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Impact of climate change on water quality of Zarqa Stream Basin: Evidence from Jordan

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ABSTRACT

Climate change poses substantial threat to water quality in Jordan. It may lead to saline water intrusion into freshwater reserves, increased water pollution, and scarcity of freshwater. This study aims to investigate the impact of climate change on water quality in Zarqa Stream Basin, Jordan. One hundred and twenty water samples were collected from Zarqa Stream, and were distributed equally between the three study locations, namely, Jerash, Zarqa, and King Talal Dam. Laboratory analyses and tests, that is; basic water components, were performed on the water samples according to the standards approved in the specialized laboratories of the Ministry of Health, Jordan, and the Ministry of Water and Irrigation, Jordan. The study results uncovered variations in concentrations of chemical parameters of water quality among the three studied sites (Zarqa, Jerash, and King Talal Dam), suggesting diverse effects due to environmental pollution and surrounding conditions. Water quality varies in Zarqa Stream Basin from a location to another, and despite the fact that some indicators meet international standards, the water has high level of turbidity, high concentrations of dissolved substances, and a high electrical conductivity, making it unsuitable for human drinking. The study highlights organic pollution and changes in certain chemical elements. This necessitates adoption and implementation of effective measures to improve and protect the water quality in this basin. Non-essential water components have been significantly affected by climate change, with some surpassing safe limits. This calls for rapid treatment and continued monitoring to avoid negative consequences. These changes should be considered in water quality assessments. Additionally, awareness of the impact of climate change on water quality should be raised and the local communities should be encouraged to take action to preserve water resources and protect the water quality from deterioration.

تأثير المرحلة التطورية وموعد الحصاد لنبات النعناع الفلفلي في النمو وحاصل الزيت الطيار

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الخلاصة

لدراسة تأثير ثلاث مراحل نمو لنبات النعناع الفلفلي *Mentha piperita* L. (ما قبل التبرعم ، التبرعم و 50% تزهير) وثلاثة مواعيد حصاد خلال اليوم الواحد (7:00 صباحاً، 12:00 ظهراً و5:00 مساءً) في نمو وحاصل الزيت الطيار، أجريت التجربة في حقول محطة البحوث الزراعية (منطقة البندر) التابعة لكلية الزراعة جامعة المثنى، تحت الظروف البيئية لمحافظة المثنى الواقعة جنوب العراق عند خط عرض 31.32139° شمالاً و45.30407° شرقاً، للفترة من 2024/2/15 إلى 2024/6/16، ونفذت وفق تصميم القطاعات العشوائية الكاملة وبثلاث مكررات، أظهرت نتائج الدراسة التأثير المعنوي للمراحل التطورية للنبات في جميع الصفات المدروسة. أذ تفوقت نباتات النعناع المحصودة عند مرحلة 50% تزهير بشكل معنوي وأعطت أعلى القيم في ارتفاع النبات (61.33 سم)، عدد الأفرع (27.38 فرع. نبات$^{-1}$)، الوزن الطازج للكتلة الخضرية (19.07 غم. نبات$^{-1}$)، الوزن الجاف للكتلة الخضرية (4.74 غم. نبات$^{-1}$)، الوزن الطازج للأوراق (12.80 غم. نبات$^{-1}$)، الوزن الجاف للأوراق (3.10 غم. نبات$^{-1}$)، النسبة المئوية للزيت الطيار (2.40٪) وحاصل الزيت الطيار لكل نبات (74.06 ميكرولتر. نبات$^{-1}$). بينما كان لأوقات الحصاد تأثير معنوي في صفات الوزن الطري للمجموع الخضري ووزن الأوراق الطري ومحتوى الزيت الطيار وحاصل الزيت الطيار للنبات الواحد فقط، والتي تفوقت بها نباتات النعناع التي تم حصادها عند الساعة 7.00 صباحًا وأعطت أعلى القيم (17.00 غم نبات$^{-1}$، 11.50 غم نبات$^{-1}$، 2.29٪ و 65.20 ميكرولتر نبات$^{-1}$) على التوالي، ولم يكن لأوقات الحصاد اي تأثير معنوي على صفات النمو الخضري الأخرى.

