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Groundwater quality assessment using water quality index and geospatial tools: Kabul Province case study

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ABSTRACT

This study aimed to evaluate the suitability of Kabul Province's groundwater for drinking by way of analyzing the data collected from 34 ground monitoring wells. The purpose was helped through the assessment of a set of groundwater physico-chemical parameters (pH, turbidity, total dissolved solids (TDS); sulfate, fluoride, nitrate, and boron content; total hardness (TH) as calcium carbonate, sodium, calcium, magnesium, and total iron), as well as the determination of the Water Quality Index (WQI) developed based on sampling the water points located in the districts of Kabul Province and Kabul City in the course of 3 years (2018 to 2020) to provide a clear and concise representation of water quality status, and cat-egorize groundwater into different quality classes ranging from "excellent" to "unsuitable for drinking". Moreover, the spatial distribution of WQI and 12 physico-chemical parameter values was mapped using the Inverse Distance Weighted (IDW) Interpolation in Arcmap 10.7 environment, revealing distinct water quality patterns across the study area. The water qual-ity testing outcomes under this investigation show compliance of multiple water contaminant concentrations with the World Health Organization (WHO) Water Quality Guidelines and Afghanistan National Drinking Water Quality Standards (ANDWQS). The WQI values range between 27.5 and 112 (as per ANDWQS) and between 33 and 127.5 (as per WHO Guide-lines); the WQI (WHO) display 9% and WQI (ANDWQS) display 3% of groundwater unsuit-able for drinking. Spatial variation maps (IDW Interpolation) demonstate that turbidity, TDS, TH, and magnesium concentration values for the provinces's central and eastern sec-tions exceed the permissible thresholds. The study's findings underscore the need for target-ed groundwater management strategies, including pollution control and regular monitoring, to safeguard water quality and public health in Kabul Province.

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1. Introduction

Groundwater quality constitutes a critical issue in urban areas, particularly in developing regions where access to safe potable water is limited. Sustainable access to clean drinking water is reflected in the UN Sustainable Development Goal (SDG) 6, Targets 6.1 and 6.3 (The 17 Goals | Sustainable Development, n.d.). The chemical and biological makeup of groundwater determines its suitability for various applications, such as drinking, farming, and industrial (Hamidi et al., 2023). Natural processes like climate, aquifer lithology, and surface water-aquifer interaction affect groundwater's physical and chemical properties. Anthropogenic activities – inter alia over-exploitation, infiltration of wastewater and agricultural fertilizers, urbanization, industrialization, and population increase – also have an impact (Hamidi et al., 2023).

Groundwater resource contamination manifests a major concern in Kabul due to the city's fast growth and poor infrastructure (Sediqmal et al., 2022). Previous studies have shown that Kabul's groundwater has high concentrations of heavy metals and total dissolved solids (TDS), jeopardizing public health (Jawadi et al., 2020).

Mere 20-27% of Kabul City's residents have sporadic access to central water delivery, the majority relying on shallow hand-pumping groundwater wells for domestic and microagricultural water use due to the lack of stable centralized water supply (Omid et al., 2018). The penetratin of sewage water into the main domestic water supply networks propels further deterioration of shallow groundwater quality (Noori & Nasimi, 2019). With recent droughts, surface and groundwater evaporation has created a negative hydrological balance characterized by increased soil salinity, aggravating the situation even more (Ii, 2003). Given these adverse natural influences, it is important to understand groundwater quality. Past research on Kabul's groundwater quality has yielded the corresponding Water Quality Index (WQI) maps deeming only 0.2% of the city groundwater to be of excellent quality, 19.69% – of good quality, 62.21% – of poor quality, 13.65% – of very poor quality, and 4.25% – unfit for human consumption, according to WHO Water Quality Guidelines (Gesim & Okazaki, 2018). Furthermore, as per the WHO Guidelines, the Kabul Basin does not have any excellent (WQI = 0-25 WQI value) groundwater; 40% of its water is of high quality; over 50% of samples indicate poor to very poor quality; and, 6% of its groundwater is completely unsuitable for human consumption (Basin, 2020a). In their study, (Jawadi et al., 2020) have applied WQI to assess the groundwater quality of the Kabul Basin, however that project was limited to few samples (15 sampling points) located inside the city limits of Kabul. Hence, tha lack of comprehensive studies integrating various water quality parameters to render an in-depth evaluation of groundwater suitability for drinking. As per (Hamidi et al., 2023), little is understood about the bacterial pollution, natural processes, as well as the effects of human activity on the city's groundwater quality.

The objectives of this study were to assess the suitability of Kabul's groundwater for drinking based on WQI calculation, and to map the spatial distribution of several physico-chemical contamination parameters with the help of ArcGIS-based Inverse Distance Weighted (IDW) Interpolation. By way of examining a broad range of physico-chemical parameters, and comparing the values against ANDWQS and WHO Guidelines, this research sought to provide a clearer picture of the current status of groundwater quality and its implications for public health and sustainable water management. The combination of Geographic Information System (GIS) techniques and IDW Interpolation is widely applied to regularly assess and monitor groundwater quality. GIS has proven to be an effective tool for analyzing and evaluating spatial water resource related information (Ram et al., 2021).

The WQI digitally summarizes water quality measurement data into a single number (Saleem et al., 2016; Krishan, 2015). Classification reflecting the combined effects of several water quality parameters can be carried out using WQI (Ramakrishnaiah et al., 2009). Creation of IDW-based groundwater quality maps is helpful for improving monitoring and implementation of standards and regulations associated with effective pollution management and control (Oke & Ogedengbe, 2013).

The findings of this research will assist governmental and non-governmental organizations, particularly these engaged in water supply section, to select locations and treatment technologies for their water supply projects; as well as ensure public access to information about groundwater supplies on hand, specifically, safe and unsafe drinking water points.

2. Methodology

2.1. Study area

The study region (Kabul Province), located 1,800 m ASL in the eastern part of Afghanistan, has an approximate area of 4,523 km^2 (National Geographic, n.d.) and is subdivided into 14 (fourteen) districts (Fig. 1.). It's climate is arid continental with cold winters and extremely hot and sunny summers (Kabul Climate, 2022), mean annual precipitation of approx. 300 mm and annual evapotranspiration of 1,600 mm. Low rainfall and high evaporation rates impose a major effect on community health, groundwater storage and quality (Hamidi et al., 2023).

The Kabul Basin (Fig. 2.) represents a valley formed by the Paghman Mountains to the west and the Kohe Safi Mountains to the east of Kabul City, extending about

40 km north of the city (Mack et al., 2013). The Kabul Basin's faulting has produced a number of mountain-encircled sub-basins divided into six areas: Central Kabul, Deh-Sabz, Logar, Paghman and Upper Kabul, Shomali, and Panjsher, as shown in Fig. 2. The sub-basin boundaries typically correspond to catchments receiving surface water drainage (USGS, 2013). Whereas the surrounding mountains and inter-basin ridges are made up of uplifted crystalline and sedimentary rock, the sub-basins are full of quaternary and tertiary sediment and rock. In the valleys, quaternary sediments are usually less than 80 m thick. Based on estimates, the underlying tertiary sediment stratum under the city of Kabul is up to 800 meters thick, exceeding 1,000 m in certain other parts of the valley (USGS, 2013).

Four major aquifers in the target basin comprise sand-gravel deposits created as river terraces. The Paghman-Darulaman Sub-Basin includes the first two aquifers flowing alongside the Paghman River and the upper stream of the Kabul River. The other two aquifers follow the Lower Kabul and Logar Rivers in the southern parts of the Kabul and Logar Basins. The groundwater flow direction is generally from the basin center to its eastern margin, passing through the western or south-western margins (Tünnermeier & Houben, 2005).

