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Physicochemical and Microbiological Investigation of Groundwater in Al-Salman District, Southern Iraq

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Abstract

Background: In many of southern Iraq's rural and semi-arid areas, groundwater serves as the primary supply of drinking and household water. The study's objective is to provide a thorough assessment of the water safety for human consumption by evaluating the physicochemical and biological quality of groundwater in the Al-Salman district of Iraq by identifying bacterial contaminants, analyzing their antibiotic resistance, and measuring important chemical parameters. Material and methods. In the spring of 2024, groundwater samples were taken from two sites in the Al-Salman district using sterile bottles. Standard analytical techniques were used to determine physicochemical parameters, including pH, temperature, electrical conductivity (EC), total dissolved solids (TDS), alkalinity, nitrate, nitrite, sodium, potassium, and phosphorus. Samples were enriched in Brain Heart Infusion (BHI) broth and incubated for 24 hours at 37 °C before being subcultured on MacConkey agar, blood agar, and Mannitol salt agar for bacteriological examination. Biochemical assays and colony morphology were used to identify the bacterial isolates. The Kirby-Bauer disk diffusion method was used to test for antibiotic susceptibility against a variety of antibiotics in accordance with CLSI standards. Results: According to the physicochemical investigation, the groundwater had a nearly neutral pH ranging from 7.00 to 7.10 and relatively high temperatures between 30 and 33 °C, which may promote microbial growth. Electrical conductivity (EC) and total dissolved solids (TDS) were very high, indicating a large amount of salt and minerals in the water. Alkalinity (ALK) was within permissible limits at less than 250 mg/L. Nitrate (NO_3^-) levels exceeded the allowable limit of 50 mg/L, while nitrite (NO_2^-) remained within the safe range around 50 mg/L. Potassium (K^+) concentrations were higher than the recommended limit of 10–15 mg/L, and sodium (Na^+) was also elevated above 250 mg/L, whereas phosphorus (P) was within acceptable levels around 0.4 mg/. The biological analysis showed several pathogenic bacteria were isolated, including *Escherichia coli*, *Staphylococcus aureus*, *Klebsiella pneumoniae*, *Staphylococcus epidermidis*, *Proteus vulgaris*, *Enterobacter* spp., and *Pseudomonas aeruginosa*, many of which exhibited multidrug resistance. However, antibiotics such as meropenem, gentamicin, amikacin, and netilmicin showed the highest effectiveness against most isolates. Conclusion: The investigated groundwater samples showed evidence of physicochemical and microbiological contamination, suggesting potential risks for direct human consumption without adequate treatment.

Keywords: Bacteria, Physicochemical, Antibiotic susceptibility, Groundwater.

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1. Introduction

According to the United Nations Office for (GAR Special Report, 2023), the availability of clean and safe water is crucial for human health. The supply of clean drinking water is severely strained in developing nations due to industrialization, animal husbandry, and population growth (Akoachere et al., 2013). Microbiologically polluted water is a possible source of intestinal infections in humans and is a sign of inadequate upkeep of the infrastructure connected to cleanliness and issues with the application of control measures (Sitotaw et al., 2021). Surface water and groundwater, both renewable and non-renewable, are being heavily exploited worldwide due to the expanding demands brought on by population increase, fast urbanization, and the expansion of economic activity, especially agriculture and industry (Harrat & Achour, 2010).

