Spatial And Seasonal Variation For Water Quality Indices of Gomal Zam Dam And Its Tributaries In The South Waziristan District, Pakistan

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Research Article

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Abstract

This study investigated the quality of water in the Gomal Zam Dam and its tributaries, south Waziristan District, Pakistan. For this purpose, water samples were collected from the Gomal Zam Dam and its tributaries in the winter and summer seasons (n=24 in each season). Water samples were analyzed for the anions using a multi-parameter analyzer (CONSORT 6030, Belgium) and cations by the Atomic Absorption Spectrophotometer (AAS, AAnalyst 700, PerkinElmer). Water characteristics were compared and found within drinking water guidelines set by the world health organization (WHO), except turbidity. Water characteristics were evaluated for the water quality index (WQI) and sodium hazards such as sodium adsorption ratio (SAR) and sodium percentage (Na%). Based on WQI and sodium hazards, the water of Gomal Zam Dam and its tributaries were observed as good and in permissible levels for drinking and irrigation water, respectively. The winter season has slightly poor water quality compared to the summer season due to higher contamination. Gibbs's and Piper's models showed that the water quality of Gomal Zam Dam and its tributaries was mainly characterized by the weathering of bedrocks. The studied water is classified as Na-Cl type and Mg-HCO3 types in the summer and winter seasons, respectively. Statistical analyses revealed that geogenic sources of rock weathering are the dominant factor for controlling the water quality of the area.

Introduction

Water is one of the fundamental resources supporting human survival and economic development (Li &Qian 2018). The freshwater that can be readily used for various purposes accounts only for a small portion of the total water resources on earth. Among freshwater, surface water plays an important and irreplaceable role. Freshwater such as lakes/Dam and rivers are considered as the most vulnerable to contamination from both natural (weathering and erosion of bedrocks and ore deposits) (Muhammad &Usman 2021) and human (agricultural, mining, industrial, domestic waste) activities (Zhang et al. 2021). These activities continue to deteriorate water quality leads to declined or loss of the self-purification function, and destroying ecological balance (Wu et al. 2017, Zhou et al. 2021). The clustered contaminants in lakes and rivers will lead to eutrophication (Jaiswal &Pandey 2019) and affect the daily use and life of the dependent local population (Zhao et al. 2018). This contaminated water for irrigation could destroy the soil structure, fertility (Li et al. 2018, Mandal et al. 2008), and contaminate food crops (Muhammad et al. 2019), while the drinking of such water having deleterious substances could cause health problems (Muhammad &Ahmad 2020).

Water quality assessment is an imperative and crucial task in the balanced development and use of freshwater resources (Snousy et al. 2021, Zhou et al. 2016). Water quality assessment information is carried out to obtain the degree of pollution of a water reservoir for the facilitation of decision-making for its management and protection (Li &Wu 2019). In the last few decades, the water quality assessment techniques that have been widely applied in various environmental studies such as single factor evaluation, pollution index (Liu et al. 2021), water quality index (Jahin et al. 2020), geospatial analysis (Muhammad &Usman 2021) and multivariate statistical analyses including correlation, principal components and factor analyses (Varol 2020). These techniques have been observed with avoiding unnecessary repetition of data analyses, water quality evaluation, and decision-making for the management of water reservoirs (Adimalla 2021, Varol 2020).

Recently, water quality contamination has been observed from both developed and developing countries e.g., Poland (Pecyna-Utylska et al. 2021), Italy (Ioele et al. 2020), Iran (Amiri et al. 2021), India (Kumar et al. 2021), and China (Zhang et al. 2021). The problem of water quality deterioration is more severe in developing countries like Pakistan due to higher population growth and low capital investment in aquatic ecosystem degradation (Jadoon et al. 2019). The Gomal Zam Dam is a source of drinking and irrigation water, fisheries, and recreational activities for millions of human population. Rivers feeding the Gomal Zam Dam traversed from the rich mineralized geology and could be a possible source of contamination to the water (Ullah et al. 2019). However, so far the water quality of the Gomal Zam Dam and its feeding tributaries has not been explored. Therefore, it is imperative to investigate the water quality of the Gomal Zam Dam and its tributaries. Hence this study is aimed to study the water quality of Gomal Zam Dam and its feeding tributaries including Gomal River and Zhob River. Water was evaluated for the water quality index (WQI), sodium hazards, and provenance of contamination using multivariate statistical analyses.