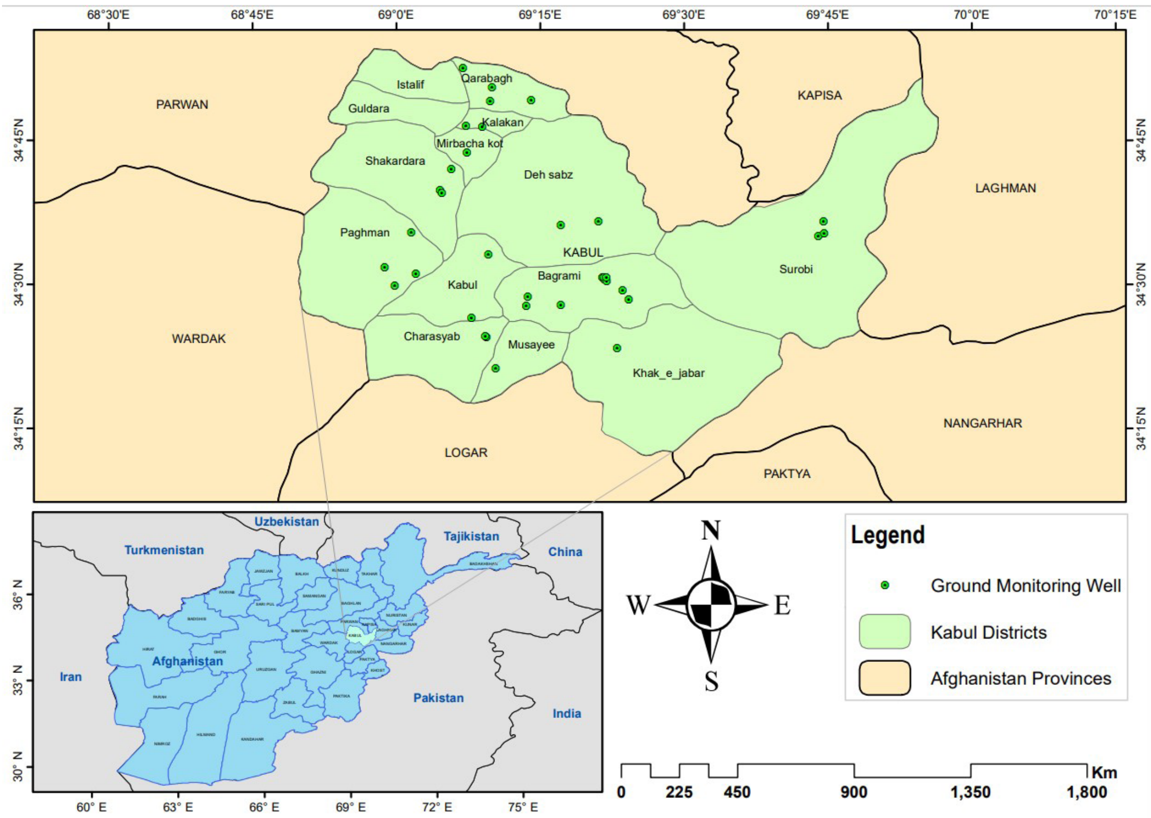

Figure 1. Map of Afghanistan and Kabul Province with groundwater sampling points.

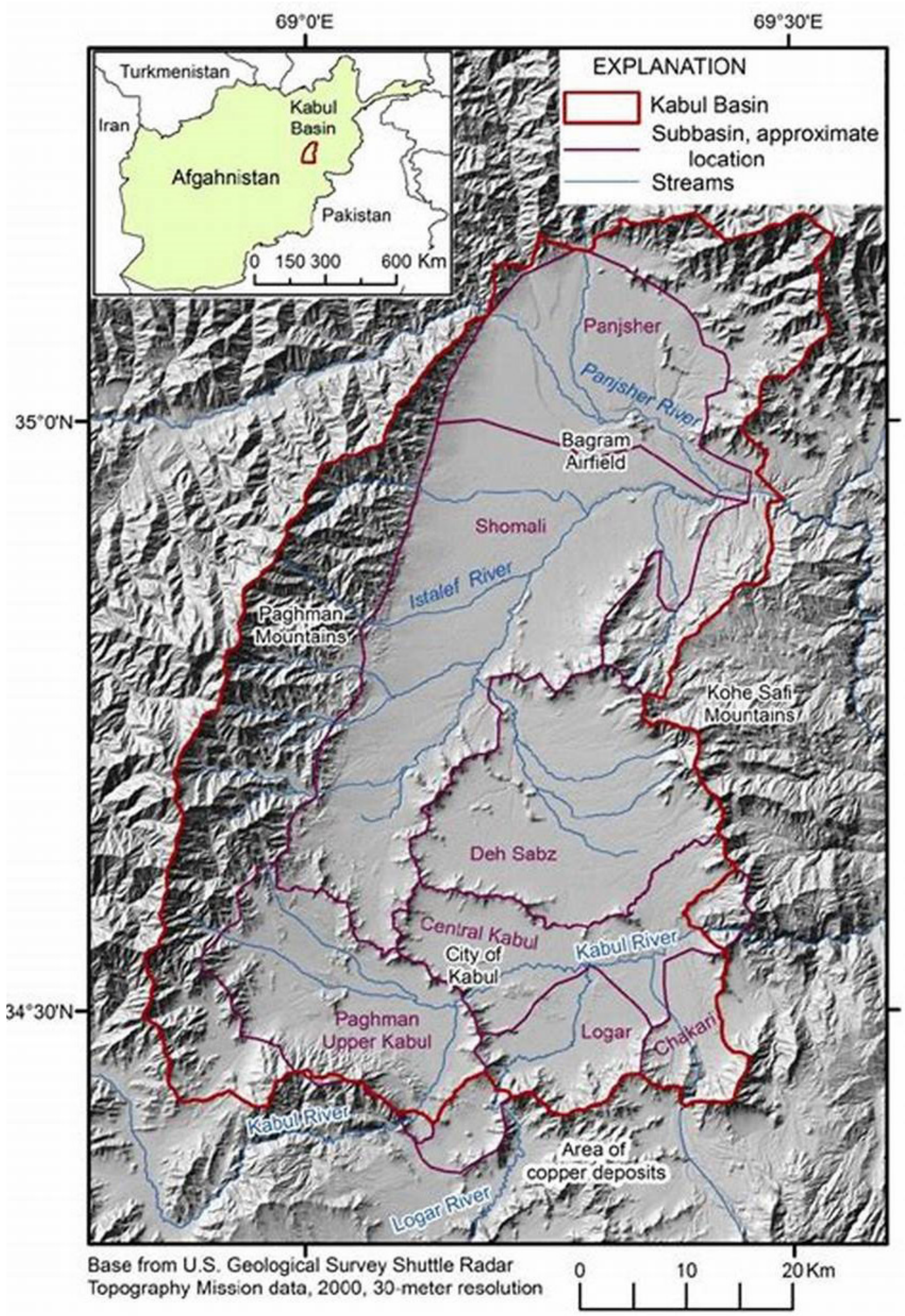

Figure 2. Kabul River Basin.

2.2. Data collection

For the purpose of this investigation, data were collected from the Danish Committee for Aid to Afghan Refugees (DACAAR) existing 34 (thirty-four) ground monitoring wells (GMWs) as depicted in Fig. 1. in Kabul Province for 3 (three) years (2018 through 2020). Water samples were harvested from all 34 wells twice each year by a responsible collector using plastic bottles and transferred to the DACAAR's water quality testing laboratory as per the specified schedule, sampling periods and frequency presented in Table II. The physical parameters – power of hydrogen (pH), total dissolved solids (TDS), and turbidity – were tested on-site with the help of portable water quality kits. The collected samples were stored in conditions recommended by the WHO Guidelines (WHO, 2017b). The samples for nitrate and sulfate analyses were gathered in 50 ml glass bottles, and in 100 ml plastic bottles for other parameters. The coordinates of all GMWs registered using the Global Positioning System (GPS) are listed in Table I.