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In addition, the pollution with copper oxide can cause damage to the organs (Haleem & Khaleel, 2020). With 70% of the demand coming from agriculture, this industry continues to be the most water-intensive. 93% of total water use, mostly in developing nations, is attributed to this sector's high rate of demand. Groundwater will become more susceptible to pollution as a result of agricultural practitioners' use of surface water and precipitation, as well as their withdrawals from subsurface resources (Baechler, 2013; Yapo et al., 2016). These surface groundwater bodies are frequently impacted by diffuse contamination, mainly bacterial pollution from feces, followed by pollution from agricultural practices, especially nitrates and pesticides, or localized pollution from industrial or unintentional sources (HANANOU, 2025). These resources are unfit for ingestion once they get contaminated. The WHO estimates that 4.2 billion people lack proper sanitation and that at least 2 billion people use drinking water sources tainted by feces (Abdoulaye et al., 2024) water contamination with various elements and pollutants, including the monosodium glutamate industry, with potential adverse effects on animal reproductive tissues, as demonstrated in experimental studies (Abduljaleel & Ali, 2022; Khaleel et al., 2025). In addition, the pollution occurs from the plants that contain the damaged chemicals (Majeed et al., 2025). Antibiotics and antibiotic-resistant microorganisms in drinking water pose a serious threat to human health (Mirani & Naz, 2018). Nowadays, it is commonly acknowledged that antimicrobial resistance poses a hazard to global public health and calls for multisectoral preventative and mitigating measures (Larsson et al., 2018). Significant selective pressures have been added to the naturally occurring resistance within and between bacterial species as a result of anthropogenic effects and behaviours, such as the abuse or overuse of human and veterinary antimicrobials (Van Boeckel et al., 2014). As a result, bacterial isolates, including clinically important species like *Pseudomonas aeruginosa*, *Staphylococcus aureus*, and *Enterobacteriaceae* spp., have been found to exhibit a global increase in acquired resistance characteristics (Andrade et al., 2020). Although groundwater is a major source of drinking water in many areas of southern Iraq, including the Al-Salman district, there is a lack of recent and integrated studies that combine physicochemical analysis with bacteriological investigation and antibiotic resistance profiling. Therefore, there is insufficient information on the potential public health risks associated with antibiotic-resistant bacteria in the groundwater resources of Al-Salman district, which necessitates a comprehensive and multidisciplinary investigation. The study Hypotheses are that the groundwater in the Al-Salman district is contaminated with potentially pathogenic bacteria and the bacterial isolates from groundwater exhibit varying degrees of resistance to commonly used antibiotics. Physicochemical characteristics of groundwater significantly influence the presence and distribution of bacterial contamination. The present study aimed to evaluate the biological and physicochemical quality of groundwater in the Al-Salman district, south of Iraq. Specifically, it seeks to assess the main physicochemical parameters of groundwater and compare them with international drinking water standards, particularly those recommended by the limited Iraqi standard as well as isolate and identify bacterial contaminants present in groundwater samples and determine their antibiotic susceptibility patterns. Furthermore, it intends to investigate the potential relationship between physicochemical characteristics and bacterial contamination levels, in order to provide a comprehensive assessment of groundwater safety and its suitability for human consumption.

The novelty of this study lies in the integrated assessment of groundwater quality in the Al-Salman district through the simultaneous evaluation of physicochemical characteristics, bacteriological contamination, and antimicrobial resistance profiles of isolated bacteria. Unlike previous studies conducted in southern Iraq, which mainly focused on either water chemistry or microbial contamination separately, the present investigation combines both approaches and provides updated evidence regarding the occurrence of multidrug-resistant bacterial species in groundwater used for human consumption.

This study provides one of the few integrated assessments of groundwater quality in the Al-Salman district by simultaneously evaluating physicochemical characteristics, bacterial contamination, and antimicrobial resistance profiles. Unlike previous investigations that focused primarily on either water chemistry or microbiological contamination separately, the present work combines both aspects to provide a more comprehensive evaluation of groundwater safety and potential public health risks in a region where groundwater represents an important water resource.

2. Methods

2.1. Samples Collection and Studied Areas

Groundwater samples were collected from the Al-Salman district, which encompasses an area of 9,484 km² located southwest of Al-Samawa city and the Euphrates River in Al-Muthanna Province, Iraq. The geographical coordinates range from E44°1'20" to E45°15'25" longitude and N30°1'50" to N31°15'51" latitude. Sampling occurred during the spring of 2024 from two locations within the Al-Salman district center. Groundwater samples were collected from a depth ranging between 20 and 30 meters below the ground surface using bore wells available at the selected locations. Prior to sampling, each well was purged for several minutes to remove stagnant water and ensure that the collected samples were representative of the aquifer. Groundwater samples were obtained using two distinct sterilized bottles: a 1-liter bottle for chemical parameters and a 100-milliliter bottle for bacteriological parameters, from each area in the designated locations, as in Figure 1.

