /L). After taking the measurement, we rinse the probe with distilled water to avoid contamination, and finally, turn off the device and store it according to the manufacturer's guidelines. Both gravimetric and traditional field methods are being employed in the measurement of TDS and TSS. These approaches are constrained by their restricted spatial coverages, labor costs, and other factors. However, in recent decades, remote sensing (RS) applications have been employed as a substitute to get over these restrictions. (Adjovu et al., 2023).

2.1.4 EC test of sample water

Electrical Conductivity (EC) measures how well water can conduct electricity, which indicates the presence of dissolved ions, such as salts and minerals. The higher the concentration of these ions, the higher the EC value. EC is often used to assess water quality, as it can help indicate the level of Total Dissolved Solids (TDS) in the water. It's usually measured in micro Siemens per centimeter (µS/cm). To measure Electrical Conductivity (EC) we use EC/ TDS/Salinity Pocket Tracer, first we turn on the device and calibrate it as per the manufacturer's instructions. Collect both water sample in a clean container at room temperature, then immerse the probe into the sample, ensuring it's fully submerged but not touching the bottom. Wait for a few seconds until the reading stabilizes, then record the EC value displayed in micro Siemens per centimeter (µS/cm). After measurement, we rinse the probe with distilled water to prevent contamination, and finally, turn off the device and store it according to the manufacturer's guidelines. Water sample conductivity was measured with a digital conductivity meter (AD3000, ADWA) and expressed in µS/cm. A digital conductivity meter (AD3000, ADWA) was applied to quantify the samples' total dissolved solids, which were n expressed in mg/l. (Kanwal et al., 2017).

2.1.5 Salinity test for water

Sample Salinity is a measure of the concentration of dissolved salts in water, primarily sodium chloride (table salt) along with other salts. It's usually expressed in parts per thousand (t) or practical salinity units (PSU). Salinity is an important factor in determining water quality and affects the density, temperature, and chemistry of water bodies. EC/TDS/Salinity Pocket Tracer were used to measure salinity level, calibrate device as per SOP. Collect a water sample` in a clean container at room temperature, and then immerse the probe into the sample, ensuring it's fully submerged but not touching the bottom. Wait a few seconds for the reading to stabilize, and then record the salinity value, typically in parts per thousand (PPt) or practical salinity units (PSU). After taking the measurement, rinse the probe with distilled water to avoid contamination, and finally turn off the device and store it according to SOP. Titrimetric, gravimetric, and photometric methods are employed to determine vital variables such alkalinity, hardness, Ca2+, Mg2+, K+, Na+, F−, Cl−, NO3−, SO42−, and PO43− (Alam, 2020).

2.1.6 pH test for water sample

pH is a measure of the acidity or alkalinity of water samples. If water is too acidic can cause rusting in metallic pipes and plumbing components to rust. While, alkaline water promotes water disinfection. WHO and NDWQS recommendations indicate that the pH range of regular drinking water is 6.5 to 8.5 (Rahmanian et al., 2015). Tested the pH of water with a pH meter, after calibrate the meter using standard solute tap water sample in 3 beakers of 100ml and also took glacial water in three 100ml beaker. Consecutive three times reading of tap sample and glacial sample by Submerge the probe of the pH meter into the water without touching the bottom, and wait for a few seconds until the reading stabilizes and record the pH value displayed on the meter. The chosen water samples' pH values fell within 6.5 and 8.5, which is between WHO and NEQ recommendations. The samples' pH was between 6.78 to 7.09 (Saif-Ud-Din & Adeel, 2016).

2.1.7 Turbidity test of water sample

Turbidity is the cloudiness or haziness of a liquid, primarily caused by the presence of suspended particles such as sediments, organic matter, or microorganisms. To measure turbidity with a turbidity meter, turn on the device. Collect tap water sample in a clean container and rinse the sample cup with the tap water before filling it to the marked line. Place the cup in the meter, ensuring proper alignment, and wait for the reading to stabilize. Recorded the turbidity value in (Nephelometric Turbidity Units (NTU). These process is repeated for glacial water and note the valve of turbidity. The Electronic Turbid meter (TB1, VELF SCIENTIFICA) was used to determine the turbidity, and findings were given in NTU (Kanwal et al., 2019).

2.1.8 Nitrite test for water sample

The nitrite test measures the concentration of nitrite ions (NO_2^-) in water, which is important for assessing water quality, particularly in aquatic environments and drinking water. To conduct a nitrite test using a multi-direct photometer, initially turn on the device and allow it to thermally stabilize. First rein the cup with tap water and fill the cup with sample up to marked Place the cup in the meter, and set zero when system show zero at the screen of multi direct photometer then remove the sample from the photometer. Add 1 tablet of nitrite and dissolve tablet completely and then place the cup in in photometer and press the test button ensuring proper alignment water sample in multi direct photometer. Now note the reading which is display on screen. similarly, this test performs for glacial water and note reading in note book. A spectrophotometric approach for measuring nitrate and nitrite levels in water and pharmaceutical samples has been developed. Nitrite is measured utilizing sulfanilic acid and methyl anthranilate as coupling agents, and in the presence of Zn/ NaCl, nitrate is reduced to nitrite. (Narayana & Sunil, 2009).