Table I. GMW locations.

Well ID	Latitude	Longitude	Well ID	Latitude	Longitude
1	34.55278	69.16004	311	34.49850	68.99734
2	34.72940	69.12266	312	34.87500	69.11590
4	34.70047	69.09560	313	34.59072	69.02607
12	34.66283	69.07620	314	34.81847	69.16372
15	34.65884	69.07902	406	34.77303	69.14922
16	34.77545	69.12106	408	34.51889	69.03374
17	34.46246	69.22593	410	34.51210	69.35808
143	34.40855	69.15677	411	34.50904	69.36153
153	34.58382	69.73380	412	34.51206	69.36092
169	34.58860	69.74370	414	34.50627	69.36568
170	34.60920	69.74276	415	34.51189	69.36510
172	34.60985	69.35124	416	34.53045	68.97939
185	34.48919	69.39355	419	34.60218	69.28642
213	34.38887	69.38399	448	34.46336	69.28606
214	34.47863	69.22864	317	34.41057	69.15517
229	34.35407	69.17281	331	34.81935	69.23418
310	34.84225	69.16652	439	34.44250	69.13117

2.3. Data analysis

2.3.1. Water quality testing

All samples underwent analysis in the DACAAR water quality lab for 12 physico-chemical parameters on a time basis and results were entered into database. The physical parameters (pH, TDS, and turbidity) were tested on-site using a portable EC/pH meter and a turbidity tube meter. The 0.64 conversion factor was applied for TDS (mg/l) calculation from EC (μS/cm) value (EC to TDS Calculator, n.d.). The Palintest photometer tools were utilized for chemical analysis. The Palintest photometer is a direct-reading waterproof photometer for determining key water quality parameters for drinking, wastewater and process water samples designed for both portable and lab-based utilization. It is recommened for use with genuine Palintest reagents for optimal performance (Palintest, 2021). The chemical parameters tested in the laboratory setting included the following: sulfate (SO_4), fluoride (F), nitrate (NO_3), boron (B), total hardness as calcium carbonate (TH as $CaCO_3$), sodium (Na), calcium (Ca), magnesium (Mg), and total iron (Fe). The lab-tested parameter values for all GMW's are shown in Table III.

Table II. Water quality sampling schedule.

Sampling site (Well ID)	Parameters	Sampling period	Frequency	Notes
1, 2, 4,…439	pH, turbidity, TDS, SO4, F, NO3, B, TH, Na, Ca, Mg, Fetot	2018 to 2020	Twice per year	pH, turbidity & TDS tested on-site

Table III. Physico-chemical parameters for all tested GMWs.

GMW ID	pH	Turbidity (NTU)	TDS (mg/l)	Sulfate (mg/l)	Fluoride (mg/l)	Nitrate (mg/l)	Boron (mg/l)	TH (mg/l)	Sodium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)	Total Iron (mg/l)
1	7.8	0.55	389	8	0.38	24	0.25	288	164	63	31	0.05
2	7.6	0.6	893	48	0.59	45	0.82	478	141	62	60	0.04
4	7.8	3.9	505	101	0.81	29	0.36	273	77	50	33	0.03
12	8.1	1.3	232	58	0.80	19	1.35	353	141	23	51	0.04
15	7.6	0.8	446	27	0.59	27	0.31	383	69	69	26	0.03
16	7.8	3.0	418	48	0.53	70	0.47	273	77	37	37	0.05
17	7.8	2.5	337	50	0.45	43	0.34	237	80	45	12	0.04
143	7.7	1.2	320	10	0.39	15	0.26	197	60	54	12	0.02
153	7.4	2.3	1,265	268	1.64	34	0.70	563	197	87	67	0.03
169	7.5	0.7	493	27	0.67	34	0.47	306	98	65	24	0.04
170	7.8	5.5	392	20	0.44	15	0.32	240	67	46	27	0.05
172	7.8	8.7	381	22	0.84	23	0.34	230	78	49	22	0.04
185	7.6	1.3	403	28	0.50	23	0.50	225	93	54	21	0.02
213	7.7	2.0	351	3	0.23	18	0.35	227	80	50	18	0.02
214	7.9	1.7	285	12	0.23	15	0.59	215	55	52	18	0.03
229	7.7	1.4	566	42	0.95	34	0.66	280	108	45	37	0.06
310	7.9	16.5	417	90	0.78	20	0.40	247	64	62	0	0.06
311	7.9	5.3	429	91	0.80	14	0.32	280	113	47	30	0.04
312	7.8	2.1	454	102	0.98	17	0.48	327	109	50	34	0.05
313	7.8	0.7	486	120	0.95	37	0.92	293	101	56	33	0.06
314	7.7	6.0	505	129	0.95	34	0.39	370	125	51	37	0.06

Table III. Cont.

406	8.0	1.0	253	4	1.00	15	0.00	155	39	54	14	0.00
408	7.0	1.0	888	210	1.00	35	1.00	463	165	79	0	0.00
410	7.8	8.1	679	123	0.61	23	0.35	400	112	45	50	0.07
411	7.9	3.5	1,184	212	1.48	37	1.25	428	61	99	62	0.04
412	7.6	9.5	1,196	96	0.77	43	3.35	423	203	115	36	0.07
414	7.6	3.7	430	7	0.29	19	0.23	272	70	41	16	0.03
415	7.4	1.3	363	29	0.42	23	0.24	333	37	67	16	0.02
416	7.4	6.8	466	21	0.46	25	0.61	255	60	59	21	0.02
419	8.0	1.1	441	100	0.88	12	0.30	185	86	46	19	0.02
448	7.8	1.3	691	49	0.80	35	1.45	463	117	70	43	0.03
317	7.8	23.1	926	223	1.15	40	0.72	463	103	84	63	0.04
331	7.9	12.4	859	133	0.94	24	1.60	440	179	44	72	0.04
439	8.0	12.0	564	75	0.78	34	1.50	450	170	45	36	0.04

2.3.2. Weighted arithmetic Water Quality Index (WQI) method

The method of Water Quality Index (WQI) is considered the most effective for measuring water quality (Akter et al., 2016). As per the method, different water quality parameters are put in a mathematical formula to rate the quality of water in order to determine its suitability for consumption (Akter et al., 2016). The WQI – defined as a rating indicating the composite influence of multiple water quality parameters on the general quality of water – is applied to obtain a comprehensive picture of groundwater quality (Batabyal & Chakraborty, 2015). The Indian standard specified for drinking water (BIS, 1991) (Home – Bureau of Indian Standards, n.d.) was used for WQI calculations under this study. The WQI was computed in three steps.

First, a weight (wi) was assigned to each of the 12 target parameters (pH, turbidity, TH, TDS, B, SO_4, NO_3, F, Na, Ca, Mg, and Fetot) as per their relative force in the overall quality of water for drinking, as presented in Table 4. Nitrate was assigned the maximum weight of 5 because of its essential role in water quality; minimum weight of 2 was assigned to magnesium, calcium, and sodium due to their less significant role. Weights between 2 and 5 were assigned to the remaining parameters such as turbidity, pH, TH, SO_4, F, TDS, and B based on their relative significance in water quality assessment.

Second, the relative weight (Wi) of each chemical parameter was calculated as per the following equation:

$$W_i = \frac{w_i}{\sum_i^n w_i} \quad (1)$$

, where

Wi represents relative weight,

wi represents each parameter's weight, and

n represents the number of parameters (Vasanthavigar et al., 2010).

Table IV. Relative parameter weight.

