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Assessment of Drinking Water Quality in Sana'a City (2024-2025): Compliance with Global and Local Standard

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Abstract: *Clean, safe, and sufficient freshwater is essential for the survival of all living organisms. Water is indispensable for various purposes, and its quality must be assessed before use. In industrial applications, poor water quality can lead to severe health risks and significant economic losses. Therefore, water quality analysis is crucial for ensuring its suitability for diverse uses. The quality of water is influenced by its source and is evaluated through physical, chemical, and biological parameters..*

Keywords: Sana'a region, drinking water, Physico-chemical parameters

I. INTRODUCTION

Access to clean and safe drinking water is one of the most crucial factors influencing human health and quality of life, particularly in urban areas experiencing rapid population growth. In this context, water quality assessment becomes essential to ensure the safety of drinking water. Sana'a, the capital city of Yemen, faces significant challenges in water quality due to several factors, including water source contamination, increasing water demand, and the management of limited water resources [1].

The water sector in Sana'a is under increasing pressure due to the deterioration of infrastructure, inadequate water supply, and sanitation services, which have a direct impact on public health. This research aims to evaluate the quality of drinking water in Sana'a by analyzing water samples from various sources (such as wells, rivers, and water tanks) to assess their compliance with local and international health standards. The study seeks to understand the extent of water pollution in the city, identify the primary contaminants, and provide recommendations to improve water quality and ensure its safety [2].

A comprehensive assessment of drinking water quality in Sana'a is a vital step in identifying water-related issues, determining the causes of contamination, and laying the foundation for sustainable water management practices to improve the urban environment and public health [3,4]. Water (H_2O) is a polar inorganic compound that exists as a tasteless, odorless liquid at room temperature, with a faint hint of blue color. It is the most studied chemical compound, often referred to as the "universal solvent" and the "solvent of life." Water is the most abundant substance on Earth's surface, and uniquely, it is the only common substance that naturally exists in all three states—solid, liquid, and gas—under Earth's typical environmental conditions. Additionally, water is the third most abundant molecule in the universe, following molecular hydrogen and carbon monoxide[5].Water molecules exhibit strong polarity and form hydrogen bonds with one another. This polarity enables water to dissociate ions in salts and interact with other polar substances, such as alcohols and acids, facilitating their dissolution. The hydrogen bonding between water molecules gives rise to several unique properties, including a solid phase that is less dense than its liquid phase, a relatively high boiling point of 100°C for its molar mass, and a high heat capacity[6]. The quality of drinking water is critical to public health, and it is assessed through both physico-chemical and bacteriological parameters. The physico-chemical quality of water

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involves the measurement of various physical and chemical properties such as temperature, pH, turbidity, color, taste, odour and hardness. These properties influence the suitability of water for consumption, irrigation, and industrial use. For example, excessive levels of chemicals such as heavy metals or high concentrations of salts can make water unsafe to drink and may cause long-term health issues. Bacteriological water quality, on the other hand, focuses on the presence of harmful microorganisms, including bacteria, parasites, viruses, worms, and fungi, which can cause waterborne diseases. Common bacterial indicators, such as Escherichia coli (E. coli), are used to assess the potential for contamination and the risks to human health. A failure to meet bacteriological standards often leads to outbreaks of diseases like cholera, dysentery, and typhoid fever. Therefore, regular monitoring of both physico-chemical and bacteriological parameters is essential for ensuring that water remains safe for human consumption and complies with international health standards.

The main objective of the study was to assess the quality of drinking water in Sana'a, Yemen, and identify potential contaminants or issues affecting its quality. The research was conducted in Sana'a, the capital city of Yemen, which faces significant challenges regarding water scarcity and inadequate water infrastructure. Employing a systematic approach, the researchers collected water samples from various sources. These samples undergone analysis for different physical, chemical, and bacteriological parameters. The study's results revealed elevated levels of TDS, hardness, nitrate, chloride, and sulfate in some water sources. Additionally, the presence of heavy metals exceeding permissible limits was observed in certain samples. Bacterial contamination, indicated by coliform bacteria presence, was noted in some water sources. These findings underscore the potential health risks associated with drinking water in Sana'a, highlighting the importance of implementing appropriate water treatment and management strategies.[7,8]

II. MATERIAL & METHODS

Analytical grade chemicals were used for preparing all reagents and solutions. De-ionized and twice distilled water was used in all experiments. Before each analysis, all instruments are calibrated according to manufacturer's recommendations.

