



Spatial distribution of drinking and irrigation water quality indices of Ghizer River Basin, northern Pakistan

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Abstract

Determining the water contamination of a river that threatens the dependent ecological community is a pillar for sustainable management. For this purpose, the present study aimed to examine the water quality of the Ghizer River Basin (GRB), Gilgit-Baltistan, northern Pakistan, for drinking and irrigation. Water samples ($n = 55$) were collected from the GRB and analyzed for physicochemical parameters. Water basic parameters and anions were measured using the multi-parameter analyzer (CONSORT 6030, Belgium) and cations by the atomic absorption spectrophotometer (AAS, Analyst 700, PerkinElmer, USA). Physicochemical parameters such as pH, electrical conductivity (EC), total dissolved solids (TDS), iodide (I), chloride (Cl), fluoride (F), nitrate (NO_3), sulfate (SO_4), bicarbonate (HCO_3), turbidity, calcium (Ca), magnesium (Mg), potassium (K), and sodium (Na) were noted to be within the drinking water permissible limits set by the World Health Organization (WHO). However, pH and turbidity surpassed their respective limits in 2% and 48% of water samples, respectively. Samples were assessed for water quality index (WQI) and irrigation water quality (IWQ) indices. The WQI values for most samples in the GRB were noted in the excellent (38.2%), good (58.2%), and poor (3.6%) categories. Similarly, most IWQ indices revealed that water is suitable and recommended for irrigation. Gibbs plots showed that most water samples in the GRB were noted in the precipitation dominance zone. The piper plot revealed the calcium–chloride (Ca–Cl) dominant hydrochemical facies.

Keywords Physicochemical parameters · Water quality index · Irrigation water quality index · Geogenic

Introduction

Water is one of the most vital requirements of human beings and aquatic life (Muhammad and Ullah 2022; Versari et al. 2002). Water has economic and social importance due to recreation and tourism (Arain et al. 2008). Freshwater such as rivers, lakes, and groundwater are the likely resources used for domestic, human consumption, and irrigation purposes (Das Kangabam and Govindaraju 2019; Kumar and Rana 2022). Water consumption of these resources has increased exponentially due to the significant increase in population (Ho et al. 2003; Liu et al. 2022). In addition, the water quality has long been deteriorating by natural and anthropogenic activities (Muhammad and Usman 2022;

Uddin et al. 2021). The natural activities influencing water quality include atmospheric, hydrological, topographical, climatic, and soil factors (Magesh et al. 2013; Uddin et al. 2021). Anthropogenic activities that deteriorate the quality of water are the production and disposal of waste from agricultural, municipal, and industrial sources; livestock farming; mining; increased soil erosion or sediment runoff due to land-use change; urbanization; and an increase in water consumption (Khan et al. 2019; Lobato et al. 2015; Tokatli et al. 2022; Tokatli and Varol 2021; Varol and Tokatli 2022).

Globally, water quality monitoring indices have been developed and introduced in various regions of the world in several studies, such as the water quality index (WQI) (Panikkar et al. 2022; Tokatli 2019), risk indices (Kumar et al. 2019), and irrigation water quality (IWQ) indices (Chowdhury et al. 2022; Muhammad and Ullah 2022). In addition to these indices, geospatial and statistical techniques were also used in water quality monitoring studies (Muhammad et al. 2021; Tokatli and Islam 2022). The application of these techniques improves the decision-making skill for better management of water bodies.

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Recently, water quality monitoring and assessment have been focused on developed countries, like Italy by Çevirgen et al. (2020), Poland by Górski et al. (2019), and developing countries such as Iran by Khairy and Janardhana (2022), India by Dandge and Patil (2022), and China by Wang et al. (2022). However, the water contamination problem is more severe in developing countries, e.g., Pakistan, as Jadoon et al. (2019) reported. Human activities such as industrial and mining waste effluents had little or no influence on the water quality of remote rivers in Gilgit-Baltistan, northern Pakistan. However, in such a remote river, the water quality deterioration was due to contamination from rich mineralization in the vicinity (Muhammad and Usman 2022). The GRB has rich mineralization in the area, which could be a potential source of water contamination (Kazmi & Jan 1997; Muhammad and Usman 2022). So far, the water quality of GRB has not been studied. Therefore, this study aimed to investigate the physicochemical parameters of water in the GRB. Physicochemical parameters were used for the spatial distribution maps of the GRB in Gilgit-Baltistan, northern Pakistan. Water data were evaluated for the WQI and IWQ indices to determine their suitability for various uses.