2.1.9 Chloride test for sample mg/L water

The chloride test measures the concentration of chloride ions (Cl^-) in water, which is important for assessing water quality and identifying pollution sources. To conduct a chloride test using a multi-direct photometer, first turn on the device and allow it to warm up. First rein the cup with sample tap water and fill the cup with sample up to marked place the cup in the meter, and set zero when system show zero at the screen of multi direct photometer then remove the sample from the photometer. Add chloride tablet1 and dissolve tablet completely the color of water change into blue when chloride tablet 1 is completely dissolve now add chloride tablet 2 in the sample and dissolve completely, then place the cup in in photometer and press the test button ensuring proper alignment water sample in multi direct photometer. Now we note reading which is display on screen. similarly, this test performs for glacial water and note reading in note book. As little as 0.05 parts per millions of chloride can be found. [Fe (SCN)]++ is a colorful complex that is created when thiocyanate is converted from mercuric thiocyanate by a chloride ion and then interacts with ferric iron. It can be measured using a spectrophotometer or by visual inspection (Zall et al 1956).

2.1.1 Calcium harden test of water sample

Calcium hardness measures the concentration of calcium ions (Ca^{2+}) in water, which contributes to water hardness. To conduct calcium hardness test using a multi-direct photometer, first turn on the device and allow it to warm up. First reins the cup with tap water and fill the cup with sample up to marked place the cup in the meter, and set zero when system show zero at the screen of multi direct photometer then remove the sample from the photometer. Add 1 tablet of calcium and dissolve tablet completely and then place the cup in in photometer and press the test button ensuring proper alignment water sample in multi direct photometer now we note reading which is display on screen. similarly, this test performs for glacial water and note reading in note book. In laboratories, key variables including alkalinity, hardness, Ca2+, Mg2+, K+, Na+, F−, Cl−NO3−, SO42−, and PO43− are measured using titration, gravimetric, and photometry. (Narayana & Sunil, 2009).

3. Result

3.1 Chemical assessment of water samples.

I In order to check the climate effected Basho valley water were assessed by the eleven physical and chemical parameters for both tap water and spring water and get valuable result from experiment analysis, details mentioned in below Table 1

. **Table 1**: Water analysis of Basho valley

S#	Test	Unit	Tap water	Glacial water	WHO STANDARD
1	Color		Transparent	Muddy	<15 HU
2	Oder		No Oder	Muddy Order	ORDER LESS
3	Taste		No taste	Muddy taste	TASTE LESS
4	TSS	g/L	0.0066	0.077	<50 MG/L
5	TDS	mg/L	87.7	52.2	<400MG/L
6	EC	μS/cm	175.6	82.4	<1000 MG/L
7	Salinity	mg/L	123.03	56.7	<600
8	pH		6.14	6.54	6.5 - 8.5
9	Turbidity	NTU	0.08	276	<5 NTU
10	Nitrite	mg/L	0.01	0.01	1MG/L
11	Calcium hardness	mg/L	23	23	0-120MG/L
12	Chloride	mg/L	2.6	0.5	<250 MG/L