Water samples were collected from eight wells and eight water stations in Sana'a city. The samples undergone physical, chemical, and biological analyses to determine key parameters including color, turbidity, pH, electrical conductivity, hardness, concentrations of metals (sodium, potassium, calcium, magnesium), and the presence of bacterial contaminants like *E. coli*. Biological testing focused on detecting harmful microorganisms in the water: Total Coliform and Fecal Coliform Counts. (MF) Agar: This is a specialized agar specifically designed for use with membrane filtration. It contains nutrients that support the growth of coliform bacteria, including *E.coli*.

Nutrient Agar: This is a general-purpose medium that supports the growth of a wide variety of bacteria. It is often used as a control medium to ensure that the membrane filtration process and the agar itself are not inhibiting bacterial growth.

Muller Hinton *Agar*: This is a specific medium used for antibiotics usceptibility testing. It provides a standardized environment for determining the effectiveness of antibiotics against bacterial isolates. While not directly relevant to the coliform testing in this study, it could be used for further investigation of any bacterial isolates that might be identified in the future.

The research methodology used to evaluate the drinking water quality in Sana'a (Fig1&2) involved the examination of samples from eight wells and eight water stations.

Collection of samples: Taking samples for analysis was done from April 2024 to May 2024.

Simple size

Site Collection: Drinking water samples were collected from eight wells and eight water stations.

Methodology:

Sample Collection: Water samples were collected from wells and stations using sterile containers to avoid any contamination during the process.

Membrane Filtration: A known volume of water (typically 100 ml) was passed through a sterile membrane filter with a pore size designed to capture bacteria.

Filter Transfer: The membrane filter was carefully transferred to a petri dish containing Membrane Filter (MF) agar.

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Incubation: The petri dish was incubated at 35°C for 24-48 hours to allow the coliform bacteria to grow on the agar.
Colony Counting: After the incubation period, the number of bacterial colonies on the agar was counted. The presence of colonies indicated the presence of coliform bacteria in the sample.
Confirmation: To confirm the presence of *E. coli*, selected colonies were further tested using specific media or biochemical tests, such as EMB agar or the indole test.

Procedures:
pH Testing: pH was measured directly using a pH meter. Calibration was done with pH buffer solutions.
Total Alkalinity: Titration with a standard acid solution was conducted, with a color change indicating neutralization of hydroxide ions.
Calcium Analysis: Calcium levels were determined by complexometric titration with EDTA or AAS for more accurate results.
Chloride (Cl^-) Analysis: Chloride was measured using titration with silver nitrate ($AgNO_3$) and a potassium chromate indicator.
Sulfate (SO_4^{2-}) Analysis: Sulfate concentration was determined using turbidimetric or gravimetric methods, precipitating sulfate ions as barium sulfate.
Nitrate (NO_3^-) Analysis: Nitrate ions were analyzed using the Griess colorimetric method, producing a pink-colored complex in the presence of nitrate.
Sodium (Na^+) and Potassium (K^+) Analysis: Flame Atomic Absorption Spectroscopy (FAAS) or Inductively Coupled Plasma (ICP) techniques were employed to measure sodium and potassium concentrations.
Iron (Fe) Analysis: Iron content was determined using colorimetric methods or AAS for precise measurement.
Fluoride (F^-) Analysis: Fluoride levels were measured using ion-selective electrodes or colorimetric methods, with TISAB buffer to adjust ionic strength.