Material and methods

Study area

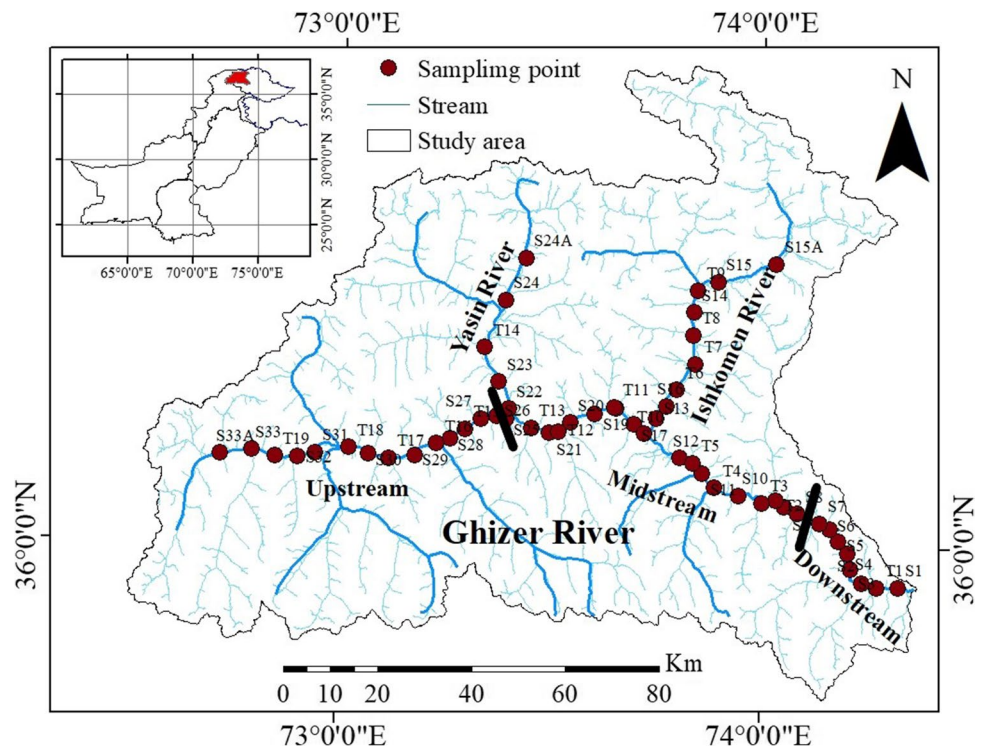
The GRB is located in the Ghizer and Gilgit Districts. Ghizer District has four tehsils (Yasin, Ishkoman, Gupis, and Puniyal)

of Ghizer Valley in Gilgit-Baltistan, located between latitudes 35.8–37.0°N and longitudes 72.5–74.4°E, covering an area of about 12,042 km² (Fig. 1). Ghizer District connects Chitral and Gilgit Districts through the Shandur pass. The study area extends from Shandur Pass to Hunza River in the east. Several rivers have cut this area into minor and four key valleys: Ghizer, Yasin, Ishkoman, and Hunza. The Ghizer River lies immediately south of the Main Karakoram Thrust (MKT). The area falls exclusively into and constitutes the northernmost domain of the Kohistan island arc (KIA). The Ghizer formation is composed of basalt and andesite-dominated crystalline and pyroclastic rocks exposed in the vicinity of Hatoon in the Ishkoman valleys. Chalt Volcanic Group (CVG) is exposed within and around Sharman Village (Kazmi and Jan 1997, Pudsey 1986).

Sampling, preservation, and field analyses

In this study, duplicates-water samples ($n=55$) were collected in August 2020 from GRB segments such as upstream Ghizer River ($n=15$), midstream Ghizer River ($n=18$), downstream Ghizer River (Gilgit region, $n=8$), Ishkoman River ($n=9$), and Yasin River ($n=5$, Fig. 1). The geographical location of each sampling point was noted using a hand-held global position system. Each polyethylene bottle was 3-times pre-washed with sampling water as adapted from the American Public Health Association (APHA 2005). One of the duplicate sampled water bottles was acidified with nitric acid (HNO₃) in the field for cations analyses. Basic parameters of water such as

Fig. 1 Location of water sampling in Ghizer River Basin



pH, turbidity, temperature, total dissolved solids (TDS), and electrical conductivity (EC) were measured in situ using a multi-parameter analyzer (CONSORT 6030, Belgium). Samples were labeled, transported, and stored in a refrigerator (4 °C) for further chemical analysis.

Laboratory analysis

In the laboratory, the concentration of anions, including chlorides (Cl), fluorides (F), iodide (I), and nitrate (NO₃), was determined by a multi-parameter analyzer (CONSORT 6030, Belgium). Anions such as carbonates (CO₃), bicarbonates (HCO₃), and sulfate (SO₄) were measured by titration methods adapted from the APHA (2005). Potassium (K), sodium (Na), calcium (Ca), and magnesium (Mg) concentrations were determined in the acidified sample of water using an atomic absorption spectrophotometer (AAS, Perkin Elmer AAnalyst 700).

The reason for choosing the abovementioned parameters was to get enough data to evaluate the GRB's drinking WQI and IWQ indices. These indices summarize the extensive data set into small and simple, making it easy for decision-makers.

Drinking water quality indices

The drinking WQI calculation was determined using the assigned weight and relative weight (Table 1) in the following four steps as adapted from Ali et al. (2019), Yidana and Yidana (2010):

$$Wi = wi / \sum_{i=1}^n wi \quad (1)$$

Wi represents each parameter's relative weight, *wi* is each parameter's assigned weight, and *n* is the total number of parameters. Assigned weight (*wi*) for each parameter ranged from 1 to 5 based on its importance, where 1 indicated the least potential effect, while 5 is considered critical for health.

Each parameter quality rating was calculated by dividing its concentration in studied samples by its guidelines values world health organization (WHO 2017) and multiplying by 100, described below as Eq. 2:

$$qi = Ci/Si \times 100 \quad (2)$$

Here, *qi* represents the quality rating, and *Ci* represents the actual parameter concentration in each collected water sample. Calculation of sub-index value (SI) is measured by Eq. 3:

$$SI_i = Wi \times qi \quad (3)$$

Here, the *SI_i* is the sub-index for the *i*th parameter; *qi* is the quality rating of the parameter (Eq. 2), and *I* is the relative weight (Eq. 1). The water quality index is calculated using Eq. 4:

$$WQI = \sum_{i=1}^n SI \quad (4)$$

Table 1 Assigned weights and calculated relative weights for water quality parameters in the Ghizer River Basin