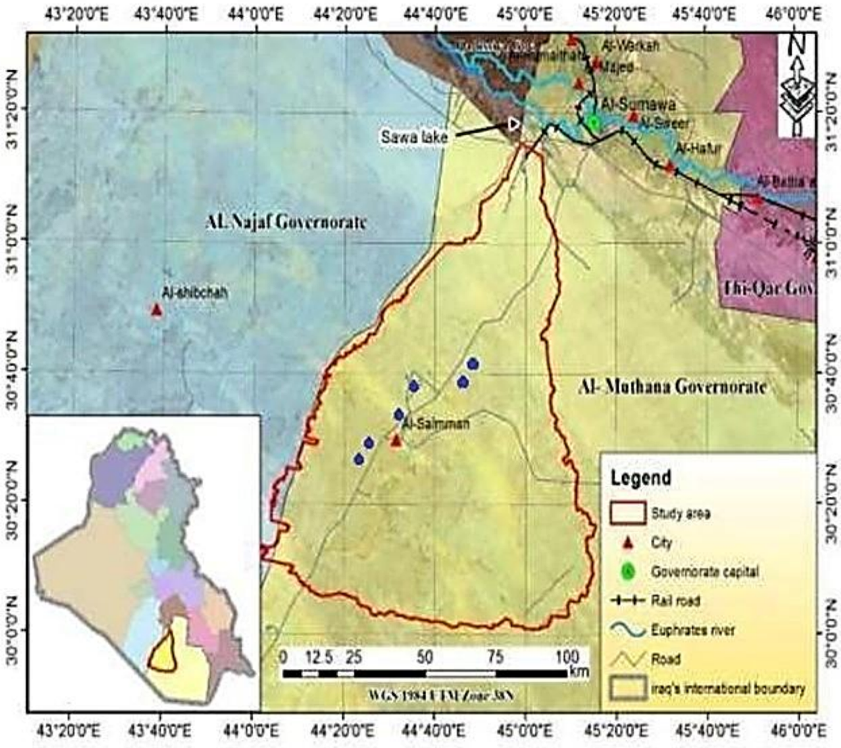

Fig.1. The studied areas in AL-Salman district (Blue Marks) (Mazeel Abed et al., 2020)

2.2. Physiochemical Parameters

The pH was measured using an automated pH meter.

Temperature: The groundwater temperature was determined using a mercury thermometer. A 1.0 automated conductivity meter was used to measure Electrical Conductivity (EC) and Total Dissolved Solids (TDS). The electrode was immersed in the water sample in the plastic bottle after being cleaned with distilled water. The sample's conductivity was measured in µS/cm. Selecting the TDS option when the electrode was immersed in the water sample allowed for the measurement of the TDS, which was then recorded (Maiti, 2003).

T.D.S (mg/L) = (A – B) ×106 / volume of sample (ml)

2.3. The Chemical Properties

Alkalinity: Followed the procedure (APHA, 1992).

Nitrate (NO3): Followed the procedure (Parson *et al.*,1984).

Nitrite (NO2): Followed the procedure (APHA, 1992).

Sulphate (SO4: Followed the procedure (APHA, 2003).

Sodium (Na) and Potassium (K): Potassium is detected via flame photometry. A flame photometer with a wavelength of 766.5 nm was used to determine the trace content of potassium (Ayers & Westcot, 1985).

Phosphorus (P) was determined by spectrophotometric detection of the brightly colored phosphomolybdenum blue (PMB). Phosphate and acidified molybdate reacted to produce 12-molybdophosphoric acid (12-MPA), which was then reduced to phosphomolybdenum blue (McKelvie et al., 1995).

Operational definitions of the measured variables were established according to standard water quality assessment protocols. pH was measured using a calibrated digital pH meter and expressed as dimensionless units. Electrical conductivity (EC) was recorded in µS/cm using a conductivity meter, while total dissolved solids (TDS) were expressed in mg/L. Alkalinity, nitrate, nitrite, sodium, potassium, and phosphorus concentrations were measured according to APHA standard methods and expressed as mg/L. Bacterial contamination was assessed through isolation and identification of bacterial species using standard microbiological procedures, and antibiotic susceptibility was evaluated according to CLSI guidelines using the Kirby–Bauer disk diffusion method.