Study Area
The study area includes the city of Sana'a and the locations selected for collecting drinking water samples are as follows:
From Stations:
Al Oshash, Hadda Street, 60th Street, 50th Street, Mojahid Street, 14th October,Sho'oub, Taiz Street
FromWell:
Al Saela, Bir Saw'an, Al Ad'aa Al Hasbah,Bir Al Graaf, , Beit Bous , BainonStreet, Nugum, Sheraton
Result & Discussion: pH, Electrical Conductivity, Total Alkalinity
Calcium, Chloride (Cl^-),Sulfate (SO_4^{2-}) ,Nitrate (NO_3^-) , Sodium (Na^+) and Potassium (K^+) And Iron (Fe) and Fluoride (F^-) Analysis
No significant changes were observed in the physical properties of the
water samples. The concentrations of chemical elements in the water samples were within or below the acceptable limits defined by WHO and Yemeni standards. All water samples were free from microbial contamination, including harmful bacteria such as *E. coli*.
Physical properties analysis.
The physical properties analysis includes:
Color, odor, taste, temperature and turbidity, these analytes were evaluated in the site of collecting samples.
The results of physical properties analysis show that all the samples were safe for drink and use for domestic purpose because the environment of water sources are clean and free from any pollution.
Chemical properties analysis:

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Table(1):showing the (mean, Min, Max) for Electrical Conductivity (EC) checks in the water of stations and wells.

	Mean	Minimum	Maximum
Wellwater	731.80	395	1000
Stationwater	831.38	502	1671
V.R(YEMEN)	750-3500		
V.R(WHO)	750-2500		

The table (1) show that the maximum and minimum values for the results of the (EC) test for well water are (395 - 1000), with Mean of (731.80), these values is within the V.R(Yemen) and V.R(WHO), while the maximum and minimum values for the results of the (EC) test for station water are (502 - 1671)with Mean of (831.38), these values is within the V.R(Yemen) (750-3500) and the V.R(WHO) (750-2500).

Table (2): showing the (mean, Min, Max) for PH checks in the water of stations and wells.

	Mean	Minimum	Maximum
Wellwater	7.4820	7.03	8.41
Stationwater	7.4525	6.82	8.09
V.R(YEMEN)	6.9 – 9.2		
V.R(WHO)	6.5 – 8.5		

The table (2) show that the maximum and minimum valuesfor the results of the (PH) test for well water are (7.03 – 8.41), with Mean of(7.482),these values is within the V.R(Yemen) and V.R (WHO),while the maximum and minimum values for the results of the (PH) test for station water are (6.82 – 8.09) with Mean of (7.4525), these values is with in theV.R(Yemen)(6.9-9.2)andtheV.R(WHO)(6.5- 8.5).

Table(3):showingthe(mean,Min,Max)forTotalalkalinitychecksinthewaterofstations and wells.

	Mean	Minimum	Maximum
Wellwater	179.000	114.8	242.4
Stationwater	288.050	160.0	709.0
V.R(YEMEN)	200Max		
V.R(WHO)	200Max		

The table (3) show that the maximum and minimum valuesfor the results of the Total alkalinity test for well water are (114.8–242.4),with Meanof(179.00),thesevaluesiswithintheV.R(Yemen)and V.R(WHO), while the maximum and minimum values for the resultsoftheTotalalkalinitytestforstationwaterare(160.0–709.0)withMean of(288.050),these values is bigger than V.R(Yemen)(200) and the V.R(WHO) (200).

Table (4): showing the (mean, Min, Max) for PH alkalinity$CaCO_3$checks in the water of stations and wells.

	Mean	Minimum	Maximum
Well water	0.6	0	6
Station water	46.50	0	372
V.R(YEMEN)	-		
V.R(WHO)	-		

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The table (4) show that the maximum and minimum values for the results of the PH alkalinity $CaCO_3$test for well water are (0 – 6),with Mean of (0.6), while the maximum and minimum values for the results of the Total alkalinity test for station water are (0– 372) with Mean of (46.50).

Table (5): showing the (mean, Min, Max) for Total Hardness $CaCO_3$ checks in the water of stations and wells.