الكلمات المفتاحية: **النعناع الفلفلي Mentha piperita L ، المرحلة التطورية ، وقت الحصاد ، الزيت الطيار.**

INTRODUCTION

Climate change is a long-term phenomenon that leads to an increase in temperature of the Earth. It is attributed to human activities such as the burning of fossil fuels. This change has a variety of negative effects like sea level rise, increase of the intensity of extreme weather events, and plant and animal life pattern changes (UNO, 2023). It has an evident and real impact on water quality, which makes it a focus of great interest and importance for researchers since increase in global temperature leads to shifts in rainfall patterns, which causes droughts and floods that disrupt the natural hydrological cycle. These changes lead to increase in incidence of water pollution, including by rainwater runoff, which results in the proliferation of harmful algae. The rise in sea level resulting from climate change also brings about saltwater intrusion into freshwater reserves, which causes groundwater to lose its quality and reduces availability of freshwater (O'Donnell *et al*., 2024; Zamrsky, Essink & Bierkens, 2024).

Climate change is a long-term shift in the average weather patterns that define the local, regional, and global climates of the Earth. It has a wide range of impacts, including rising sea levels, more extreme weather events, and changes in plant and animal life. We can mitigate climate change by reducing greenhouse gas emissions, protecting forests, developing new technologies, and adapting to changes that actually take place (NASA, 2023; Javadinejad *et al*., 2020; Wang *et al*., 2023). Global cooperation to reduce carbon emissions and take action to adapt infrastructure and communities to this accelerating change in climate is essential (Azadi *et al*., 2020). Agricultural, urban, and industrial activities have dramatically increased water pollution with nitrogen and phosphorus by greatly raising their concentrations in the water, thus threatening the water quality and biosecurity of major waterways, which, in turn, reduce fish and shellfish production, increase harmful algal blooms that cause taste and odor problems and threaten the safety of drinking water and aquatic food supplies; and lead to deterioration of the cultural and social values of these waters (Sinclair *et al*., 2023).

Jordan in particular faces the challenges of climate change, where temperature rises and weather variability increases are recorded. To address these challenges, the Jordanian government is working on implementation of strategies for adaptation with climate change and contributing to efforts for carbon emission cuts (MoE, 2022), especially in Zarqa Basin, where these changes lead to a decrease in the rainfall rates, thus causing water shortages and. consequently, constituting a threat to water security in this area, which is highly dependent on water sources. This, ultimately, impacts agriculture and natural resources in the area adversely and increases pressure on the environment (Khashroum *et al*., 2016; Kloub & Alzboon, 2023).

Climate change is one of the most serious challenges which the World faces today as it significantly affects all aspects of life, including water. In Zarqa Stream Basin, climate change is expected to lead to increase in temperatures, a decrease in rainfall, and increase in evaporation. These changes affect the basic properties of water in the basin, including pH and concentrations of nutrients and organic matter (Khashroum, 2024; Dao *et al*., 2024). The organic matter can affect water quality because it can make the water more turbid, which may make it difficult for plants and animals to live in. Concentrations of organic matter in the water of Zarqa Basin are expected to increase by effect of the projected drop in rainfall and increase in temperature. Low rainfall and high temperatures can result in fast decomposition of organic matter, which increase the levels of dissolved organic matter in water (IPCC, 2022; UNEP, 2021).

Water quality assessment is an issue of paramount importance in Jordan for several reasons. First, because of water scarcity, Jordan relies heavily on groundwater as a primary source of fresh water, which makes it necessary to assess and monitor its quality in order to ensure safety of the human consumption, agriculture, and industry. Second, Jordan faces environmental challenges such as water pollution and climate change, which can affect water quality greatly. Accordingly, assessing and monitoring water quality is vital for sustainable water resource management, development support, and environmental protection in Jordan (Ministry of Water and Irrigation, 2023).

Jordan faces several water resource problems due to its geographical location, climate, population growth, and refugee population increase. The water crisis is considered a major impediment to development and economic progress, which is exacerbated by population growth and inefficient water use (Al-Kharabsheh, 2020). The research problem is the negative impact of climate change on the quality of water. This problem has multiple facets since climate change causes a number of environmental changes (increases in temperatures and changes in rainfall patterns). These changes have high impact on water quality (changes in its basic components) in the study area. The increased frequency and severity of extreme weather phenomena (floods and droughts) can pollute water (Qiu *et al*., 2022). They supply water with sediments and chemicals, which affect water quality in the study area. It is important to take steps to reduce the negative impacts of climate change and protect the quality of water in the study area. This study comes to warn and shed light on the extent of these effects on water quality. The important question in this study is: does climate change affect water quality? Based on the foregoing issues, the main objective of this study is to elucidate the extent of the impact of climate change on the quality of water in the study area. Therefore, the study aimed at achieving the goal of knowing the extent to which the basic components of water in three main locations in Zarqa Stream Basin (Zarqa, Jerash, and King Talal Dam) were affected by climate change during the study period.