Parameter	Standard limits	Assigned weight (<i>wi</i>) (33)	Relative weight (<i>Wi</i>)
pH	7	4	0.09
TDS	500	5	0.11
Turbidity	5	3	0.07
NO ₃	10	5	0.11
F	1.5	5	0.11
HCO ₃	120	1	0.02
Cl	250	3	0.11
SO ₄	250	3	0.11
Ca	75	2	0.04
Mg	50	2	0.04
Na	200	3	0.09
K	12	2	0.04
		∑ <i>wi</i> = 38	∑ <i>Wi</i> = 1

TDS, total dissolved solids; *NO₃*, nitrate; *F*, fluoride; *HCO₃*, bicarbonates; *Cl*, chloride; *SO₄*, sulfate; *Ca*, calcium; *Mg*, magnesium; *Na*, sodium; *K*, potassium. pH is unitless; turbidity is measured in NTU and the rest of the parameters in mg/L

The WQI value is considered excellent, good, poor, very poor, and unsuitable if recorded as < 50, 50–100, 100–150, 150–200, and > 200, respectively (Ramakrishnaiah et al. 2009).

Irrigation water quality

The IWQ indices parameters were calculated using the following Eqs. 5 to 11. The concentrations of the elements were measured in meq/L. The permeability index (PI) is reported to be class I (unsuitable), class II (suitable), and class III (excellent) if recorded as < 25, 25–75, and > 75%, respectively (Doneen 1964; Singaraja 2017). The PI is expressed as Eq. (5):

$$PI = \{ (Na + HCO_3) / [\sqrt{(Ca + Mg + Na)}] \} \times 100 \quad (5)$$

Kelley's ratio (KR) classified water for irrigation into three groups: suitable, marginal, and unsuitable. The KR values < 1 showed water suitability for irrigation purposes, 1–2 showed marginal, and > 2 is unsuitable (Kelley 1963). The adapted by Kelley (1963) is described as Eq. (6):

$$KR = Na / (Ca + Mg) \quad (6)$$

Magnesium hazard (MH), also known as magnesium adsorption ratio (MAR). The MH is known as magnesium adsorption ratio (MAR) and is classified into two classes; < 50 shows the water is suitable, and > 50

indicates the water is unsuitable (Ragunath 1987). The MH is calculated as Eq. (7) by Ragunath (1987):

$$MH = Mg \times 100 / (Ca + Mg) \quad (7)$$

The sodium percent (Na%) is considered excellent, good, permissible, doubtful, and unsuitable if recorded as 0–20, 20–40, 40–60, 60–80, and > 80, respectively (Singaraja 2017; Wilcox 1955). The Na% is calculated as Eq. (8) by (Singaraja (2017), Verma et al. (2020)):

$$Na\% = (Na + K) / (Na + Ca + Mg + K) \times 100 \quad (8)$$

The sodium adsorption ratio (SAR) is noted to be excellent, good, fair, and poor if recorded as 0–10, 10–18, 18–26, and > 26, respectively (Richards 1954; Singaraja 2017). The SAR is calculated by Eq. (9):

$$SAR = Na / \sqrt{Ca + Mg} / 2 \quad (9)$$

The residual sodium carbonate (RSC) is reported to be good, medium, and bad if recorded as < 1.25, 1.25–2.5, and > 2.5, respectively (Richards 1954; Singaraja 2017). The RSC is expressed as Eq. (10):

$$RSC = (CO_3 + HCO_3) - (Ca + Mg) \quad (10)$$

The potential salinity (PS) index values < 3 and > 3 are considered suitable and unsuitable, respectively. The PS is determined as below in Eq. (11):

$$PS = Cl + 1/2SO_4 \quad (11)$$

Statistical analysis

The measured results were analyzed for descriptive statistics such as mean, standard deviation, and ranges, and the one-way ANOVA and Pearson correlation using SPSS software version 25 (Chicago, SPSS Inc. IL, USA), Gibbs models, Piper plots, and Arc GIS software version 10.3.

Results and discussion

Physicochemical parameters

Physicochemical parameters concentration/values in the water of the GRB and the WHO drinking water guidelines were summarized (Table 2). The majority of the physicochemical parameters such as TDS (74.1 ± 27.3 mg/L), EC (190 ± 48.3 μ S/cm), Cl (16.2 ± 8.6 mg/L), Ca (16.9 ± 5.7 mg/L), and Mg (10 ± 2.6 mg/L) concentrations were found statistically higher ($p < 0.01$) in the Ishkoman River. Higher contaminations of these physicochemical

parameters were due to the upstream bedrock geology and settlement along with the Ishkoman River. These values of studied parameters were noted below the WHO drinking water guidelines, except for turbidity in 48% of samples that surpassed the respective limit. Statistical higher values of *pH* (8.2 ± 0.2), *I* (0.011 ± 0.006 mg/L), *F* (0.22 ± 0.07 mg/L), and *K* (3.7 ± 2.5 mg/L) were observed downstream, while NO_3 (3.7 ± 0.7 mg/L) in the upstream Ghizer River (Table 2). Higher NO_3 concentration upstream of the Ghizer River could be attributed to agricultural and animal farming activities in the Phander valley. Higher NO_3 concentration in water is often associated with agricultural and animal farming (Nakagawa et al. 2021). Higher concentrations of SO_4 (151 ± 30 mg/L) and Na (2.7 ± 2.7 mg/L) were observed in the Yasin River (Table 2). These parameters were found within the WHO drinking water guidelines, except for pH in 2% of the studied samples that surpassed the respective limit. The water quality values of this study were observed to be lower than those studied by Muhammad and Ahmad (2020) in the Hunza River. Na, Ca, and Mg values were lower than the Tokatli (2019) Ergene River of Turkey reported.