	Mean	Minimum	Maximum
Wellwater	247.640	39.2	368.0
Stationwater	255.325	83.0	440.0
V.R(YEMEN)	100-500		
V.R(WHO)	100-500		

The table (5) show that the maximum and minimum valuesfor the results of the Total Hardness $CaCO_3$test for well water are (39.2 –368.0), with Mean of (247.640), these values is within the V.R(Yemen)and V.R(WHO), while the maximum and minimum values for the resultsof the Total Hardness $CaCO_3$test for station water are (83.0 – 440.0) withMean of (255.325), these values is within the V.R(Yemen) (100-500) andthe V.R(WHO) (100-500).

Table (6): showing the (mean, Min, Max) for Calcium (Ca) checks in the water ofstationsand wells.

	Mean	Minimum	Maximum
Wellwater	71.6960	10.24	112.00
Stationwater	54.8600	4.36	91.00
V.R(YEMEN)	75 – 200		
V.R(WHO)	75 -200		

The table (6) show that the maximum and minimum values for the results of the Calcium(Ca) test for well water are (10.24 – 112.0),with Mean of (71.696), these values is lees than the V.R(Yemen) andV.R(WHO), while the maximum and minimum values for the results ofthe Calcium(Ca) test for station water are (4.36 – 91.0) with Mean of(54.86),thesevaluesislessthantheV.R(Yemen)(75-200)andtheV.R(WHO) (75-200).

Table (7): showing the (mean, Min, Max) for Chloride (Cl) checks in the water of stations and wells.

	Mean	Minimum	Maximum
Well water	69.082	27,39	163,56
Station water	57.696	15.43	205.00
V.R(YEMEN)	200-400		
V.R(WHO)	200-250		

The table (7) show that the maximum and minimum valuesfor the results of the Chloride(Cl)test for well water are (27.39 – 163.56),with Mean of (69.082), these values is less than the V.R(Yemen) andV.R(WHO), while the maximum and minimum values for the results ofthe Chloride(Cl) test for station water are (15.43 – 205.0) with Mean of(57.696), these values is less than the V.R(Yemen) (200-400) and theV.R(WHO) (200- 250).

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Table (8): showing the (mean, Min, Max) for Sulfate (SO_4) checks in the water ofstationsand wells.

	Mean	Minimum	Maximum
Wellwater	93.35	49	153
Stationwater	96.25	50	179
V.R(YEMEN)	150-500		
V.R(WHO)	150-400		

The table (8) show that the maximum and minimum valuesfor the results of the Sulfate (SO_4) test for well water are (49 – 153), withMeanof(93.35),thesevaluesislessthantheV.R(Yemen)andV.R(WHO), while the maximum and minimum values for the results ofthe Sulfate (SO_4) test for station waterare (50– 179) with Meanof(96.25), these values is less than the V.R(Yemen) (150 - 500) and theV.R(WHO) (150- 400).

Table (9): showing the (mean, Min, Max) for Nitrate (NO_3) checks in the water ofstationsand wells.

	Mean	Minimum	Maximum
Wellwater	7.0840	1.76	18.04
Stationwater	3.0117	0.01	5
V.R(YEMEN)	50Max		
V.R(WHO)	50Max		

The table (9) show that the maximum and minimum valuesfor the results of Nitrate (NO_3) test for well water are (1.76 – 18.04), withMeanof(7.084),thesevaluesisleesthantheV.R(Yemen)andV.R(WHO), while the maximum and minimum values for the results oftheNitrate(NO_3)testforstationwaterare(0.01–5)withMeanof(3.0117), these values is lees than the V.R(Yemen) (50 Max) and theV.R(WHO) (50Max).

Table(10): showing the(mean, Min, Max) for Sodium (Na) checks in the water ofstationsand wells.