MATERIALS AND METHODS

Research Approach

This study was conducted in three areas in Zarqa Stream Basin: Zarqa, Jerash, and King Talal Dam. Water samples were taken from these sites to determine the concentrations of several parameters (minerals, gases, organic matter, and pesticides (insecticides and herbicides)) in these samples. The study followed the descriptive analytical approach on the basis of taking samples from the study area to estimate the basic water components during specific time periods in the year 2023.

Study Area

This study was conducted in Zarqa, Jerash, and King Talal Dam in Zarqa Stream Basin (Figure 2) and water samples were taken from these sites during certain time periods (2023) in order to determine the impact of climate change on the quality of Zarqa Stream water. The concentrations of major constituents (metals, gases, organic matter, and pesticides) were estimated to determine the proportions of these constituents and their conformity to the Jordanian water quality standard, verify the quality of the water or the environment.

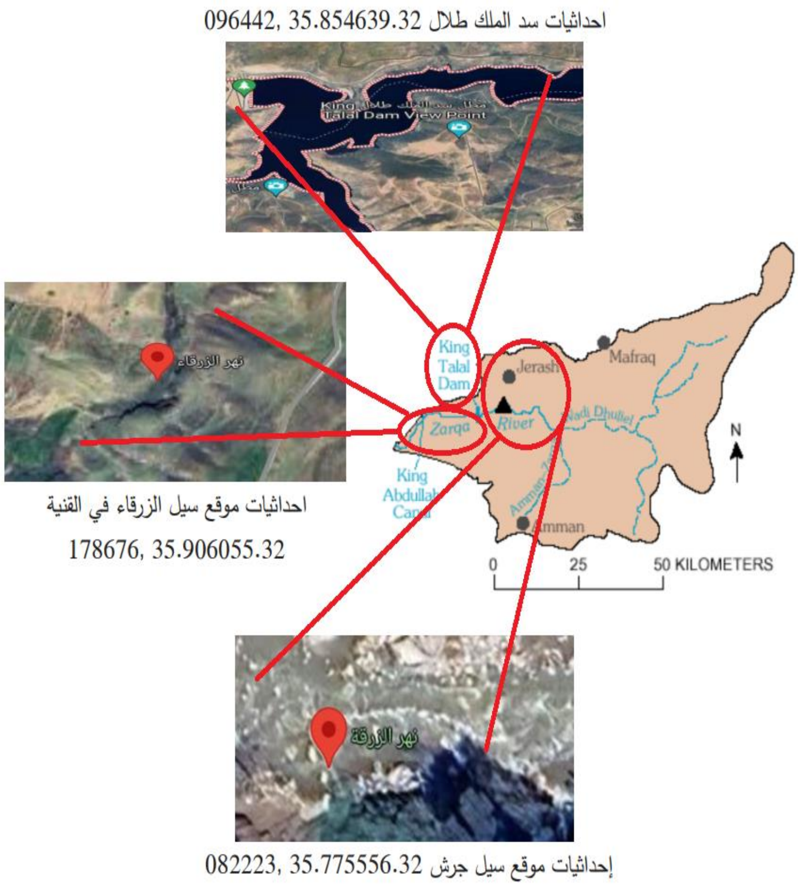

Figure 1: Map of the study area and locations of water sample collection in Zarqa Stream Basin (Wikipedia, 2023a).

Fieldwork

Water sample collection is a vital part of this research. Monitoring points for collecting water samples were carefully selected based on expectations of the impact of climate change on water quality in the study area. Figure 2 shows the impact of climate on water quality in Zarqa Stream Basin. The low water quality may be due to water turbidity. Samples were collected at the points where streams meet other water sources and at the points where streams exit to other water bodies. Clean and sterile containers were used to avoid contamination of the water samples, and the samples were transported to the laboratory for immediate analysis. One hundred and twenty water samples were collected from Zarqa Stream, and were distributed equally between the three study locations, namely, Jerash, Zarqa, and King Talal Dam. Appropriate tools were used like sample collector and bottles of different capacities. A cooler box was used to preserve heat-sensitive samples and ensure that they are not spoiled during transportation. A means of transportation (vehicle) was used to warrant that the quality and temperatures of the samples were preserved during transportation and storage.

Figure 2.1: Water quality and purity. Figure 2.2: Water quality is low.
Figure 2: Climate impact on water quality in Zarqa Stream basin (Wikipedia, 2023b).