Materials And Methods

2.1. Study area and geology

The proposed study area of Gomal Zam Dam and its tributaries are located between latitude 32°55'S and longitude 69°52'E, approximately the 50 Km away from the Tank District (Fig. 1). Gomal Zam Dam is constructed in 2013 on the Gomal River having height of 133 m and power generation of 17.4 MW (Wang et al. 2014).

The study area represents the northern extremity of the Suleman fold belt (SFB) is a large folding and thrust belt (>300km) formed because of the Transpressive environment. The SFB rocks are divided into three north-south units, including (I) Flysch deposits characterized by Zhob Valley Muslimbagh ophiolite (II) shallow to deep marine deposits and (III) continental molasses strata of younger age (Ullah et al. 2019). The study area is bordered by the Indus Basin to the east, the Chaman Fault, and the Katawaz Basin to the southwest (Khurshid 1991) the sedimentary sequence exposed in this part of the Indus Basin is composed of Jurassic to Eocene shallow to deep marine rocks that were deposited on the northwestern margin of the Indo Pakistani Cretan, late tertiary non-marine foreland basin deposits, and post-collissional molasses deposits (Shafique 2001). The area is mainly composed of sedimentary sequences ranging in age from Jurassic to present with Paleocene and Eocene successions are particularly well developed. The sedimentary sequence is more than 4000 meters thick in the South Waziristan region (Hemphill et al. 1973). The northwestern side of the area is characterized by ophiolite emplacement with low-grade metamorphic rocks (Badshah et al. 2000). The Jurassic Chilton Limestone is the oldest formation that can be seen near the Gomal Zam Dam along the road from Jandola to Gomal Zam Dam, while Chaudhwan Formation is the youngest.

2.2. Sampling and field analyses
The samples of water were collected from Gomal Zam Dam (n = 9) and its tributaries, outlet (n = 5 each) (Fig. 1). For seasonal variability, water samples were collected twice a year i.e. summer and winter seasons (n = 24 each season) in pre-washed polythene bottles according to standard methods adapted from (APHA 2005). Coordinates for the location of each water sample were recorded using a handheld global positioning system (GPS, Germin etrex 10) and noted in the field handbook. Each sample was collected in two pre-labeled separate bottles: one was acidified with nitric acid (HNO₃). Total dissolved solids (TDS), turbidity, acidity (pH), and electrical conductivity were determined during the field through a multi-parameter analyzer (CONSORT C6030, Belgium). All the water samples were carried to the Geochemistry Laboratory of the National Center of Excellence in Geology, University of Peshawar. For further analysis samples were kept under optimum temperature (4°C).

2.3. Analytical procedure

Different physicochemical parameters analyses including iodide (I), fluoride (F), and chloride (Cl) were measured using a multi-parameter analyzer (CONSORT C6030, Belgium), and sulfate (SO₄) by spectrophotometer (UV-1900i, Shimadzu Co., Japan) according to adapted methods from APHA (2005). Light elements i.e. Mg, Ca, K and Na were examined using the atomic absorption spectrometer (AAnalyst 700, PerkinElmer, USA). The reagents used during the study were extremely analytical grade and deionized water was used for dilution. To determine the measurement accuracy of AAS, the reagent standard solution and the blank were set and run after every 10 samples. The accuracy of the instrument was found at 86 ± 7 at the confidence level.

2.4. Water quality index

The WQI showed the collective impact of various measured parameters on water quality and has been reported to be an effective model for evaluation and decision making (Karunanidhi et al. 2021). WQI models depend: (1) selection of water quality parameters, (2) generation of sub-indices for each parameter, (3) calculation of weighting parameters, and (4) aggregation of sub-indices to determine the overall WQI (Uddin et al. 2021). WQI values were calculated using the following equations (Alver 2019, Sahu & Sikdar 2008):

\[ W_i = \frac{w_i}{\sum w_i} \text{(1)} \]

\[ Q_i = (C_i - C_{ip})/C_{ip}/100 \text{(2)} \]

\[ S_i = w_i \times Q_i \text{(3)} \]

\[ WQI = \sum S_i \text{(4)} \]

where \( w_i \) is taken as the relative weight, \( w_i \) the weight of each number of parameters and the parameters of water quality if shown by "n" although \( C_{ip} \) represents the concentration of each parameter in studied water, \( C_{ip} \) is the optimal value (\( C_{ip} = 7 \) for pH, \( C_{ip} = 0 \), for other parameters) in freshwater).