Parameters	ANDWQS	WHO Guidelines	Weight (wi)	Relative weight (Wi)
pH	6.5-8.5	6.5-8.5	4	0.095
Turbidity (NTU)	5	5	4	0.095
TDS (mg/l)	1,000	500	4	0.095
Sulfate (mg/l)	250	250	4	0.095
Fluoride (mg/l)	1.5	1.5	4	0.095
Nitrate (mg/l)	50	50	5	0.119
Boron (mg/l)	2.4	2.4	4	0.095
Total Hardness (mg/l)	500	300	3	0.071
Sodium (mg/l)	200	200	2	0.048
Calcium (mg/l)	75	75	2	0.048
Magnesium (mg/l)	30	30	2	0.048
Total Iron (mg/l)	0.3	0.1	4	0.095
Total			42	1

Table IV. lists the computed relative weight (W_i) values of each examined parameter.

Third, a quality rating scale (q_i) for each parameter excluding pH was calculated by dividing its concentration in each water sample by its respective standard multiplied by 100 as per the formula:

$$q_i = \frac{C_i}{S_i} \times 100 \quad , \qquad (2)$$

where C_i is concentration of measured paramater,

and S_i is the respective standard value based on WHO Guidelines (WHO, 2017a) and ANDWQS (ANDWQS, 2013) of the ith parameter, respectively.

It is not possible to calculate the pH quality rating based on the above formula; alternatively, it is calculated as per the following formula (Alobaidy et al., 2010):

$$q_{pH} = \left(\frac{C_i - V_i}{S_i - V_i}\right) \times 100 \quad , \qquad (3)$$

where Vi represents ideal pH value (7.0).

Equations 2 and 3 ensure that qi = 0 when a pollutant is absent, and qi = 100 when the parameter value equals its permissible threshold, i.e. the higher the value of qi, the more polluted the water is (Alobaidy et al., 2010).

For the calculation of WQI, it is initially necessary to determine the sub-index (SI) with the help of the formulas below:

$$SI_i = W_i \times q_i \quad (4)$$

$$\mathrm{WQI} = \sum_{i=1}^{n} SI_i \quad , \quad (5)$$

where W_i is relative weight,

q_i is relative quality rating scale of a parameter and *WQI* is the water quality index.

In this study, *WQI* was calculated based on 3-year mean values (2018 to 2020) for each sampling point.

2.3.3. Inverse Distance Weighted (IDW) Interpolation for spatial distribution

To map the individual parameter concentrations and calculated WQIs for 34 GMWs across the entire research area, the study utilized IDW Interpolation combined with ArcMap 10.7. The IDW method allows estimating unknown values with specifying search distances, closest points, power setting and barriers (GIS Geography, 2016). The interpolation determines cell values as per a linearly weighted combination of a set of sample points. The weight being a function of inverse distance, the interpolated surface should be that of a location-dependent variable. IDW interpolation assumes that a mapped variable decreases in influence with distance from its actual sampled location (ArcMap, 2022) – the term “inverse distance weighted” itself comes from the fact that it assigns greater weights to locations that are closer to the predicted location, and that the weights decline with distance (Gesim & Okazaki, 2018).

3. Results and discussion

3.1. Physico-chemical parameters

Water is the most important substance for all living beings after oxygen, and can cause serious waterborne diseases. Hence, the necessity to regularly monitor its quality before utilizing for drinking, washing, irrigation, etc. Water’s ability to serve an efficient dissolvent for the majority of minerals affects groundwater quality. Its measurements are often classified into three types: physical, chemical, and biological (Shnizai & Iqbal, n.d.).

It is not possible to measure all physical, bacteriological, and chemical parameters of groundwater everywhere. Yet, water appropriateness can be assessed even with a small number of measurements (Jawadi et al., 2020). Under this investigation, different physico-chemical parameters of groundwater in Kabul Province were measured and compared against ANDWQS and WHO Guidelines with the help of WQI determination and IDW interpolation. The spatial variation maps (IDW interpolation) in Figures 4. and 5. indicate that – compared to the WHO Guidelines and ANDWQS – within the study area, pH, SO_4, F, NO_3, B, Ca, and total Fe values are within permissible ranges, while concentrations of other 5 physico-chemical parameters exceed them. The sub-sections below offer further explanations for some of them.

a) Turbidity (Nephelometric Turbidity Unit, NTU)

Turbidity, a measurement of water's light reflection, is commonly used to determine the quality of drinking water. High turbidity water always contains microbiological contamination, but silt and organic matter also have an impact on water turbidity after it leaves treatment facility (Mann et al., 2007). Surface activities like construction and agriculture, as well as intense rainfall and flooding, can affect groundwater turbidity (Huey & Meyer, 2010). Drinking water with excessive turbidity, or cloudiness, is unsightly and may be unhealthy. Pathogens can find food and shelter in turbidity (Turbidity and Water, n.d.). The causes of excessive turbidity may encourage bacteria regeneration, and – if not eliminated – may result in outbreaks of waterborne diseases significantly boosting intestinal illness prevalence worldwide (Turbidity and Water, n.d.). Both the WHO Guidelines (WHO, 2017b) and ANDWQS (ANDWQS, 2013) classify turbidity into 2 ranges, i.e. 0-5 NTUs and >5 NTUs. As per the spatial variation maps (IDW interpolation) in Figures 4a. and 5a., Kabul Province's groundwater turbidity in Khak-e-Jabar, Bagrami, and certain parts of Deh-Sabz, Musayee, and Surobi Districts exceeds the permissible limits, with the highest value of 23.1 NTUs and lowest value of 0.55 NTUs observed at GMW 317 and 1, respectively.

b) Total dissolved solids

Water lacking dissolved materials is unsuited for drinking and can't support aquatic life. However, too much dissolved substances in water can make it improper for many human uses and even harmful to freshwater-dependent plants and species (Sherrard et al., 1987). Among other factors, water filters may wear out quicker due to high concentration of total dissolved solids (What Is TDS in Water and It's Effects? How to Reduce TDS of Water?, n.d.). Lower TDS denotes demineralized water, or water lacking in potassium and sodium, which may lead to the loss of minerals in body tissues and have other detrimental side effects (What Is TDS Level in Water? Find Permissible Limit of TDS in Drinking Water, n.d.).

Whereas the WHO Guidelines (WHO, 2017b) recommend 300 mg/l as the TDS desirable limit and 500 mg/l as the maximum permissible limit, the latter as per ANDWQS (ANDWQS, 2013) amounts to 1,000 mg/l. Based on the aforementioned values, the spatial variation maps in Figures 4c. and 5c. confirm that TDS in the central and eastern parts of Kabul Province violate the permissible limits and fall within them in its northern and northwestern sections. Under the ANDWQS, approx. 97% of the province's groundwater satisfy the quality requirements, with the lowest value of 232 mg/l and highest value of 1,265 mg/l TDS registered at GMWs 12 and 153, respectively.

c) Total hardness as CaCo3

Hard water use in homes and businesses leads to multiple issues caused by the buildup of scale in hot water pipes, kitchen appliances, water supply facilities, boilers, cooling towers, clogged membranes, as well as lower heat exchanger efficiency, reaction to soap, and hard foam development (Malakootian et al., 2010). Consuming high-TH water may likewise stimulate salt accumulation in human body and suppress stomach motility. Drinking water with high calcium and magnesium ion concentrations may adversy affect cardiovascular system. Long-term use of hard water can result in joint disorders, as well as renal and biliary tract stone formation (What Causes Water Hardness - Effects and Solutions for Hard Water, n.d.). The WHO Guidelines (WHO, 2017b) classify TH into 2 ranges (permissible – 0-300 mg/l; and maximum – >300 mg/l). Under the ANDWQS (ANDWQS, 2013), the corresponding ranges are 0-500 mg/l and >500 mg/l. Based on these value ranges and IDW-interpolated spatial variation maps in Figures 4h. and 5h. elaborated within the framework of this study, as per the WHO Guidelines, groundwater TH concentrations in the central and eastern segments of Kabul Province go beyond and correlate with the permissible thresholds in the province's northern and northwestern parts. Pursuant to the ANDWQS (ANDWQS, 2013), all target groundwater falls within the permissible limits. In accordance with the WHO (Hardness in Drinking Water, 2010), water hardness is classified based on the concentration of calcium carbonate ($CaCO_3$) in milligrams per liter (mg/l) as: soft (0-60 mg/l), moderately hard (61-120 mg/l), hard (121-180 mg/l), and very hard (>180 mg/l), deeming 100% of the studied water samples "very hard", as shown in Table V.