Drinking water quality index

Results of the WQI of the Ghizer River were summarized (Fig. 2ab). The majority of water samples were classified as a good and excellent class except for two samples in the poor category as defined by Ramakrishnaiah et al. (2009). The result showed that water samples of upstream Ghizer, Ishkoman, and Yasin Rivers were classified into good and excellent categories. However, one sample in the midstream and downstream of the Ghizer River was in the poor class (Fig. 2b). Poor water quality in one sample midstream and downstream Ghizer River could be attributed to local activities (domestic wastewater and bedrock geology). The variation among the GRB segments was found insignificant ($p = 0.05$). WQI values were observed to be better than that noted by Muhammad and Ullah (2022) for Gomal Zam Dam, Pakistan, and Tokatli (2019) for the Ergene River of Turkey. Poor water quality of the Gomal Zam Dam, Pakistan, and Ergene River of Turkey could be attributed to agricultural and industrial activities in the vicinity (Muhammad and Ullah 2022; Tokatli 2019).

Irrigation water quality indices

The results of the IWQ indices of the GRB water were summarized (Fig. 2ac-i). Water suitability for irrigation purposes was determined using several IWQ indices such as PI, KR, MH, Na%, SAR, RSC, and PS.

Table 2 Physicochemical parameters concentration/values in the water of the Ghizer River Basin

Parameters	Upstream Ghizer River (n = 15)		Midstream Ghizer River (n = 18)		Downstream Ghizer River (n = 8)		Ishkomen River (n = 9)		Yasin River (n = 5)		P value	WHO (2017)
	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD		
pH	7.3–8.4	7.8 ± 0.3	7.2–8.1	7.7 ± 0.3	8–8.6	8.2 ± 0.2	7.5–8.2	8 ± 0.2	7.8–8.1	7.9 ± 0.2	P < 0.01	8.5
TDS	13–46	35.2 ± 10	19–86	51.6 ± 19.8	47–76	65.3 ± 9.5	53–126	74.1 ± 27.3	58–65	63.3 ± 3	P < 0.01	1000
EC	64.8–123	99.3 ± 17.9	57.1–184	126 ± 44.4	92.7–168	150 ± 23.5	144–269	190 ± 48.3	143–187	165 ± 21	P < 0.01	1400
Turbidity	0.5–37.2	14.5 ± 11.9	0.3–98.6	21.9 ± 27.6	0.8–43.6	28.2 ± 12.9	1.1–42.1	34.5 ± 16.7	21.7–26	24.5 ± 1.6	P ≥ 0.54	5
NO ₃	2.7–5.1	3.7 ± 0.7	2.2–6.5	2.9 ± 1.2	1.9–4.5	2.7 ± 0.8	1.1–2.4	1.7 ± 0.5	1.9–3.1	2.3 ± 0.5	P < 0.01	10
I	0.003–0.01	0.005 ± 0.002	0.003–0.008	0.005 ± 0.001	0.005–0.02	0.011 ± 0.006	0.005–0.015	0.007 ± 0.003	0.004–0.007	0.005 ± 0.001	P < 0.01	
F	0.04–0.14	0.10 ± 0.03	0.04–0.25	0.14 ± 0.08	0.06–0.3	0.22 ± 0.07	0.10–0.26	0.18 ± 0.07	0.15–0.16	0.16 ± 0.01	P < 0.01	1.5
HCO ₃	36.6–250	94.6 ± 54.9	36.6–214	86.4 ± 37.7	67.1–104	82.3 ± 11.8	79.3–220	119 ± 46	73.2–140	112 ± 25.7	P ≥ 0.27	500
Cl	0.3–12.3	5.37 ± 3.7	0.3–22.3	9.2 ± 6.7	2.3–20.3	9.1 ± 5.9	0.3–25.3	16.2 ± 8.6	1.3–9.3	4.9 ± 3	P < 0.01	250
SO ₄	65.1–163	120 ± 35.8	74.8–170	124 ± 28.9	118–161	137 ± 12.4	96.3–196	143 ± 32.1	97.6–167	151 ± 30	P ≥ 0.15	250
Ca	4.5–14.1	8.1 ± 2.2	1.9–16	11 ± 4.3	8.3–17.9	14.7 ± 2.8	11.5–26.2	16.9 ± 5.7	12.8–17.9	15.1 ± 1.9	P < 0.01	200
Mg	2.2–7.5	5.1 ± 1.5	2.9–12.2	6.7 ± 4.2	7–13	9.4 ± 1.7	6.7–15.2	10 ± 2.6	7.5–12	9.2 ± 1.9	P < 0.01	50
Na	0.3–1.4	0.9 ± 0.3	0.1–1.6	0.9 ± 0.4	0.6–2.2	1.4 ± 0.6	0.1–1.6	0.8 ± 0.5	0.4–6.8	2.7 ± 2.7	P ≥ 0.15	200
K	0.5–1	0.7 ± 0.1	0.3–4.7	1.6 ± 1.3	0.8–8.5	3.7 ± 2.5	0.3–4.3	2.4 ± 1.9	0.9–1.2	1.1 ± 0.1	P < 0.01	12

n, number of water samples; SD, standard deviation, pH is unitless; electrical conductivity (EC) is measured in µS/cm; turbidity in NTU; total dissolved solids (TDS), nitrate (NO₃), fluoride (F), iodide (I), bicarbonates (HCO₃), chloride (Cl), sulfate (SO₄), calcium (Ca), magnesium (Mg), sodium (Na), and potassium (K) are measured in mg/L