2.5. Sodium hazards for irrigation water quality

Sodium adsorption ratio (SAR) and sodium percent (Na%) were calculated using the following equations adapted from (Allison and Richards 1954, Pal and Poonia 1979):

\[ SAR = \frac{Na}{Ca+Mg} \text{(5)} \]

\[ Na\% = \frac{Na+K}{Na+K+Ca+Mg} \times 100 \text{(6)} \]

2.6. Hydrogeochemistry

Gibbs model plots and Piper-Hill diagram were applied for the classification of Gomal Zam Dam and its tributaries water sources and type using the online scatter plot maker.

2.7. Statistical analyses

The MS Excel and statistical package for social sciences (SPSS), ver. 25 (Chicago, SPSS Inc. IL, USA) and interpolation tool of Arc GIS software were used for geospatial analysis of water characteristics in the Gomal Zam Dam and its tributaries. Statistical analyses such as Pearson's correlation and principal component analyses (PCA) were performed using SPSS software.

Results And Discussion

3.2. Water characteristics

Water characteristics mean values of Gomal Zam Dam and its tributaries of the study area in both winter and summer seasons were presented in Fig. 2. The highest mean value of pH was observed in the Gomal River inlet, while the lowest was in the Zhob River in both winter and summer seasons. The values of TDS and EC were highest in the Zhob River, while the lowest in Gomal Zam Dam and Gomal River outlet in the winter and summer seasons, respectively. Maximum mean values of turbidity were observed in water collected from the Zhob River and the lowest in the Gomal Zam Dam in both seasons. The values of pH, TDS, EC, and turbidity were observed within the drinking water guidelines set by the world health organization (WHO 2017), however that of turbidity surpassed the permissible limit in the Gomal River inlet and outlet, and Zhob River. TDS and EC are considering important parameters for industrial and
irrigation purposes. Maximum electrical conductivity shows a higher concentration of inorganic dissolved solids (Peavy et al. 1985). A higher value of TDS and EC in Zhob River could be related to natural weathering and erosion, and agricultural activities. Higher TDS and turbid water is rich in organic nutrients including phosphate and nitrate and leads to eutrophication, depletion of oxygen, and reduces light penetration which could reduce photosynthetic activity and impact the aquatic organism (Gregory & Northcote 1993, Schueler & Holland 2000).

The mean concentrations of Ca and Mg were highest in the Gomal River Inlet, while lowest in the outlet in both seasons (Fig. 2). Na and K showed maximum mean concentrations in the Gomal River Inlet and Zhob River in the winter and summer seasons, respectively (Fig. 2). Higher concentration of these elements could be attributed to their higher concentration in upstream carbonates bedrocks rich in these elements in the vicinity of water resources and human activities such as mining and agricultural activities (Kozisek 2020, Liu et al. 2019). However, the concentration of these elements was found within the drinking water guidelines set by the WHO (2017). Among anions, the highest mean concentrations of CO$_3$$^2^-$, HCO$_3^-$, F, I, and Cl were found in the Gomal River Inlet, while the lowest in its outlet in both seasons. A higher concentration of anions could be attributed to their higher concentration in upstream carbonates bedrocks having fluorides-rich beds in the vicinity of water resources and human activities such as mining, agricultural activities (Kozisek 2020, Liu et al. 2019). However, the concentrations of SO$_4$$^2^-$ were highest in the Zhob River compared to other tributaries. Higher SO$_4$$^2^-$ could be attributed to the enrichment of sulfate mineralization in the Zhob and its vicinity.

### 3.3. Water quality index

The Gomal Zam Dam and its tributaries’ water were examined through a water quality index (WQI) for drinking and irrigation purposes in the study area. The WQI was recognized, if the value of WQI was recorded < 50, then the quality of water is considered excellent. Water value is considered good if the WQI value is between 50 and 100. Moreover, it is considered poor water quality if its value range comes between 100 and 150. If a value is noted between 150 and 200, it is considered very poor water quality, and higher than 200 value of water is not suitable for drinking purpose and need to be paid much attention (Ramakrishnaiah et al. 2009). WQI values of the Gomal Zam Dam and its tributaries have been summarized (Table 1) and spatial distribution (Fig. 3ab). Gomal Zam Dam and its tributaries of both winter and summer seasons fall in the good water category as per the classification of Ramakrishnaiah et al. (2009). The geospatial distribution pattern showed that WQI values of Gomal River outlet were observed in excellent category in last two sampling sites of the river. This lowering of WQI values along the flow could be attributed to the natural purification of the river itself. Among the season, the tributaries of Gomal Zam Dam had slightly higher WQI values of water in the winter season compared summer season. Higher WQI values of water could be attributed to its higher contamination in the winter season.