	Mean	Minimum	Maximum
Wellwater	55.320	36.10	76.00
Stationwater	76.6613	1.99	358.00
V.R(YEMEN)	200 -400		
V.R(WHO)	200Max		

The table (10) show that the maximum and minimum values for the results of Sodium (Na) test for well water are (36.10 –76.00), with Mean of (55.32), these values is lees than the V.R(Yemen)and V.R(WHO), while the maximum and minimum values for the resultsof the Sodium (Na) test for station water are (1.99 - 358) with Mean of(76.6613), these values is lees than the V.R(Yemen) (50 Max) and theV.R(WHO) (200Max).

Table (11): showing the (mean, Min, Max) for Potassium (K) checks in the waterofstations and wells.

	Mean	Minimum	Maximum
Wellwater	3.0450	1.58	7.00
Stationwater	4.8338	0.15	17.00
V.R(YEMEN)	8 -12		
V.R(WHO)	8 – 12		

The table (11) and figure (11) show that the maximum and minimumvalues for the results of Potassium (K) test for well water are (1.58 –7.00), with Mean of (3.0450), these values is lees than the V.R(Yemen)and V.R(WHO), while the

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maximum and minimum values for the resultsof the Potassium (K) test for station water are (0.15 – 17.0) with Mean of(4.8338), these values is lees than the V.R(Yemen) (8- 12) andtheV.R(WHO) (8-12).

Table (12): showing the(mean, Min, Max) for Iron (Fe) checks in the water ofstationsand wells.

	Mean	Minimum	Maximum
Wellwater	0.166	0.03	0.50
Stationwater	1.3488	0.02	8.80
V.R(YEMEN)	0.3 -1		
V.R(WHO)	0.3Max		

The table (12)show that the maximum and minimumvalues for the results of Iron (Fe) test for well water are (0.03–0.50),with Mean of (0.166), these values is lees than the V.R(Yemen) andV.R(WHO), while the maximum and minimum values for the results oftheIron(Fe)testforstationwaterare(0.02–8.80)withMeanof(1.3488), these values is lees than the V.R(Yemen) (0.3- 1) and theV.R(WHO) (0.3Max).

Table (13): showing the(mean, Min, Max) for Fluoride (F) checks in the water ofstationsand wells.

	Mean	Minimum	Maximum
Wellwater	0.5450	0.27	1.12
Stationwater	0.9238	0.32	1.98
V.R(YEMEN)	1.2 – 1.4		
V.R(WHO)	1.2 – 1.5		

The table (13) show that the maximum and minimumvalues for the results of Iron (Fe) test for well water are (0.27–1.12),with Mean of (0.545), these values is lees than the V.R(Yemen) andV.R(WHO), while the maximum and minimum values for the results ofthe Fluoride (F) test for station water are (0.32 – 1.98) with Mean of(0.9238), these values is lees than the V.R(Yemen) (1.2 – 1.4) and theV.R(WHO) (1.2– 1.5).

The biological properties result

Twopotentialtypesofwatercontaminationmicrobiologicalandbacteriological,thedecisionwasmadetolimitthestudytotheinvestigation of the presence of total coliform and *Escherichia coliform* inorder to evaluate the quality of drinking water in Sana'a city. This isimportant indicator of whether or not is safe to drink and use for domesticpurpose.Samples from wells and stations were collected carefully and tested. Allsamples were free from total coliform or Escherichia coliform.

Discussion

The results of physical elements analysis show that all the samples weresafefordrink and use fordomesticpurpose becausetheenvironmentof watersourcesareclean and free from any pollution, While the mean of water PH in wellsand stations is (7.5), total dissolved solid, total hardness-$CaCO_3$are (247,255) and total alkalinity are (179,288) are within the acceptableWHOandYemenstanders,themeanvaluesofsomechemicalelementsin water from wells and stations such as Na (55 & 77), K (3 & 5), Ca(72&55),SO_4(93&96),NO_3(7&3)Fe(0.2&1.3),Cl(69&58) and F (0.5 & 0.9) show a low concentrations compared to WHO orYemen specifications, this means that sampling and testing water is goodqualityandsuitabledrink and use fordomesticpurpose theresultsofchemicalparametersanalysisindicatethatallthecollectingwatersamplesarerequesteddepending to local (Yemen) or international (WHO)specifications, thevalues of purposes, also samples from wells and stations were collectedcarefully and microbiological tested, the outcome was that all sampleswere free from total coliform or Escherichia coliform. This mean that thewater in Sana'a city no contaminated and is safe to drink and use fordomesticpurpose