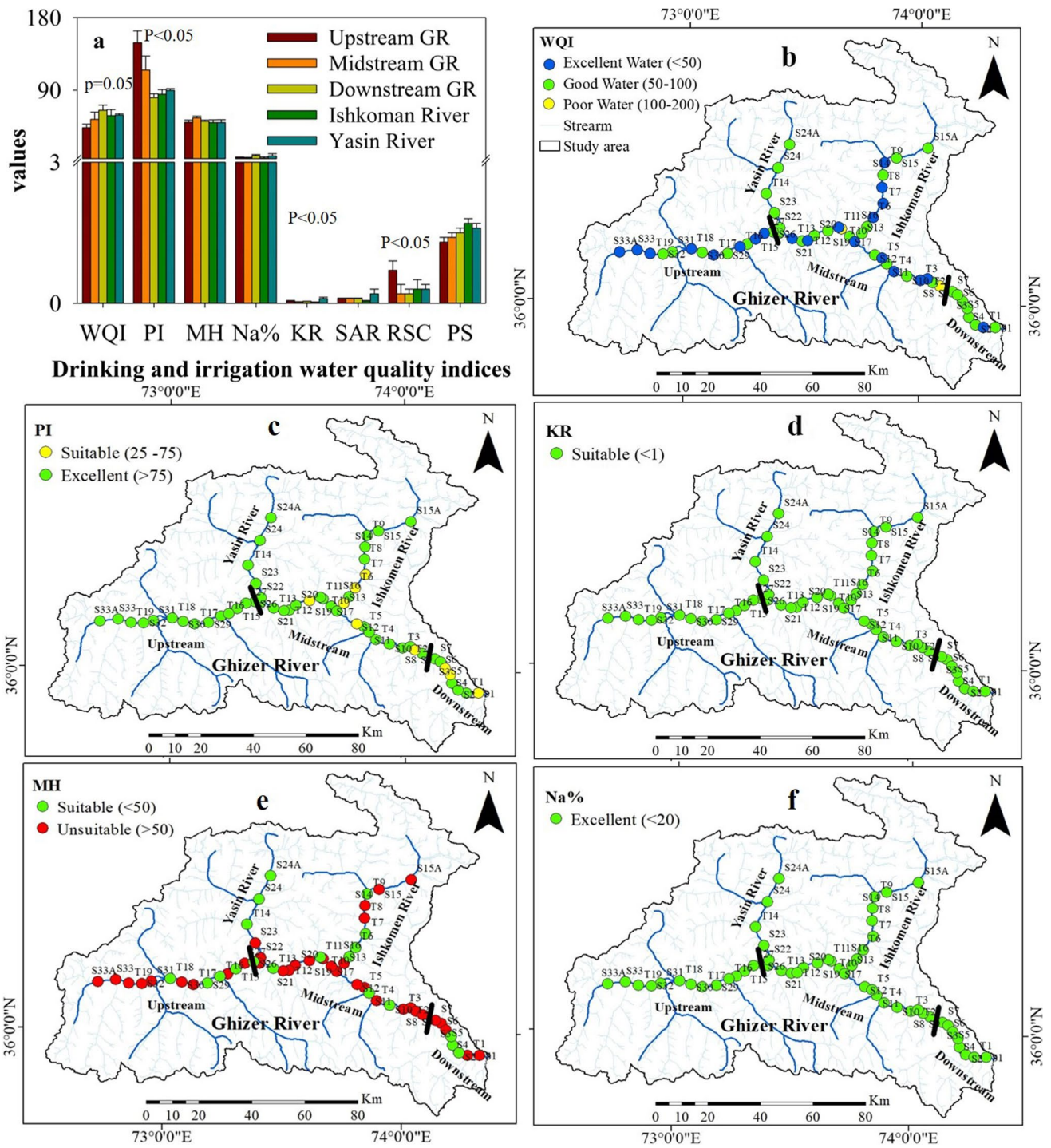


Fig. 2 Average values of water quality index and irrigation water quality indices and their spatial distribution in the Ghizer River Basin, Ghizer river (GR), Water Quality Index (WQI), Permeability

index (PI), Kelly’s ratio (KR), Magnesium hazard (MH), sodium percentage (Na%), sodium adsorption ratio (SAR), residual sodium carbonate (RSC), and potential salinity (PS)

Permeability index

The GRB’s average PI values and spatial distribution were summarized (Fig. 2ac). Based on the PI values of Doneen’s (1964)

classification, most of the GRB samples were categorized in class III (excellent category). However, only two samples of the midstream Ghizer River and three samples each in Ishkoman River and the downstream Ghizer River were classified as class