Laboratory Work

Laboratory analyses and tests were performed on the water samples according to the standards approved in the specialized laboratories of the Ministry of Health, Jordan, and the Ministry of Water and Irrigation, Jordan. The analyses were performed in the laboratories of the Jordanian Ministry of Health in the year 2023 using appropriate tools such as bottles of different capacities (e.g., half liter, 1.0 liter, and 1.5 liters) and a refrigerated box to store the samples. Bottles with a capacity of 1.0 liter were used to store large samples while bottles with a capacity of 0.5 liter were used to store small samples. A refrigerated box was also used to ensure that the samples were kept cool during storage (Figure 3).

Figure 3: Water sample bottles and fractionation tubes.

The list of the suitable tools used in the analysis includes a set of basic tools that included an incubator; a microscope to analyze the samples microscopically and reveal their fine details; an electronic balance to determine the masses of the samples; test bottles for mixing and chemical reaction tests; and fractionation tubes to divide the samples for other experiments, in addition to a set of small tools used in handling fine samples. Table 1 presents the names of the water quality parameters studied, the unit of measurement of each parameter, and the analytical instruments or methods used in the laboratory analyses.

Data Curing

The process of data curing includes office planning and preparation, where the appropriate timing and locations of sampling and number of samples are determined. Samples are, then, collected using clean tools and containers and important information is documented. This is followed by proper preservation and storage and careful transportation of samples to the laboratory. Analysis is performed using approved methods that comply with recognized standards, with equipment calibrated to ensure accuracy of the results. Data are carefully documented and statistical analysis is performed to interpret the data. This is followed by preparing a laboratory report that contains the results. The samples are temporarily stored for re-analysis, if necessary, before being disposed of properly and in compliance with local and national regulations.

Statistical Analysis

Obtaining accurate and reliable results for assessing water quality and ensuring its safety for environmental use is important. Values of the relative variation coefficients (RVC) can be used to track changes in water component concentrations over time. They are also used to identify potential sources of pollution, target purification efforts, and prevent further pollution. As to water resource management, the RVC values can be used to develop water resource management strategies in the basin, which allows for addressing water quality challenges and directing efforts toward alternative sources or treating water to make it safe for use. In general, the RVC values are a valuable tool for understanding diversity of the water components and managing the water resources in the water basin.

Table 1: Test parameters and the devices or methods used in their analysis.

No.	Test Variable	Unit	Measurement Instrument/Method
1.	pH	-	pH-meter
2.	Temperature	°C	Thermometer
3.	Turbidity	NTU	Turbidity Meter
4.	Electric Conductivity (EC)	mS/cm	Electric Conductivity Meter
5.	Total Dissolved Solids (TDS)	mg/L	TDS Meter
6.	Total Suspended Solids (TSS)	mg/L	TSS Meter
7.	Biological Oxygen Demand (BOD)	mg/L	BOD Meter
8.	Chemical Oxygen Demand (COD)	mg/L	COD Meter
9.	Oil and Grease	mg/L	Oil and Grease Meter
10.	Bicarbonate (HCO_3^-)	mmol/L	Calorimeter or crystallizer for the determination of bicarbonate
11.	Carbonate (CO_3^{2-})	%	Volumetric Analysis Device
12.	Calcium (Ca)	mg/L	Volumetric Analysis Device
13.	Magnesium (Mg)	mg/L	EDTA Titration
14.	Potassium (K)	mmol/L	Atomic Absorption Spectrometer
15.	Sodium (Na)	mg/L	Atomic Absorption Spectrometer
16.	Sodium Adsorption Ratio (SAR)	meq/cm^3	Sodium absorption meter The device depends on the concentration of sodium ions
17.	Sulfate (SO_4^{2-})	mg/L	Optical absorption device
18.	Chloride (Cl^-)	mg/L	Optical absorption device
19.	Nitrogen (N)	mg/L	Photometer
20.	Nitrate (NO_3^-)	mg/L	Ion Chromatography
21.	Nitrite (NO_2^-)	mg/L	Ion Chromatography
22.	Total N	mg/L	Electrolysis device
23.	Phosphate (PO_4^{3-})	mg/L	Phosphorus meter
24.	Phosphorous (P)	mg/L	Ultraviolet Spectrophotometer
25.	Ammonia (NH_3)	mg/L	Ammonium meter
26.	Ammonium ion (NH_4^+)	mg/L	Spectrophotometer
27.	Fluoride (F^-)	ppm	Spectrophotometer
28.	Aluminum (Al)	mg/L	Spectrometer
29.	Arsenic (As)	ppb	The analyzer uses ultraviolet or infrared light.
30.	Barium (Ba)	ppb	Ultraviolet or infrared element analyzer
31.	Lithium (Li)	ppm	Ultraviolet spectrometer
32.	Boron (B)	mg/L	Light absorption meter
33.	Cadmium (Cd)	ppb	Atomic absorption spectrometer
34.	Chromium (Cr)	ppm	Atomic absorption spectroscopy
	Cobalt (Co)	µg/L	Atomic absorption spectroscopy
35.	Copper (Cu)	mg/L	Atomic absorption spectrometer
36.	Iron (Fe)	mg/L	Atomic absorption spectrometer
37.	Lead (Pb)	mg/L	Atomic absorption spectrometer
38.	Manganese (Mn)	mg/L	Atomic absorption spectrometer
39.	Nickel (Ni)	mg/L	Atomic absorption spectrometer
40.	Zinc (Zn)	mg/L	Atomic absorption spectrometer
41.	Mercury (Hg)	mg/L	Atomic absorption spectrometer
42.	Molybdenum (Mo)	mg/L	Atomic absorption spectrometer
43.	Selenium (Se)	mg/L	Atomic absorption spectrometer
44.	Silver (Ag)	mg/L	Atomic absorption spectrometer
45.	Vanadium (V)	mg/L	Atomic absorption spectrometer
46.	Methylene Blue Active Substances (MBAS)	mg/L	Surface tension device