Table V. Sampled groundwater TH, hardness grade, and percentage.

Well ID	Total hardness	Hardness grade	Percenage	
			Hard	Very Hard
	(mg/l)		%	%
1	288	Very Hard	0	100
2	478	Very Hard		
4	273	Very Hard		
12	353	Very Hard		
15	383	Very Hard		
16	273	Very Hard		
17	237	Very Hard		
143	197	Very Hard		
153	563	Very Hard		
169	306	Very Hard		
170	240	Very Hard		
172	230	Very Hard		
185	225	Very Hard		
213	227	Very Hard		
214	215	Very Hard		
229	280	Very Hard		
310	247	Very Hard		
311	280	Very Hard		
312	327	Very Hard		
313	293	Very Hard		
314	370	Very Hard		
406	155	Very Hard		
408	463	Very Hard		
410	400	Very Hard		
411	428	Very Hard		
412	423	Very Hard		
414	272	Very Hard		
415	333	Very Hard		
416	255	Very Hard		
419	185	Very Hard		

d) Magnesium (Mg)

Although magnesium constitutes an essential element of cardiac and vascular functions, its high concentrations in drinking water may have a laxative effect, especially in case of magnesium sulfates. Mg has multiple positive effects on human health, yet its excess can lead to negative consequences (Razowska-Jaworek, 2014). High manganese content in potable water was also linked to neurological issues in children and babies, inter alia poor behavior, speech and memory, IQ, coordination, etc. (Manganese in Drinking Water | Effects | Earth and Human, n.d.). The groundwater samples harvested across Kabul Province exhibited Mg concentrations ranging from 0 mg/l to 67 mg/l, i.e. exceeding both the ANDWQS (ANDWQS, 2013) and WHO (WHO, 2017b) recommended values – specifically, 30 mg/l in its eastern and central parts, as shown in Figures 4k. and 5k. The relatively high magnesium concentrations detected under this research are likely associated with the composition of geological materials in the target area (Basin, 2020b).

e) Water Quality Index (WQI)

WQI is a dimensionless value combining multiple water quality parameters into a single figure based on a mathematical formula. It is a very useful and important tool for assessing the suitability of water quality for various purposes (Khwakaram et al., 2012). The calculated WQI values are classified into five categories: excellent water (WQI = 0-25); good water (WQI = 26-50); poor water (WQI = 51-75); very poor water (WQI = 76-100); and water unsuitable for drinking (WQI > 100) (Munagala et al., 2020; Yogendra & Puttaiah, 2008). Table VI. shows the WQI range and water types under the study; Tables VII. and VII. list the WQI values, water types, and percentages for the 34 target GMWs across Kabul Province based on the ANDWQS (ANDWQS, 2013) and WHO Guidelines (WHO, 2017b). As can be seen, the WQI in the research area varies substantially ranging from 34 to 111 as per the WHO Guidelines and points to the fact that the target province has no high quality (0-25) groundwater, and only 38% groundwater of good quality. Over half of the harvested samples indicate very poor to poor groundwater quality, as shown in Table VIII. Nine (9) % of the sampled water is unsuitable for drinking, specifically at GMWs 412, 317 and 331 located in Bagrami, Charasyab and Deh-Sabz Districts, respectively, due to high TDS, TH and sulfate content.

Table VI. WQI ranges and water types.

WQI range	Water quality	Water type
0-25	Excellent water	Safe, drinking water
26-50	Good water	Generally safe
51-75	Poor water	Moderately polluted
76-100	Very poor	Heavily polluted

f) IDW mapping for parameter spatial distribution

The IDW Interpolation method was applied under the project for mapping parameter concentrations and WQIs for 34 sampling points in the study region, i.e. the measured location-specific values were interpolated to generate the predicted values that were more influenced by the measured values located the closest to the prediction site than by those located farther away (Gesim & Okazaki, 2018). To ensure better representation, spatial variation maps (IDW interpolation) were used. The derived (interpolated) WQI values were classified as denoting excellent (WQI = 0-25), good (WQI = 26-50), poor (WQI = 51-75), very poor (WQI = 76-100) water, and water unsuitable for drinking (WQI > 100) across the study area, as shown in Fig. 3. Moreover, Figures 4. and 5. present the spatial distribution of IDW-interpolated concentrations for all 12 parameters compared to the WHO Guidelines and ANDWQS values. Thuswise, as per the ANDWQS, in Bagrami District groundwater falls under very poor quality category; and, based on the WHO Guidelines, very poor quality groundwater was detected in Bagrami, some parts of Khak-e-Jabar, Deh-Sabz and Surobi Districs. The northern districts of Kabul Province have demonstrated good groundwater quality. Overall, under the WHO Guidelines, turbidity, TDS, TH, Ca and Mg values are above the permissible limits in the central and eastern sections of the target province (Fig. 4.); under the ANDWQS, turbidity, Ca and Mg concentrations exceed the permissible ranges in its central and eastern parts (Fig. 5).

3.2. Policy implications of the study

The findings of this investigation emphasize the pressing need for policies and actions focused on groundwater quality protection and contamination risk mitigation in Kabul Province and, more broadly, across Afghanistan. Based on the study's results, policymakers should consider implementing stricter regulations on industrial waste disposal, agricultural runoff, and municipal waste management. Such regulations would help to prevent pollutants entering groundwater sources, particularly in the areas with low WQI values. Establishing monitoring and enforcement protocols around these regulations can ensure due prioritization of both public health and environmental sustainability.

3.3. Designing sustainable water use in Kabul: insights, challenges, and recommendations

The outputs and outcomes of this study underline the urgency of sustainable water resource management in Kabul Province facing mounting pressure from population growth, over-extraction, and climate change. This section elaborates on the parameters crucial for designing a sustainable water use framework, identifies the associated challenges, as well as proposes actionable recommendations.

i. Key sustainable water use parameters

The study’s results point to several critical parameters for consideration to achieve sustainability in water use - groundwater quality and quantity, demographic dynamics, water demand, and climate change.

ii. Challenges identified

Over-extraction of groundwater could result in irreversible damage to the target region's water storage capacity; in addition, water pollution due to unregulated industrial effluent discharge and lack of wastewater treatment facilities manifest significant contributors to water quality degradation. Furthermore, institutional and policy gaps, poor enforcement of water laws and absence of coordinated management among stakeholders hinder effective water resource governance. Moreover, inadequate public awareness of water conservation practices among local communities prompts heavy wastage and poor hygiene practices.

iii. Proposed solutions and recommendations

Based on the findings, the study team proposes the following strategies to address the challenges identified:

1. Mainstreaming Integrated Water Resource Management (IWRM): IWRM can help coordinate the development and management of water, land, and related resources. The associated actions include stakeholder engagement, capacity building, and community participation.

2. Recharge and storage solutions: natural and artificial approaches like construction of check dams and recharge wells, as well as rainwater harvesting by promoting rooftop solutions can reduce reliance on groundwater.