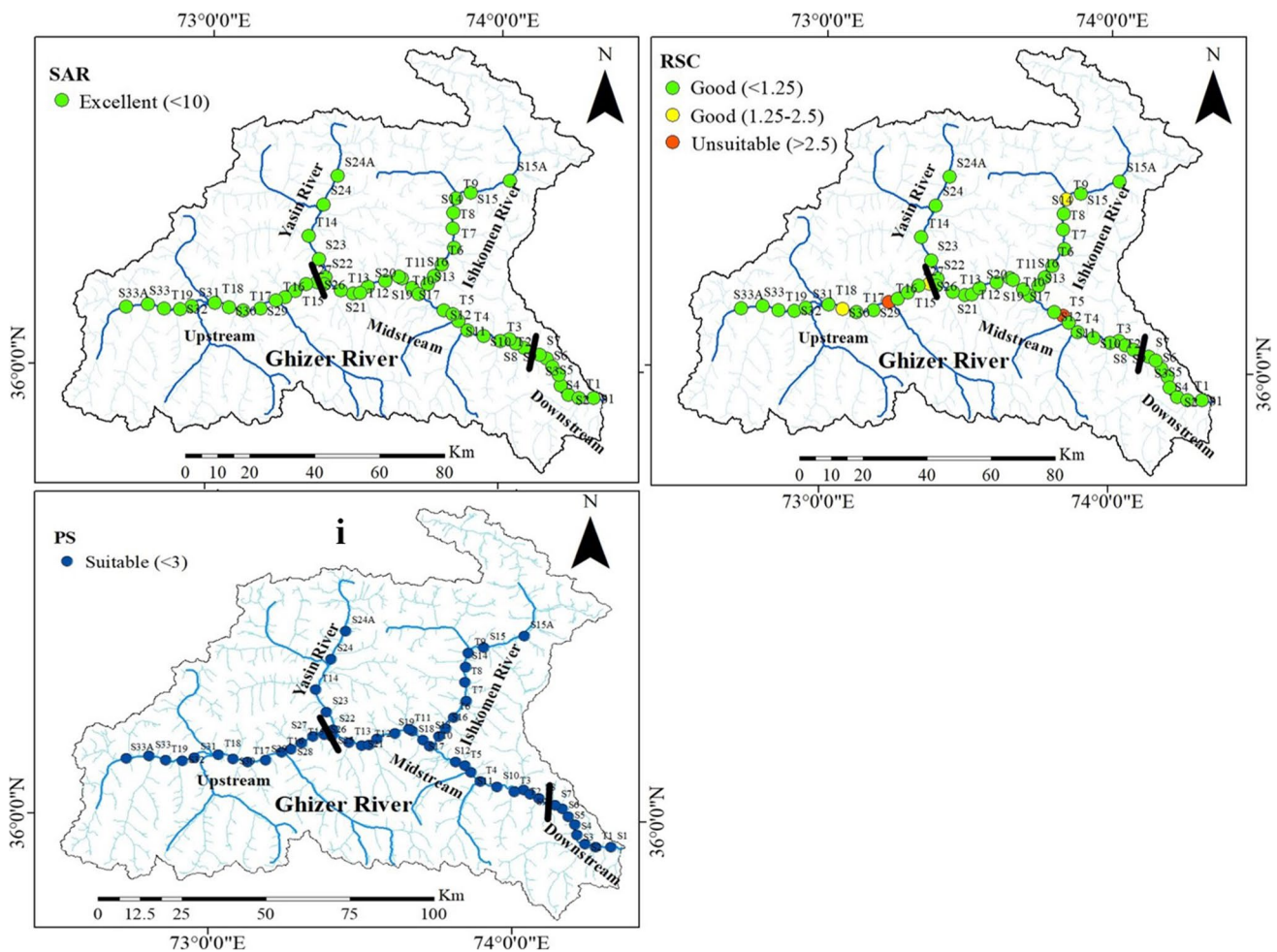


Fig. 2 (continued)

II (suitable category, Fig. 2c). Both of these classes were known as excellent and suitable for irrigation purposes with no restrictions. The PI values of the GRB segments showed a statistically significant variation ($p < 0.05$). Average PI values of GRB were observed to be higher than that noted by Ali and Muhammad (2022) in the Astore River Basin, northern Pakistan, suggesting its more suitable for irrigation purposes.

Kelly's ratio

Results revealed that water samples of GRB were noted to be suitable for irrigation purposes (Fig. 2ad) as categorized by Kelley (1963). The KR values of the GRB showed a statistically significant variation ($p < 0.05$) in its segments. The KR values of the GRB were lower than those reported by Radinogana et al. (2020) in southern Africa. The lower KR values of GRB could be attributed to a low level of contamination, suggesting its higher suitability for irrigation.

Magnesium hazard

The GRB's average MH values and spatial distribution were summarized (Fig. 2ae). Based on the MH values of Raghunath's (1987) classification, most GRB samples surpassed the threshold limit and were categorized as unsuitable. MH values of the GRB were consistent due to higher Mg contents in water with those reported by Chebet et al. (2020) in the Molo River, Kenya.

Sodium percentage

Results revealed that water samples of GRB were noted as excellent for irrigation purposes (Fig. 2af) as categorized by Wilcox (1955). The Na% values were experienced lower than a previous study by Muhammad and Ullah (2022) for the Gomal Zam Dam Basin. The lower Na% in GRB could be attributed to its lower contents of Na in water.

Sodium adsorption ratio

The SAR is one of the most effective IWQ indices (Ayers & Westcot 1985). The SAR mean values of water samples and spatial distribution in the GRB were summarized (Fig. 2ag). Based on Richards’s (1954) classification, water samples of GRB were classified as excellent. The SAR values of GRB were experienced better than that of Khan et al. (2019) for the Soan River, Pakistan. The better water quality of GRB than the Soan River could be attributed to a lower concentration of Na and a higher concentration of other elements that counter its effect.

Residual sodium carbonate

The RSC mean values of water samples and spatial distribution in the GRB were summarized (Fig. 2ah). Based on the Richards (1954) classification, water samples of the GRB were classified as good for irrigation purposes. However, one sample each in upstream and midstream Ghizer River was noted as unsuitable. Mean RSC values are observed with statistically significant variation ($p < 0.05$) in GRB segments

(Fig. 2ah). The RSC values of the GRB were better than those reported by Shil et al. (2019) for the Mahananda river.