RESULTS AND DISCUSSION

This study aimed mainly at elucidating the extent of the impact of climate change on the quality of water in the study area, particularly determining the extent to which the basic components of the water that may be available in three main locations in Zarqa River Basin (Zarqa, Jerash, and King Talal Dam) were impacted during the research period. Table 2 shows the basic components of water that were not affected (Group A) by climate change in the study area (Zarqa River Basin). Variables in this group have acceptable coefficients of variation (C.V), which mean that the variance of the readings falls within the normal distribution curve of variance. Table 3 lists the main components of water that were affected to a low degree (Group B) by climate change in the study area (Zarqa River Basin). Variables in this group have critical coefficients of variation. Table 4 shows the basic components of water that were moderately affected (Group C) by climate change in the study area (Zarqa River Basin).

Table 2: The basic water components that were not affected (Group A) by climate change in the study area.

No.	Variable	Unit	Lowest Value	Highest Value	C.V
1.	pH	-	6.22	10.67	5.69
2.	Temperature	ºC	20.6	33.0	14.62
3.	EC	mS/cm	1788	3000	19.1
4.	V	mg/L	0.01	0.09	19.91
5.	Cu	mg/L	0.01	0.22	23.94

Table 3: The basic components of water that were affected to a low degree (Group B) by climate change in the study area.

No.	Variable	Unit	Lowest Value	Highest Value	C.V
1.	K	mg/L	4.74	58.28	37.75
2.	SAR	%	0.61	8.0	39.51
3.	Ba	mg/L	0.04	0.42	46.47
4.	HCO_3^-	mg/L	101.5	890.5	47.0
5.	N	mg/L	0.10	20.5	47.67
6.	Cl^-	mg/L	49.7	1422.6	53.4
7.	As	mg/L	0.01	0.07	55.25
8.	Total N	mg/L	1.50	122.3	57.02
9.	Ni	mg/L	0.01	0.1	58.21
10.	Na	mg/L	41.5	923.4	58.9

Table 4: The basic components of water that were moderately affected (Group C) by climate change in the study area.

No.	Variable	Unit	Lowest Value	Highest Value	C.V
1.	NO_2^-	mg/L	0.20	20.8	64.32
2.	Co	mg/L	0.01	0.13	66.38
3.	B	mg/L	0.29	1.97	68.06
4.	TDS	mg/L	29.0	7930	70.8
5.	Mg	mg/L	6.54	197.9	73.09
6.	NO_3^-	mg/L	0.25	177.83	75.4
7.	P	mg/L	0.20	5.2	80.4
8.	Cr	mg/L	0.01	0.1	81.89
9.	Mo	mg/L	0.01	0.07	85.41
10.	Cd	mg/L	0.003	0.06	88.39
11.	F^-	mg/L	0.30	3.4	89.65
12.	PO_4^{3-}	mg/L	0.02	27.63	91.04
13.	Pb	mg/L	0.01	0.20	92.39
14.	Ca	mg/L	17.4	691	94.3

Table 5 presents the basic components of water that were highly affected by climate change (Group D) in the study area (Zarqa River Basin).

Table 5: The basic components of water that were highly affected by climate change (Group D) in the study area.