3. Water infrastructure modernization: upgrading outdated water supply pipelines and irrigation systems to reduce leakage and wastage, and installing smart water meters for efficient usage monitoring.

4. Introduction of pollution control measures: establishing decentralized wastewater treatment plants for urban and peri-urban areas, and stimulating organic farming techniques to minimize chemical runoff.

5. Conducting public awareness and culturally sensitive campaigns to educate the population on water conservation and hygiene involving local leaders and organizations to build trust and ensure widespread adoption.

Table VII. Water types and condition percentages in the study area (as per ANDWQS).

Well ID	WQI	Water type	Well ID	WQI	Water type	Condition percentage				
						Excellent	Good	Poor	Very poor	Unsuitable for drinking
1	38	Excellent	311	48	Good					
2	58	Good	312	47	Good					
4	49	Good	313	52	Good					
12	48	Good	314	60	Good					
15	39	Excellent	406	30	Excellent					
16	54	Good	408	53	Good					
17	41	Excellent	410	64	Good					
143	28	Excellent	411	80	Good					
153	80	Good	412	91	Good	0%	53%	26%	18%	3%
169	40	Excellent	414	34	Excellent					
170	41	Excellent	415	32	Excellent					
172	51	Good	416	45	Good					
185	34	Excellent	419	38	Excellent					
213	31	Excellent	448	56	Good					
214	31	Excellent	317	112	U.S					
229	48	Good	331	87	Good					
310	67	Good	439	77	Good					

Table VIII. Water types and condition percentages in the study area (as per WHO Guidelines).

Well ID	WQI	Water type	Well ID	WQI	Water type	Condition percentage				
						Excellent	Good	Poor	Very poor	Unsuitable for drinking
1	47	Good	311	58	Good					
2	74	Poor	312	57	Good					
4	59	Good	313	63	Poor					
12	56	Good	314	73	Poor					
15	48	Good	406	33	Good					
16	63	Poor	408	65	Poor					
17	49	Good	410	79	Poor					
143	34	Good	411	97	Poor					
153	99	Poor	412	111	U.S	0%	38%	38%	15%	9%
169	50	Good	414	43	Good					
170	50	Good	415	40	Good					
172	59	Good	416	53	Good					
185	42	Good	419	45	Good					
213	37	Good	448	69	Poor					
214	37	Good	317	127	U.S					
229	60	Good	331	102	U.S					
310	77	Poor	439	89	Poor					

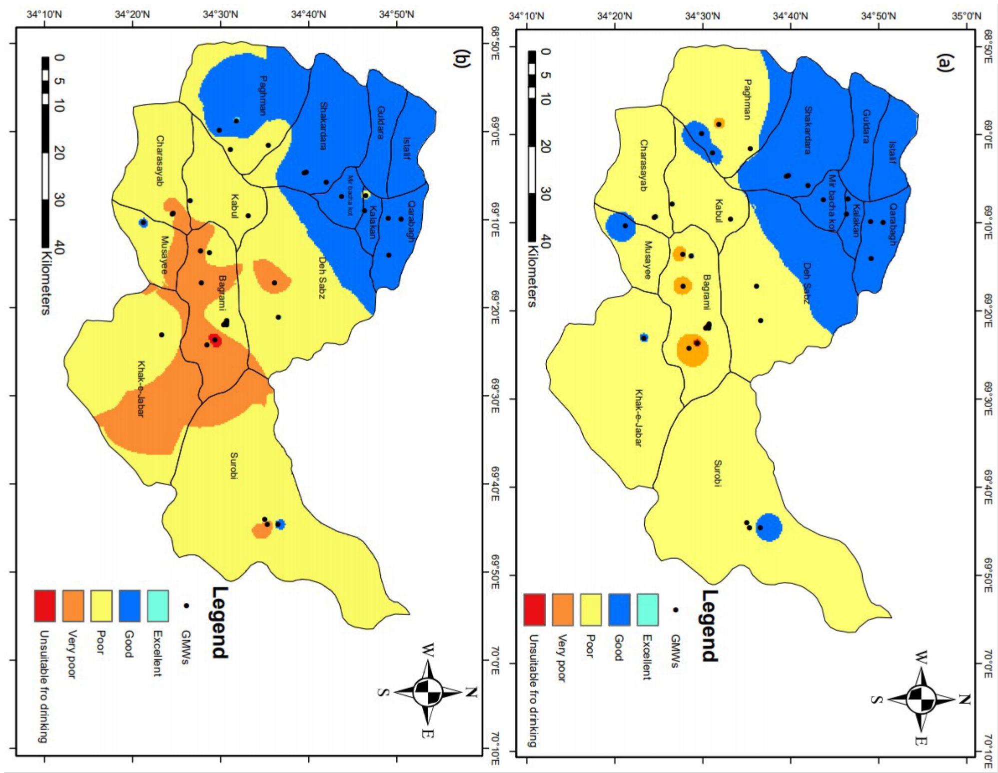

Figure 3. Groundwater quality (WQI) map (based on ANDWQS (a); based on WHO Guidelines (b)).

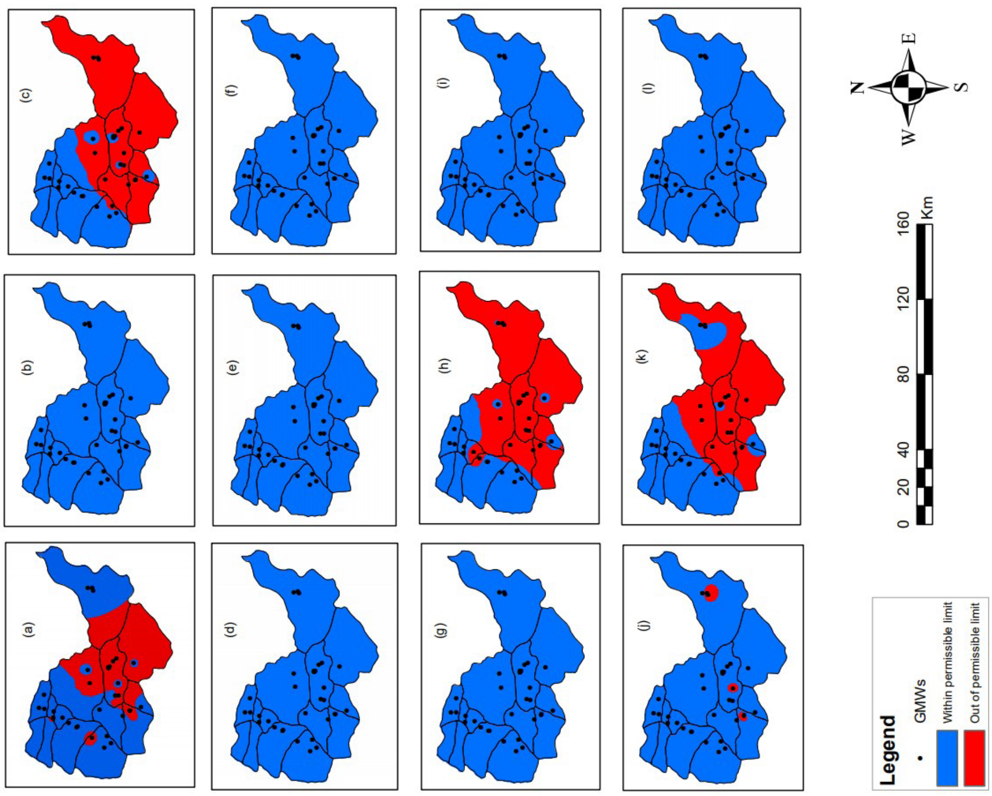

Figure 4. Physico-chemical parameter concentrations against WHO Guidelines: (a) turbidity, (b) pH, (c) TDS, (d) SO4, (e) F, (f) NO3, (g) B, (h) TH, (i) Na, (j) Ca, (k) Mg, (l) Fe.