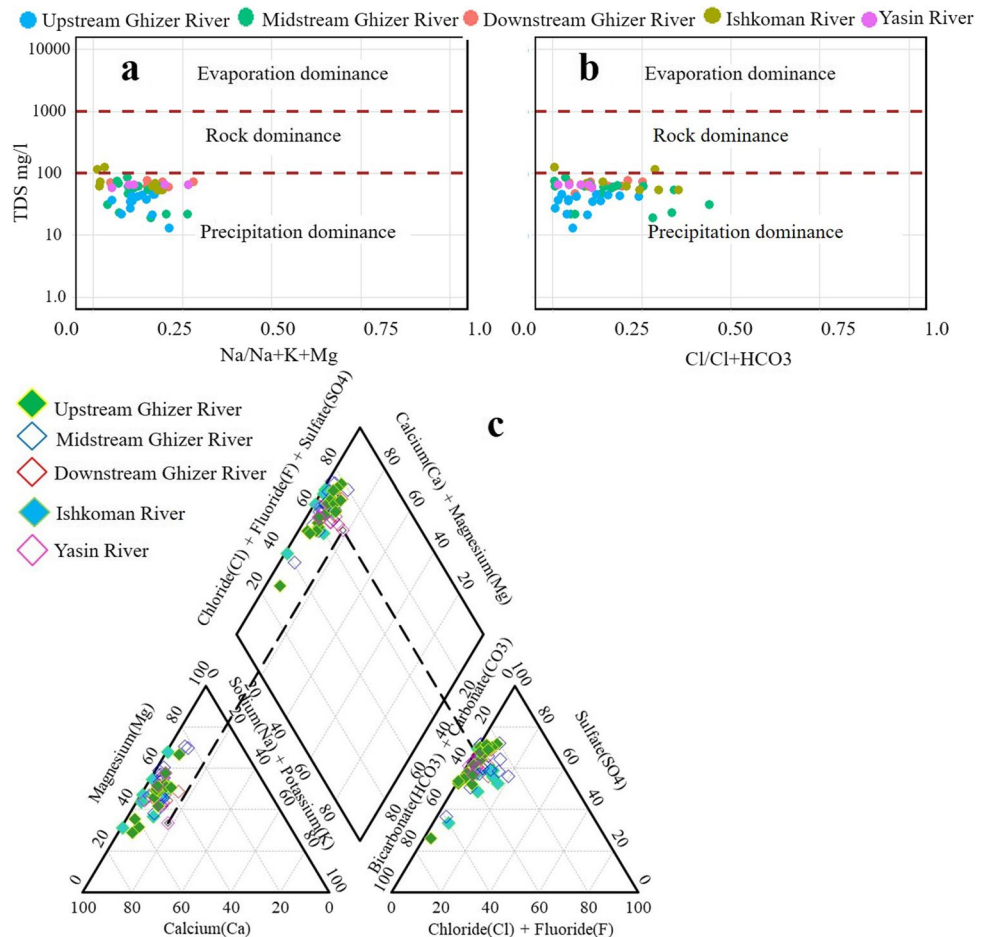
Potential salinity

The PS mean values of water samples and spatial distribution in the GRB were summarized (Fig. 2ai). The PS index values of GRB water samples ranged from 1.3–1.7. Based on Doneen (1964), the PS values of water samples in the GRB were classified as suitable for irrigation. The average PS value of the water samples in GRB was noted to be much lower than reported by Singaraja (2017). The lower PS value of water samples in GRB could be attributed due to its lower Cl concentration.

Hydrogeochemistry and statistical analyses

Gibbs plot models were used to identify the key processes accountable for regulatory of water chemistry, and the results of Gibbs plot models were summarized (Fig. 3ab). Results revealed that water chemistry is principally determined by precipitation dominance (96%), rock dominance (2%), and no impact from the evaporation process. This study further used

Fig. 3 Gibbs diagrams and piper plot to identify natural mechanism dominance on water chemistry of Ghizer River Basin, total dissolved solids (TDS), sodium (Na), potassium (K), calcium (Ca), magnesium (Mg), chloride (Cl), fluoride (F), sulfate (SO₄), bicarbonates (HCO₃)



the Piper-Hill diagram for hydrogeochemical facies of water in the GRB (Piper 1944), and the results of this study were summarized in Fig. 3c. Results revealed that most of the studied samples were grouped as calcium chloride (Ca–Cl) type, followed by a mixed group calcium bicarbonates (CaHCO₃), and a few as the magnesium bicarbonate (MgHCO₃) types. Due to bedrock geology, this Ca–Cl dominance in the GRB occurred. The Ca–Cl dominance of this study is unlikely in those reported sodium chloride (Na–Cl) for Gomal Zam Dam by Muhammad and Ullah (2022).

The correlation analysis for physicochemical parameters of water was performed and summarized (Fig. 4). These results showed a strong correlation (>0.75) of TDS with EC (0.93) and Ca (0.86), and a moderate correlation (0.50–0.75) with SO₄ (0.64) and Mg (0.72). Parameters such as EC showed a strong correlation with Ca (0.87) and a moderate correlation with SO₄ (0.63) and Mg (0.75). Similarly, a strong correlation of F with K (0.80) and a moderate correlation of pH was found with TDS (0.50), Ca (0.52), and Turbidity with F (0.67). A strong correlation of these parameters showed their natural association and attributed to the geogenic source of contamination.

Ghizer River Basin water resources management

Globally, the world seems besieged by water stress. However, studies have suggested that the main problem is not water scarcity but poor management, which is developing into a crisis (Biswas & Tortajada 2011). Water stress is coupled with its quality deterioration and population growth. In the present era, rivers are rich ecosystems that support life by providing water for drinking, irrigation, fish products, power generation, transportation and recreation, and habitat for flora and fauna. In the last 2 or 3 decades, the country has proliferated with the dramatic expansion in agriculture and urbanization, and that has severely impacted the river water (Sabir et al. 2017). The cost of river water degradation has been observed to be high by the impact on the water supply, tourism, and recreation resulting in water pollution and flooding (Chan 2002, 2012). Water resource management is of the utmost importance due to its vital role in human society.