### 3.4. Sodium hazards for irrigation water quality

Sodium hazards for irrigation water were assessed using the SAR and Na%, and results were summarized in Table 1 and spatial distribution in Fig. 3cdef. Results showed that water of the Gomal Zam Dam and its tributaries were found less than 10 and classified as an excellent category (Zaman et al. 2018). Further, SAR also provides more details regarding the hazards of excessive Na and counter effects of Ca and Mg in irrigation water (Shammi et al. 2016). SAR value greater than 26 is considered unsuitable for irrigation purposes. For Na hazards assessment of irrigation water quality, the Na% is a key parameter that helps in determining its potential threats. A higher concentration of Na in irrigation water may significantly impact the aeration, infiltration, and structure of the soils. Generally, the Na% values < 20, 20–40, 40–60, 60–80, and > 80 are considered excellent, good, permissible, doubtful and unsuitable, respectively. Based on Na%, the water of Gomal Zam Dam is classified as a permissible category in both seasons, Gomal River Inlet and Zhob River as good and doubtful in summer and winter seasons, that of Gomal River outlet as permissible. Low quality of irrigation water in Gomal and Zhob Rivers could be attributed to their higher Na concentration in the winter season.

| Table 1 | Seasonal water quality index and sodium hazards of Gomal Zam Dam and its tributaries in south Waziristan District, Pakistan |
### 3.5. Hydrogeochemistry

This study applied the Gibbs plot model for the identification of major processes responsible i.e. precipitation, rock weathering, and evaporation dominance for controlling surface water chemistry. The data points on the Gibbs plot suggested that surface water chemistry of both seasons is principally controlled and determined by rock weathering Fig. 4ab. This factor was leading to increased salinity and low quality of water (Nazzal et al. 2014, Rao 2002). Rock weathering may include weathering of soft evaporites sedimentary rocks such as carbonate/bicarbonates (calcites and dolomites etc.), sulfates (gypsum), chlorides (halite), and silicates.

This study applied the Piper-Hill diagram for hydrogeochemical facies evolution of the water in the Gomal Zam Dam and its tributaries (Piper 1944). Results showed that the majority of the samples (72%) were classified as Na-Cl type, followed by mixed type (16%) and 12% samples in the Mg-HCO$_3$ types of the winter season (Fig. 5a). Samples collected from the Gomal Zam Dam and Gomal River outlet contributed to the mixed type of water. However, the summer season showed that the majority of samples (76%) were classified in Mg-HCO$_3$ types with 24% in the mixed type as well (Fig. 5b). It is further evident that samples collected from the Gomal River inlet mostly contributed to the mixed type of water.

### 3.6. Statistical analyses

The parameters correlation was found by Pearson's correlation for various water characteristics and results were summarized in Table 2. The pairs with significant positive correlation are EC-TDS, Ca-Mg, Mg-Na, HCO$_3$-CO$_3$, Ca-CO$_3$, Ca-HCO$_3$, Mg-CO$_3$, Mg-HCO$_3$, I-F (Table 2). Higher correlations of these physicochemical parameters were attributed to their common contamination. Gomal Zam Dam tributaries are passing through the mineralized zone (Ullah et al. 2019), and various weathering may include weathering of soft evaporites sedimentary rocks such as carbonate/bicarbonates (calcites and dolomites, etc.), sulfates (gypsum), chlorides (halite), and silicates. Pearson's correlation analyses are in support of the Gibbs model plot that rocks weathering and erosion have a major role in the determination of water quality in the area.