Conclusions:

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The water quality in Sana'a city generally meets both the World HealthOrganization (WHO) and local Yemeni standards. The physical analysis of the water samples collected from various wells and stations showed no changes in their physical properties, indicating stable water quality. The chemical analysis results demonstrated that the concentrations of key chemical elements in the water were within or below the prescribed limits of WHO and Yemeni standards, ensuring the water is not chemically hazardous. Additionally, the biological analysis confirmed the absence of microbial or bacterial contamination. The lack of colonies on MF agar after incubation further supported the finding that the water samples were free from total coliform and E. coli, indicating the drinking water is microbiologically safe for drink and use for domestic purpose.

Based on these findings, it can be concluded that the water from the wells and stations studied is of good quality and suitable for drink and use for domestic purpose. The water samples tested across different distribution systems showed that both the physicochemical and microbiological parameters were within acceptable limits, further confirming the water's suitability for drink and use for domestic purpose.

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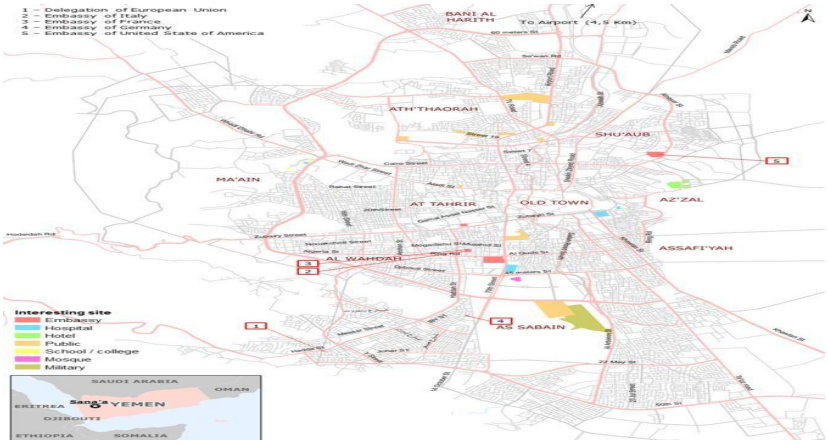

Fig.(1)Geographical Location of Sana'a City Location Map of the Sana'a City

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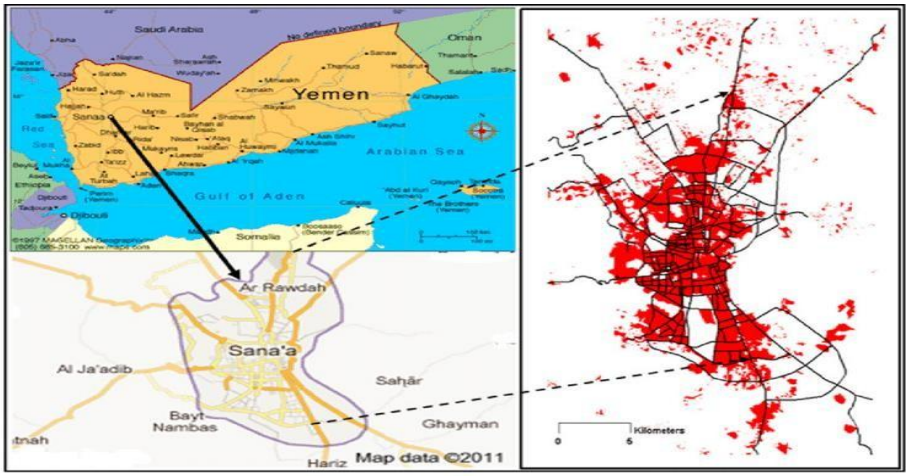

Fig(2) Location Map of the Sana'a City