Chemical Parameters Total Suspended Solids (TSS) The total suspended solids (TSS) analysis shows that glacial water has a significantly higher concentration (0.077 g/L) compared to tap water (0.0066 g/L). This indicates that glacial water contains more particulate than tape water. The quality of the non-filterable particles present in water samples can be assessed by their TSS values. For drinking water, the NSDWQ and WHO set an acceptable limit of 500 mg/L and 1000 mg/L, respectively. The samples under evaluation had TSS concentrations ranging from 100 to 400 mg/L. Having an average of 146.667 mg/L (Jagaba, Kutty, Hayder, Baloo, et al., 2020). Total Dissolved Solids (TDS) The total dissolved solids (TDS) analysis reveals that tap water, sourced from a spring, has a higher concentration (87.7 mg/L) compared to glacial water (52.2 mg/L). Tap water (source of tap water is spring) has a higher concentration of dissolved solids, which may include minerals and other compounds. Lower TDS in glacial water may indicate a purer source. Desirable limit for TDS is 500 mg/l and maximum limit is 1000 mg/l which prescribed for drinking purpose. The values reported ranged from 290 to 595 parts per million in the Islamic colony. The TDS range in Shahdrah area is 401-429 ppm, where as in Satellite town it is 406-694 ppm. Therefore, these values were deemed acceptable, and the TDS content is not toxic. (Mohsin et al., 2013). Electrical Conductivity (EC) The electrical conductivity (EC) analysis shows that tap water has a higher conductivity (175.6 μS/cm) compared to glacial water (82.4 μS/cm). Higher conductivity in tap water indicates a greater concentration of ions and dissolved salts. While the low conductivity of glacial water indicates the low concentration of ions and dissolved salts. According to WHO standards, EC value should not have exceeded 400 μS/cm. The amount of salts in the water effects its EC value. The mean EC value in this sample was 2.0 ± 2.8 dS/m, with an interval of 0.3 to 27.6 dS/m (N. H. Solangi et al., 2021). Salinity The salinity analysis indicates that tap water has a higher salinity level (123.03 mg/L) compared to glacial water (56.7 mg/L). The higher salinity in tap water may be due to mineral content, while glacial water is comparatively lower, suggesting less dissolved material. In the pre-monsoon and post-monsoon seasons, the average total alkalinity (TA) of the water samples from the Yercaud area was 241.6 and 232.5 mg/L, respectively. In the pre-monsoon and post-monsoon seasons, the salinity levels of water samples varied from 82.1 mg/L to 368.8 mg/L and 148.4 to 359.8 mg/L, respectively. The samples had more TA when they were certified. and salinity levels below WHO-recommended limits (TA=200 mg/L). (Florence, 2012). pH The pH analysis shows that tap water has a pH of 6.14, while glacial water has a slightly higher pH of 6.54. Although both values are close, only glacial water falls within the acceptable range of 6.5 to 8.5 recommended by the WHO for drinking water. Glacial water's slightly higher pH indicates it may be less acidic. WHO has recommended maximum permissible limit of pH from 6.5 to 8.5. Water should have a pH within 6.5 and 8.5 according to Bangladesh Drinking Standards (BDS). All of the water samples, with the exception of samples D-1 (6.91) and D-5 (6.81), are somewhat alkaline and fall in 7.11 and 8.12 (Rahaman et al., 2018). Turbidity: The turbidity of tap water is measured at 0.08 NTU (Nephelometric Turbidity Units), which is considered very low and indicates that the water is relatively clear, making it suitable for consumption. In contrast, glacial water has a turbidity of 276 NTU, which is extremely high.: Extremely high turbidity in glacial water indicates significant particulate matter, making it unsuitable for drinking without proper treatment. The WHO recommended value of 5.00 NTU. Water from hand-dug wells has a turbidity rating of 47.13 NTU. This is greater than the 5 NTU maximum that the proposed by NSDWQ and World health organization (Jagaba, Kutty, Hayder, Latiff, et al., 2020). Nitrite: Both the tap water and glacial water have a nitrite concentration of 0.01 mg/L, which is quite low. This level of nitrites is generally considered safe and falls within the acceptable range for drinking water as per the World Health Organization (WHO) permissible limit. Methemoglobinemia, frequently referred to as "blue baby disease," is a medical problem in humans caused by nitrites which inhibit oxygen transport and cause "brown blood disease" in fish. This is especially harmful for babies younger than three months. Babies shouldn't drink water with nitrite levels higher than 1.0 mg/L, while warm-water fish may usually tolerate at lower levels (Kumar & Puri, 2012). Calcium Harden Both the tap water and glacial water have a calcium hardness level of 23 mg/L, indicating similar calcium content. Similar hardness levels indicate comparable calcium content, which may contribute to overall water quality. According to WHO standards, its permissible range in drinking water is 75 mg/l. Hardness was also detected in water samples from different GB valleys, with values ranging from 4.66 ± 16.66 mg/L in Nagar Valley, 160 ± 190 mg/L in Danyore valley, 130.54 ± 76.75 mg/L in Chu Tran Valley, and 102.9 ± 10.44 mg/L in Basho Valley. (Fatima et al., 2023). Chloride The chloride concentration in tap water is 2.6 mg/L, while glacial water has a much lower concentration of 0.5 mg/L. Higher chloride levels in tap water could indicate the high concentration of chloride ion, while lower levels in glacial water suggest a cleaner source. According to WHO standards, concentration of chloride should not exceed 250 mg/l. The mean Cl concentration was 1136 ± 310 mg/L, with an average of 131 to 6275 mg/L. The level of Chloride in approximately 94% of the water samples was higher than allowed (Y. A. Solangi et al., 2019).

4. Conclusion

Chemical analysis of tap water and glacial water of Basho valley were carried out, to check the potential hazards due to climate changes and GLOF activities in BASHO valley Gilgit-Baltistan. Tap Water appears to be of higher quality based on clarity, odor, taste, TSS, TDS, EC, salinity, and turbidity. It meets typical drinking water standards effectively. Glacial Water, while potentially pure in its source, but shows high turbidity, muddy odor and taste, and lower TDS, indicating possible contamination or a need for filtration and treatment before consumption. This research analysis facts and findings will provide a base for NGOs, Government organizations, national and international research institutions to fill the knowledge gap, and policy making to overcome these burning issues of the area.

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