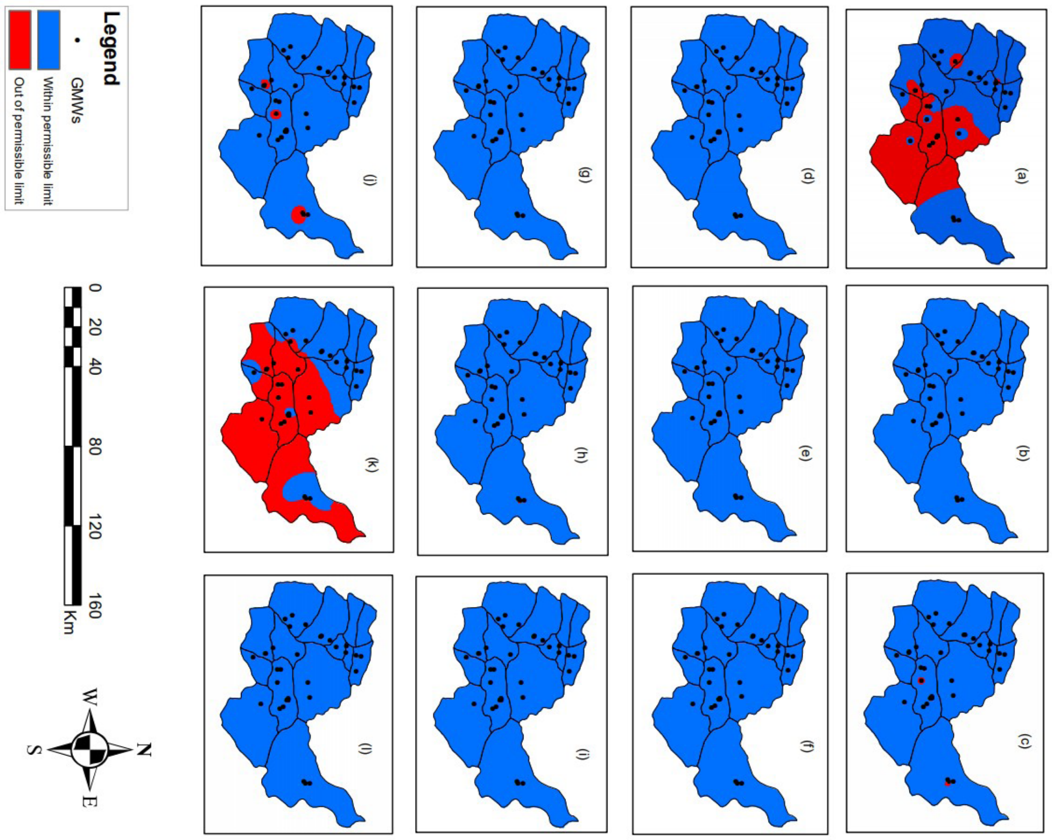

Figure 5. Physico-chemical parameter concentrations against ANDWQS: (a) turbidity, (b) pH, (c) TDS, (d) SO4, (e) F, (f) NO3, (g) B, (h) TH, (i) Na, (j) Ca, (k) Mg, (l) Fe.

4. Conclusion

Based on the regular chemical analysis of groundwater samples collected at 34 Kabul Province GMWs during 2018-2020 and its comparison with the ANDWQS and WHO Guidelines, the groundwater in the target province falls under "good", "poor", "very poor", and "unsuitable for drinking" quality categories due to high Mg, Ca, TDS, TH and turbidity. In erms of total hardness, 100% of groundwater in the study area is deemed "very hard". As to turbidity, it was found exceeding the permissible range at 11 GMWs; and pH results indicated most wells as alkaline.

Also, 95% of groundwater in the study area showed low fluoride concentrations. Overall, more than 90% of the samples tested within the framework of this research showed low nitrate and boron concent. Based on the WQI comparison with the WHO Guidelines, 38% of groundwater in Kabul Province can be classified as "good", 38% – as "poor", 15% – as "very poor", and 9% – as "unsuitable for drinking". Compared against the ANDWQS, 53% of groundwater in the studied area can be deemed "good", 26% – "poor", 18% – "very poor", and 3% – "unsuitable for drinking". Water unsuited for drinking was detected at one GMW in Bagrami District due to high calcium and magnesium concentrations, and high turbidity. As per spatial variation mapping (IDW interpolation) based on the WHO Guidelines and ANDWQS, poor and very poor groundwater quality were registered in Surobi, Khak-e-Jabar, Bagrami, Musayee, Deh-Sabz, Charasyab, Paghman, and Central Kabul Districts.

This study's findings accentuate the importance of designing sustainable water use in Kabul Province based on the key parameters associated with water quality, recharge rates, and pollution sources. To secure long-term sustainability, prioritizing potable water, enhancing water efficiency in agriculture and industry, as well as groundwater monitoring are essential. Challenges like over-extraction, contamination, and limited wastewater treatment require urgent targeted actions, including but not limited to robust groundwater management, advanced treatment technologies, and public education on water conservation. By adopting a comprehensive approach, Kabul Province can accomplish a more sustainable and resilient water future.

5. Data availability statement

All the data used during the study were provided by the DACAAR non-governmental organization.

References

Akter, T., Jhohura, F.T., Akter, F., Chowdhury, T.R., Mistry, S.K., Dey, D., Barua, M. K., Islam, M.A. & Rahman, M. (2016). Water Quality Index for measuring drinking water quality in rural Bangladesh: A crosssectional study. *Journal of Health, Population and Nutrition*, 35(1), 1-12 (https://doi.org/10.1186/s41043-016-0041-5)

Alobaidy, A.H.M.J., Abid, H.S. & Maulood, B.K. (2010). Application of Water Quality Index for Assessment of Dokan Lake Ecosystem, Kurdistan Region, Iraq. *Journal of Water Resource and Protection*, 02(09), 792-798 (https://doi.org/10.4236/jwarp.2010.29093)

ANDWQS (2013). ANDWQS.pdf

ArcMap (2022). (https://desktop.arcgis.com/en/arcmap/latest/tools/spatial-analyst-toolbox/how-idw-works.htm)

Basin, K. (2020a). Case Report: A Detailed Assessment of Groundwater Quality in Future Development, 1-19

Basin, K. (2020b). Case Report: A Detailed Assessment of Groundwater Quality in Future Development, 1-19

Batabyal, A.K. & Chakraborty, S. (2015). Hydrogeochemistry and Water Quality Index in the Assessment of Groundwater Quality for Drinking Uses. *Water Environment Research*, 87(7), 607-617 (https://doi.org/10.2175/106143015x14212658613956)

EC to TDS Calculator (n.d.). Retrieved August 7, 2024 (https://waternitylab.com/ec-to-tds/)

Gesim, N.A. & Okazaki, T. (2018). Groundwater Quality Mapping Using Water Quality Index in the Kabul City, Afghanistan. August, 6

GISGeography (2016). IDW Interpolation. GIS Geography (https://gisgeography.com/inverse-distance-weighting-idw-interpolation/)

Hamidi, M.D., Kissane, S., Bogush, A.A., Karim, A.Q., Sagintayev, J., Towers, S. & Greenwell, H.C. (2023). Spatial estimation of groundwater quality, hydrogeochemical investigation, and health impacts of shallow groundwater in Kabul city, Afghanistan. *Sustainable Water Resources Management*, 9(1), 20 (https://doi.org/10.1007/s40899-022-00808-9)

Home – Bureau of Indian Standards (n.d.). Retrieved July 25, 2021 (https://bis.gov.in/)