No.	Variable	Unit	Lowest Value	Highest Value	C.V
1.	Se	mg/L	0.01	0.12	104.76
2.	Ag	mg/L	0.01	0.10	109.99
3.	Mn	mg/L	0.01	1.31	116.91
4.	SO_4^{2-}	mg/L	23.9	1698.5	119.7
5.	Zn	mg/L	0.02	1.80	150.36
6.	CO_3^{2-}	mg/L	2.50	209.5	161.22
7.	NH_3	mg/L	0.40	13.0	168.6
8.	Oil and Grease	mg/L	1.00	228	191.33
9.	Li	mg/L	0.02	1.29	193.92
10.	Turbidity	NTU	0.70	360	195.66
11.	Al	mg/L	0.02	11.06	206.78
12.	TSS	mg/L	5.00	1804	218.28
13.	NH_4^+-N	mg/L	0.10	105.36	224.56
14.	Fe	mg/L	0.01	24.13	272.01
15.	BOD	mg/L	3.00	842	301.14
16.	Hg	ppb	0.40	154.35	415.46
17.	MBAS	mg/L	0.20	55.0	482.43
18.	COD	mg/L	10.0	12296	523.39

According to the information provided in Table 1, some analytical chemical indicators of Zarqa Stream water did not differ significantly between the three studied sites. The results indicate that the probability (*p*) value exceeds the relative acceptable value for statistical significance ($\alpha = 0.05$), which means that there are no statistically-significant differences between the three sites in the tested parameters. Hence, there may be statistical similarity between the three sites with regard to the concentrations of nitrite (NO_2^-), methylenblue active substances (MBAS), cobalt (Co), oil and grease, chemical oxygen demand (COD), manganese (Mn), vanadium (V), carbonate (CO_3^{2-}), nitrate (NO_3^-), fluoride (F^-), nickel (Ni), and silver (Ag). This means that these sites are not statistically different in terms of concentrations of these chemical indicators.

There are several reasons why the studied sites are not statistically different with respect to the aforementioned chemical indicators (NO_2^-, MBAS, Co, oil and grease, COD, Mn, V, CO_3^{2-}, NO_3^-, F^-, Ni, and Ag). They may include: (i) similarity of pollutant sources. There may be similarity in the pollutant sources present in the studied sites, i.e., the sites are receiving pollutants from the same sources like a natural pollution source (e.g., decomposition of rocks rich in a chemical element) or a nearby chemical plant, which make the chemical concentrations similar in these three sites; (ii) environmental factors. The environmental factors common to the sites may affect the similarity in chemical indicators as these sites are located in the same water system or are affected by the same climatic factors such as rain and wind, which may lead to the transport of soil rich in a certain chemical element. In other words, there may be a similar effect on the chemical indicators; (iii) measurement and analysis methods. The measurement and analysis methods used may influence the similarity of results between the sites. If uniform and reliable methods are used across all sites, then this may reduce statistical differences; and (iv) natural variation: There may be natural variation within a site that is similar to other sites with respect to chemical indicators. Sometimes, natural variation can be much greater than the statistical difference.

The presence of significant differences between the studied sites in terms of concentrations of barium (Ba), mercury (Hg), molybdenum (Mo), and water temperature is evidence of the existence of variability between these sites. Significant differences in their values indicate that there is a real difference between these variables at different sites, and this may indicate existence of difference in the effects or conditions in these sites. There may be different factors that affect water temperature and the concentrations of Ba, Hg, and Mo at these sites like environmental pollution, presence of specific types of rocks (sedimentary or igneous rocks) or soils, flow patterns, and different climatic conditions.

There are reasons that explain statistical differences between sites with respect to water temperature and chemical indicators (Ba, Hg, and Mo). Some of the reasons are: (i) differences in pollutant sources. There may be differences in the pollutant sources that affect sites. Each site may have unique pollutant sources that cause variation in chemical indicators; (ii) environmental effects. There may be differences in environmental factors that affect sites. For example, there may be differences in the terrain, soil, vegetation, and water flows surrounding each site, which may lead to variation in chemical indicators; (iii) human activities. Sites may be affected by different human activities such as agriculture and industry. These activities can contribute to the generation of different chemical pollutants and affect chemical indicators in different ways; and (iv) climatic conditions. The climatic conditions can play a role in formation of the chemical indicators. There may be differences in temperature, rainfall fluctuations, and winds, which can influence the concentrations of the chemical compounds at the sites.