The water of the GRB is used for drinking, domestic, and irrigation purposes. This study evaluated the water of GRB for drinking and irrigation uses. On the WQI and IWQ

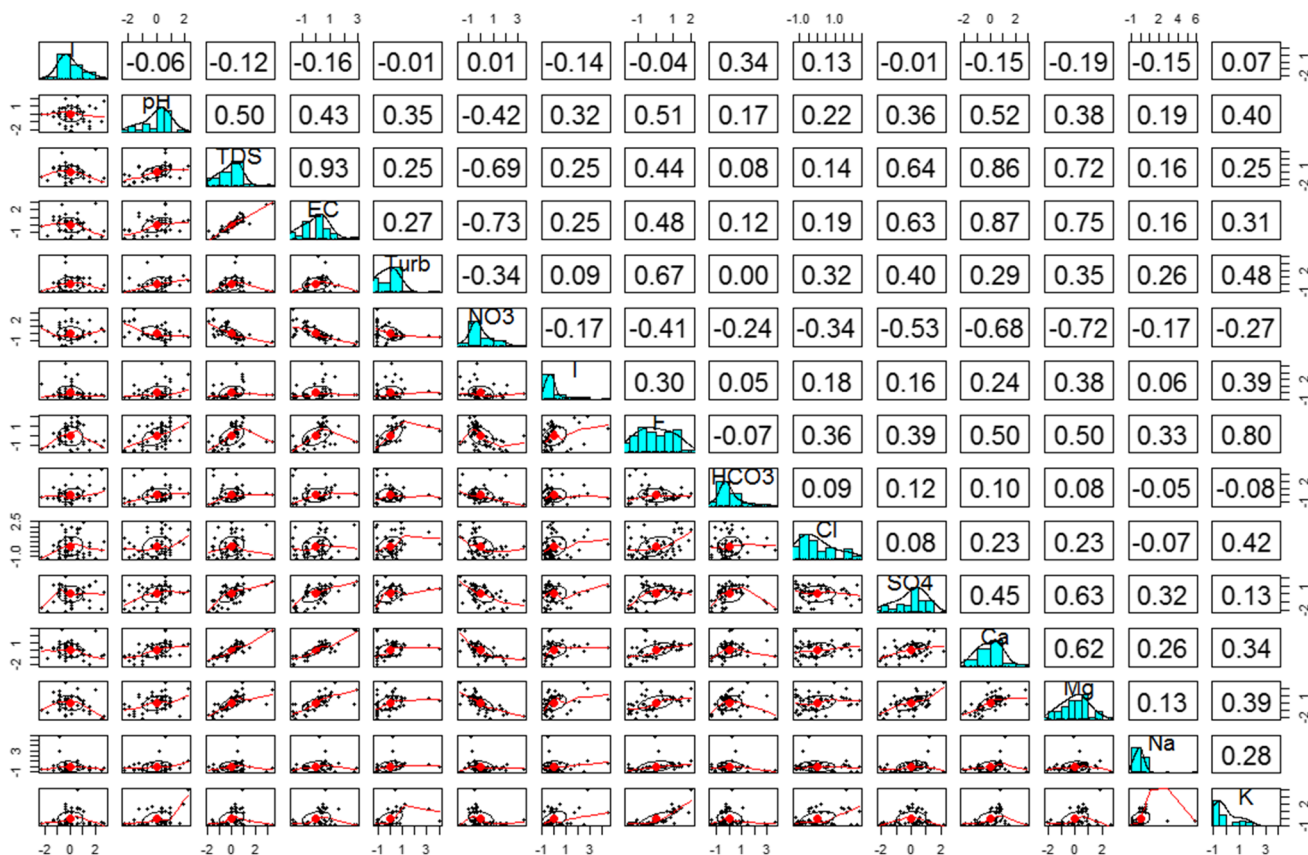


Fig. 4 Pearson correlation matrix of physicochemical parameters in Ghizer River Basin, correlation is significant at the 0.05 level. Electrical conductivity (EC), turbidity (Turb), total dissolved solids (TDS),

nitrate (NO₃), fluoride (F), iodide (I), bicarbonates (HCO₃), chloride (Cl), sulfate (SO₄), calcium (Ca), magnesium (Mg), sodium (Na), potassium (K)

indices, this study recommends using GRB water for drinking and irrigation purposes. The strength of this study is that a first report was carried out on the water quality of GRB and could be used as a baseline for future studies or any other mega project in the vicinity. The limitation of this study is that the water quality of GRB needs to be investigated on a seasonal and monthly basis to provide a comprehensive and detailed picture.

Conclusion

This study's results concluded that the water characteristics of GRB were observed under the limits set by WHO, except for pH and turbidity. Based on WQI values, 38.2% of samples belong to excellent type, whereas 58.2% exhibit the good type, and 3.6% declare poor water in GRB. IWQ indices such as *PI*, *KR*, *PS*, *Na%*, *SAR*, and *RSC* values revealed that the GRB water is excellent and suitable for irrigation purposes with no restrictions. The Gibbs diagram and statistical correlation revealed that natural processes such as precipitation and weathering are regulatory factors. The Piper diagram showed that the analyzed water is mostly Ca–Cl and slightly mixed Ca–HCO₃ water types. This study concluded that water is suitable for drinking, domestic and irrigation purposes. This study recommends future studies on the speciation of heavy metals, potential health risk assessment, and their seasonal variation.

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Authors contribution Ayaz Ul Haq, data curation and writing a draft; Said Muhammad, the conceptualization of this study, funding acquisition, methodology, project administration, resources, software, supervision, writing—review, and editing of the manuscript.

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Data availability The data supporting this study's findings are available from the corresponding author upon reasonable request.

Code availability Not applicable.

Declarations

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

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