<table>
<thead>
<tr>
<th>Sources</th>
<th>Winter season</th>
<th>Summer season</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Statistics</td>
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<tr>
<td>Gomal Zam Dam</td>
<td>Mean</td>
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<tr>
<td></td>
<td>Standard deviation</td>
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<tr>
<td></td>
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<tr>
<td></td>
<td>Maximum</td>
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<tr>
<td>Gomal River Inlet</td>
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<tr>
<td></td>
<td>Standard deviation</td>
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<tr>
<td></td>
<td>Minimum</td>
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<tr>
<td></td>
<td>Maximum</td>
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<tr>
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<tr>
<td></td>
<td>Minimum</td>
<td>54.6</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>77.6</td>
</tr>
<tr>
<td>Gomal River Outlet</td>
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<tr>
<td></td>
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</tr>
<tr>
<td></td>
<td>Minimum</td>
<td>50.2</td>
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<tr>
<td></td>
<td>Maximum</td>
<td>80.1</td>
</tr>
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</table>

Table 2. Pearson's correlation of water characteristics (n=48) in the Gomal Zam Dam and its tributaries in the south Waziristan, Pakistan.
Results of PCA had a cumulative variance of 70.3% for four factors as exhibited (Table 3). Factor I of PCA contributed 33.6%, the maximum to total commutative variance with significant loading observed for turbidity, pH, Ca, Mg, Na, CO$_3$ and HCO$_3$ (Table 3). Geogenic sources such as weathering of sedimentary carbonate rocks found in the catchment area could attribute these parameters. Factor II contribution to total variance was 15.2% and suggesting both geogenic (weathering and erosion) and anthropogenic sources (agricultural activities) to the presence of high loading TDS and EC. Factor III and Factor IV contributed higher loading on Cl and SO$_4$ of 11.8% to accumulative variance, and F and I of 9.7% to accumulative variance suggested different natural sources.

Table 3 Factor loading for selected heavy metal in Gomal Zam Dam and its tributaries in south Waziristan District, Pakistan (n=48).
Conclusions

This study concluded that water characteristics of the Gomal Zam Dam and its tributaries were observed within the WHO drinking water guidelines, except for turbidity. The winter season has a slightly higher level of contamination than the summer season. The WQI values showed that Gomal Zam Dam and its tributary water are classified as a good category for drinking purposes. For irrigation water quality, the Gomal Zam Dam and its tributaries' water were classified as in permissible levels. However, those of the Gomal River inlet and Zhob River were classified as doubtful in the winter season only. Piper-Hill diagram showed dominancy of Na-Cl type in winter season Mg-HCO$_3$ types in summer. Gibbs plot model and statistical analyses showed that natural sources such as rock weathering are the controlling factor for water quality.

Declarations

Author Contribution  Said Muhammad designed this study, performed data analyses, drafted and edited the manuscript. Insha Ullah performed laboratory analyses and edited this manuscript.

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Data Availability  The data that support the findings of this study are available from the corresponding author upon reasonable request.

Code Availability  Not applicable

Ethics Approval  Not applicable

Consent to Participate  All authors reviewed and approved the final manuscript.

Consent for Publication  All authors approved for this publication.

Conflict of Interest  The authors declare no competing interests.

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Figures

Figure 1

Location of water sampling in the Gomal Zam Dam and its Tributaries, south Waziristan, Khyber Pakhtunkhwa, Pakistan.

Figure 2

Physicochemical parameters values/concentration of water in the Gomal Zam Dam and its Tributaries, South Waziristan, Khyber Pakhtunkhwa, Pakistan: a. Basic parameters and cations in winter season, b. Anions in winter season, c. Basic parameters and cations in summer season, d. Anions in summer season.
Figure 3
Spatial distribution of water quality index and sodium hazards: a. winter season WQI, b. summer season WQI, c. Winter season SAR, d. summer season SAR, e. winter season Na%, f. summer season Na% in the Gomal Zam Dam and its Tributaries, South Waziristan, Khyber Pakhtunkhwa, Pakistan.

Figure 4
Exemplified Gibbs diagrams to identify natural mechanism dominancy on water chemistry both winter and summer season of Gomal Zam Dam and its tributaries in South Waziristan a. Na/Na + Ca (Meq/L) versus TDS data b. Cl/Cl+HCO3 (Meq/L) versus TDS.
Figure 5

Piper diagrams showing proportion of cations and anions a. Winter season, b. Summer season in the Gomal Zam Dam and its Tributaries, South Waziristan, Khyber Pakhtunkhwa, Pakistan.