Huey, G.M. & Meyer, M.L. (2010). Turbidity as an Indicator of Water Quality in Diverse Watersheds of the Upper Pecos River Basin. *Water,* 2(2), 273-284 (https://doi.org/ 10.3390/w2020273)

Ii, P. (2003). Hydrogeology of the Kabul Basin Part II: *Groundwater geochemistry and microbiology*

Jawadi, H.A., Sagin, J. & Snow, D.D. (2020). A Detailed Assessment of Groundwater Quality in the Kabul Basin, Afghanistan, and Suitability for Future Development. *Water*, 12(10), 2890 (https://doi.org/10.3390/w12102890)

Kabul climate (2022). https://www.climatestotravel.com/climate/afghanistan/kabul

Khwakaram, A.I., Majid, S.N. & Hama, N.Y. (2012). Determination of Water Quality Index (WQI) for Qalyasan Stream in Sulaimani City/Kurdistan Region of Iraq*, Salih N. Majid*, Nzar Y. Hama** Faculty of Agricultural Sciences, University of Sulaimani, Kurdistan Region. *International Journal of Plant, Animal and Environmental Sciences*, 2(4), 148-157

Krishan, G. (2015). Assessment of Groundwater Quality for Drinking Purpose by Using Water Quality Index (WQI) in Muzaffarnagar and Shamli Districts, Uttar Pradesh, India. *Journal of Waste Water Treatment & Analysis,* 07(1) (https://doi.org/10.4172/2157-7587.1000227)

Mack, T.J., Chornack, M.P. & Taher, M.R. (2013). Groundwater-level trends and implications for sustainable water use in the Kabul Basin, Afghanistan. *Environment Systems and Decisions*, 33(3), 457-467 (https://doi.org/10.1007/s10669-013-9455-4)

Malakootian, M., Mansoorian, H.J. & Moosazadeh, M. (2010). Performance evaluation of electrocoagulation process using iron-rod electrodes for removing hardness from drinking water. *Desalination*, 255(1-3), 67-71 (https://doi.org/10.1016/j.desal.2010.01.015)

Manganese in Drinking Water | Effects | Earth and Human (n.d.). Retrieved July 26, 2021 (https://earthandhuman.org/manganese-in-drinking-water/)

Mann, A.G., Tam, C.C., Higgins, C.D. & Rodrigues, L.C. (2007). The association between drinking water turbidity and gastrointestinal illness: A systematic review. *BMC Public Health,* 7(xx), 1-7 (https://doi.org/10.1186/1471-2458-7-256)

Munagala, S., Jagarapu, D.C.K. & Ratnamala Reddy, B.S.S. (2020). Determination of water quality index for ground water near municipal dump site in Guntur. *Materials Today: Proceedings*, 33(xx), 724-727 (https://doi.org/10.1016/j.matpr.2020.06.030)

National Geographic (n.d.). Retrieved August 6, 2024 (https://www.nationalgeographic.com/)

Noori, K.M.A. & Nasimi, M.N. (2019). Kabul city groundwater and need for artificial recharge. International Conference on Civil, *Structural and Transportation Engineering,* 1-7 (https://doi.org/10.11159/iccste19.215)

Oke, A.O. & Ogedengbe, K. (2013). Mapping of River Water Quality Using Inverse Ogun-Osun River Basin, Nigeria. *Lanskap & Environment*, 7(2), 48-62

Omid, S.M., Tsutsumi, J.G., Nakamatsu, R. & Hasanyar, M.H. (2018). *Assessment of Groundwater Level To Improve Water Resource in Kabul City,* 6(6), 6-13

Palintest (2021). Palintest photometer.pdf (https://www.palintest.com/wp-content/uploads/2019/04/ZIINST7500-V5-EN.pdf)

Ram, A., Tiwari, S.K., Pandey, H.K., Chaurasia, A.K., Singh, S. & Singh, Y.V. (2021). Groundwater quality assessment using water quality index (WQI) under GIS framework. *Applied Water Science,* 11(2), 46 (https://doi.org/10.1007/s13201-021-01376-7)

Ramakrishnaiah, C.R., Sadashivaiah, C. & Ranganna, G. (2009). Assessment of water quality index for the groundwater in Tumkur taluk, Karnataka state, India. *E-Journal of Chemistry,* 6(2), 523-530 (https://doi.org/10.1155/2009/757424)

Razowska-Jaworek, L. (2014). Calcium and Magnesium in Groundwater. In Calcium and Magnesium in Groundwater (https://doi.org/10.1201/b17085)

Saleem, M., Hussain, A. & Mahmood, G. (2016). Analysis of groundwater quality using water quality index: A case study of greater Noida (Region), Uttar Pradesh (U.P), India. *Cogent Engineering*, 3(1), 1-11 (https://doi.org/10.1080/23311916.2016.1237927);

Sediqmal, M., Seddiqi, M.S., Turabi, H. & Wadat, M.N. (2022). Urbanization impact in terms of quality and quantity of groundwater: Case study of Kabul city. I*nternational Journal of Advanced Academic Studies*, 4(2), 138-141 (https://doi.org/10.33545/ 27068919.2022.v4.i2c.788)

Sherrard, J.H., Moore, D.R. & Dillaha, T.A. (1987). Total dissolved solids: Determination, sources, effects, and removal. *Journal of Environmental Education*, 18(2), 19-24 (https://doi.org/10.1080/00958964.1987.9943484)

Shnizai, Z. & Iqbal, A.R. (n.d.). Physico-Chemical Properties of Groundwater In The Kabul Basin, Afghanistan

The 17 Goals | Sustainable Development (n.d.). Retrieved August 6, 2024 (https://sdgs. un.org/goals)

Tünnermeier, T. & Houben, Dr.G. (2005). Hydrogeology of the Kabul Basin Part I: *Geology, aquifer characteristics, climate and hydrography*, 46

Turbidity and Water (n.d.). Retrieved July 26, 2021 (https://www.usgs.gov/special-topic/water-science-school/science/turbidity-and-water?qt-science_center_objects=0#qt-science_center_objects)

USGS (2013). Groundwater Levels in the Kabul Basin, Issue 182

Vasanthavigar, M., Srinivasamoorthy, K., Vijayaragavan, K., Rajiv Ganthi, R., Chidambaram, S., Anandhan, P., Manivannan, R. & Vasudevan, S. (2010). Application of water quality index for groundwater quality assessment: Thirumanimuttar sub-basin, Tamilnadu, India. *Environmental Monitoring and Assessment*, 171(1-4), 595-609 (https://doi.org/10 .1007/s10661-009-1302-1)

What Causes Water Hardness – Effects and Solutions for Hard Water (n.d.). Retrieved July 26, 2021 (https://ecolifemaster.com/what-causes-water-hardness/)

What is TDS in Water and it's Effects? How to Reduce TDS of Water? (n.d.). Retrieved July 26, 2021 (https://www.bestrowaterpurifier.in/blog/what-is-tds-level-in-water/)

What is TDS Level in Water? Find Permissible limit of TDS in drinking water (n.d.). Retrieved July 26, 2021 (http://water-purifiers.com/tds-level-water-need-maintain/)

World Health Organization (WHO), Hardness in drinking water (2010)

WHO (2017a). Guidelines for drinking-water quality: Fourth edition incorporating first addendum (4th ed. + 1st add) (https://iris.who.int/handle/10665/254637)

WHO (2017b). Guidelines for drinking-water quality: Fourth edition incorporating first addendum (4th ed. + 1st add) (https://iris.who.int/handle/10665/254637)

Yogendra, K. & Puttaiah, E.T. (2008). Determination of Water Quality Index and Suitability of an Urban Waterbody in Shimoga Town, Karnataka. Proceedings of Taal2007: The 12th World Lake Conference: 342-346 *Determination*, 342-346