Highly-significant differences were found among the three studied sites (Zarqa, Jerash, and King Talal Dam) in pH, turbidity, electrical conductivity (EC), Sodium Adsorption Ratio (SAR), sulfate (SO_4^{2-}), and the concentrations of aluminum (Al), calcium (Ca), ammonium (NH_4^+), zinc (Zn), selenium (Se), boron (B), lithium (Li), iron (Fe), total dissolved solids (TDS), total suspended solids (TSS), biological oxygen demand (BOD), bicarbonate (HCO_3^-), magnesium (Mg), potassium (K), sodium (Na), chloride (Cl^-), nitrate (NO_3^-), total nitrogen (Total N), orthophosphate (PO_4^{3-}), phosphorous (P), arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), and lead (Pb). These significant differences may be explained by the presence of different factors, e.g., pollution of the source, industrial activity in the area, environmental changes around the sites, agricultural activity, and natural effects. Considering these differences, it can be confirmed that there are large variations in water quality and concentrations of chemicals and biological indicators between the studied sites. There are very high variations in EC and the concentrations of NO_3^-, PO_4^{3-}, TDS, NH_4^+, total nitrogen, and K. That is, there were statistically-significant differences between the sites in terms of physical indicators (pH, turbidity, EC, TDS, and TSS) and chemical indicators (Al, Ca, NH_4^+, Zn, Se, B, Li, Fe, BOD, HCO_3^-, Mg, K, Na, SAR, SO_4^{2-}, Cl^-, NO_3^-, total nitrogen, PO_4^{3-}, P, As, Cd, Cr, Cu, and Pb). This indicates large differences in the concentrations of these parameters and confirms the existence of big differences between the three sites under study. The possible reasons for these differences encircle (i) variation in pollutant sources. There may be a large variation in the pollutant sources at sites, which bring about large differences in the chemical indicators. This may be related to industrial sources of pollution (e.g., chemical plants) or natural sources of pollution; (ii) diverse human activities. Sites may be statistically different in water quality due to presence of diverse and different human activities at each site. There may be farms or industrial facilities in specific locations that cause different accumulation of chemical compounds and result in statistical differences in chemical indicators; and (iii) environmental interferences. There may be various environmental interferences that affect chemical concentrations in the different locations. These interferences may include factors like the surrounding soil, groundwater system, and impacts of local climatic factors. The highly-significant differences between the studied sites in the concentrations of these compounds and indicators signifies that there are large differences in water quality and the effects of climate change in Jordan, including the impacts of changes in temperatures and rainfall patterns on water composition, freshwater availability, salt concentrations and salinity, and metal corrosion and deposition (Al-Addous *et al*., 2023; Al-Hasani *et al*., 2023).

The statistical values of the analysis of the basic components of water in Zarqa River Basin point out that the chemical composition of the water in this basin is highly diverse. This indicates significant potential impacts on the environment and the health of communities dependent on this water. As well, this points to existence of pollution or harmful effects on the aquatic environment. This information can be used to take appropriate measures to protect and improve water quality. The basic components may have an impact on water sustainability and ecological balance. Using this information, that is, the results of this study, best practices for water resource conservation and effective planning of water use can be identified; environmental studies can be implemented that are related to the environment, prediction of future changes, and environmental impact assessments of future projects so as to contribute to understanding the aquatic ecosystem and improving its management and protection.

Based on Table 2, values of some of the basic water components (K, SAR, Ba, HCO_3^-, NO_3^-, Cl^-, As, total N, Ni, and Na) were almost twice the C.V threshold of 30%. This indicates deviation of their distributions from the normal distribution. Therefore, it is of utmost importance to implement follow-up measures and treatments to prevent these components from reaching levels that can affect the water quality negatively. This can be an indication of water quality instability with regard to these components. Based on these analysis results, the variations of these components should be monitored, followed up, and corrected for regularly to assess water quality and identify and control any potential changes in them. Additional urgent action may be needed to control high variability and ensure sustainable and safe water quality for use. On the other hand, the coefficients of variation of pH, temperature, EC, concentration of V, and concentration of Cu varied within the range of 5.69-23.94 (Table 1), which is less than 30% (normal distribution curve). This means that readings of these parameters fell within the safe range for water safety.

On the basis of the analysis results presented in Table 3, the C.V values of many of the essential water components (e.g., NO_2^-, Co, B, TDS, Mg, NO_3^-, P, Cr, Mo, Cd, F^-, PO_4^{3-}, Pb, and Ca) were almost twice the 30% threshold. This indicates that distributions of these parameters deviate significantly from the normal distribution. Therefore, it is of paramount importance to implement follow-up measures and treatments to prevent these components from reaching levels that can affect the water quality negatively. This highlights instability of the water quality in terms of the foregoing components. In consequence, regular monitoring and intervention are essential to assess water quality, identify any potential changes, and effectively manage and mitigate fluctuations in it. To ensure sustainable and safe water for use, it may be necessary to implement additional quick and effective measures to control the high variations observed. These measures should aim at maintaining the water quality within acceptable limits. By closely monitoring and addressing the variability of these components, it is possible to accurately assess water quality and take appropriate actions to maintain its safety and usability.

Considering the analysis outcomes provided by Table 4, the C.V values of many of the basic water components (e.g., Se, Ag, Mn, SO_4^{2-}, Zn, CO_3^{2-}, NH_3, oil and grease, Li, water turbidity, Al, TSS, NH_4^+, Fe, BOD, Hg, MBAS, and COD) were at least three times the 30% threshold. This implies that distributions of these parameters deviated highly from the normal distribution. These high variations suggest contamination and instability of water quality in terms of the aforementioned components. Thereupon, it is of utmost importance to implement follow-up measures and rapid treatments to prevent these components from reaching levels that can effectively affect water quality adversely. Regular treatment, monitoring, and intervention are essential to assess and address water quality and to manage, mitigate, and effectively address fluctuations in it. To guarantee sustainable and safe water for use, it may be necessary to implement additional quick and effective measures in order to control the high variations observed. These measures should aim at keeping water quality within acceptable limits. By closely monitoring and addressing the variability of these components, it is possible to assess water quality accurately and take appropriate actions to preserve its safety and usability.

The variations in the basic water components listed in Tables 2, 3, and 4 are directly related to climate change, which influences water quality through its effects on water sources and formation processes. In consequence, it is important to take into consideration the impacts of climate change when assessing water quality and taking steps to conserve freshwater resources and warrant sustainable water quality. Estimating the values of the relative coefficients of variation (CV) of some of the basic water components in Zarqa Stream Basin is useful action for understanding the variability in these components. This information can be used to monitor water quality in the basin, identify potential sources of pollution, and develop strategies for water resource management in this basin. These variations in the basic components of water are attributed to several factors, including natural variations in the water source and human activities that contribute to water pollution. The influence of natural variations in the water source, such as climate change and the natural movement of sediments, may be the cause of some of the variation that affects the components of water while human activities (e.g., unregulated industrial and agricultural discharges and waste dumping) may be the reason behind water pollution with chemicals and pollutants. To face these challenges, it is advisable to take realistic measures to control the pollution sources and improve water quality, whether through better monitoring and periodic assessment of water or developing and implementing environmental policies aimed at reducing the adverse impacts of human activities on water resources. It is also necessary to raise awareness of the importance of water conservation and the role of everyone in preserving it for future generations.

CONCLUSIONS

From the results of the study, we can conclude the following: (i) the differences in the basic water components in Zarqa Stream Basin relate to climate change. Hence, it is important to take steps to conserve freshwater resources and ensure sustainable water quality; (ii) the concentrations of the basic components of water in this basin differ significantly between the studied sites, which confirms that water in each site is affected by factors that differ from a site to another. In general, the concentrations of the basic water components are greatly influenced by the natural interactions and human activities in each site, which result in significant differences in water properties between different sites in this basin; (iii) differences in concentrations of certain basic water components between the studied sites were not statistically significant, but differences in other parameters were significant. Some parameters exhibited high differences. This ensures that the concentrations of the basic water components in each site are affected by different factors. On the other hand, statistical analysis of differences in the concentrations of the basic water components in this basin reveals that there are statistically-insignificant differences between some sites while there are significant differences in some components. This indicates that influence of environmental factors varies greatly between sites, which impact the concentrations of essential water components individually and differently at each site; and (iv) based on the values of the coefficient of relative variation, measurements/concentrations of the essential water components were classified into four groups: acceptable, critical, high, and very high. This variation emanates from natural changes in the water source or human activities that cause water pollution.

RECOMMENDATIONS

In the light of the study findings and conclusions, the researchers recommend (i) taking several steps to address the variations in basic water components, including monitoring water component levels regularly using recognized techniques and tests to detect any change in these components; (ii) taking actions to reduce variations in water components like treating those influential sources and monitoring the effectiveness of the actions so as to ensure that they contribute to improvement of water quality and reduction of variations; and (ii) raising awareness of the issue of climate change and its impact on water quality. This can be done through education and awareness programs. Raising awareness can help encourage the local community to take actions to reduce their impact on the environment and help in protection of the water resources.

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