2.4. The Bacteriological Parameters

Isolation, Identification of Bacteria, and Susceptibility Testing

Following a 24-hour incubation period at 37 °C, samples were inoculated into Brain Heart Infusion (BHI) broth, and the cultures were subsequently subculture onto blood agar MacConkey agar and Mannitol salt agar. The bacterial isolates were analyzed for colony morphology and biochemical tests were carried out for identification in accordance with standard microbiological procedures as oxidase, catalase, novobiocin, and IMVIC test (Giuliano et al., 2019). and Antibiotic susceptibility testing was performed using the Kirby–Bauer disk diffusion method in accordance with CLSI guidelines NET (Netilmicin), OF (Ofloxacin), SXT (Trimethoprim–Sulfamethoxazole), MEM (Meropenem), C (Chloramphenicol), CIP (Ciprofloxacin), LE (Levofloxacin), AK (Amikacin), TOB (Tobramycin), NOR (Norfloxacin), TE (Tetracycline), CXM (Cefuroxime), CPM (Cefepime), FOX (Cefoxitin), AMC (Amoxicillin–Clavulanic acid), AMP (Ampicillin), FF (Florfenicol), CTR (Ceftriaxone), CTX (Cefotaxime), CPD (Cefpodoxime), NA (Nalidixic acid), CN (Gentamicin), IMI (Imipenem), VA (Vancomycin), R (Rifampicin), LZ (Linezolid), DA (Clindamycin), E (Erythromycin), AZM (Azithromycin), F (Nitrofurantoin), PG (Penicillin G).

2.5. Quality Control and Bias Minimization

To minimize potential researcher bias, all physicochemical analyses were conducted according to standardized APHA protocols, while bacterial identification and antibiotic susceptibility testing followed internationally accepted microbiological and CLSI procedures. Laboratory measurements were performed using calibrated instruments and standardized operating procedures to ensure consistency and reproducibility. In addition, all observations and laboratory records were verified prior to statistical analysis to minimize potential recording errors. Prior to statistical analysis, all measurements were reviewed for completeness and consistency. The dataset was screened for potential data-entry errors and extreme values. No missing observations were detected; therefore, no imputation procedures were required. Descriptive statistics and Pearson correlation analyses were subsequently performed using SPSS software (Version 7.5).

2.6. Statically analytics

Statistical analysis was performed using SPSS software (Version 7.5). Descriptive statistics were used to summarize the physicochemical and microbiological characteristics of the groundwater samples. Pearson correlation coefficients (r) were calculated to evaluate the relationships among the measured physicochemical parameters. Correlation analyses were performed using all individual replicate measurements collected for each parameter rather than site averages. Statistical results were interpreted at a significance level of $P < 0.05$.

3. Results and Discussion

Table (1) of the data's physiochemical characteristics revealed that the areas' water pH ranged from 7 to 7.10, falling between Iraqi drinking water standards of 6.5 and 8.5 (417 second update). which concurred with research conducted at the same site by (Mazeel Abed et al., 2020). According to (Hussain et al., 2022), springtime temperatures varied from 30 to 33 degrees Celsius, which has promoted the growth of microorganisms and may have a negative effect on water quality, aggravating problems associated with microbial development. Additionally, the Electric Conductivity (EC) measured between 7100 and 7158 µs/cm, which is consistent with the findings of the study (Abbas & Ali, 2020). The suggested value of 100 mg/L for electrical conductivity in Iraqi drinking water was greatly exceeded by the TDS measurements, which varied from 1700 to 2000 mg/l.

Table 1. Physiochemical parameter of studied area

Locations	pH	Temp	EC	TDS
Area1	7	30	7100	1700
Area2	7.10	33	7158	2000
Acceptable limits	6.5 to 8.5	50 mg/L	1000µs/cm	100 /L

3.1. The Alkalinity (ALK)

According to the alkalinity data, every sample was below Iraq's allowable drinking water level of 250 mg/L. The reaction of carbonic acid with calcite and magnesium calcite is the main cause of groundwater alkalinity (Jaafer & Al-Saffawi, 2020).

3.2. Nitrate (NO3)

The nitrate levels in each area over permissible limits range of 50 mg/L, which is thought to be appropriate for Iraqi water. There is a great deal of variation because most of the areas are farmed. As a result, human consumption affects the quantity of nitrates that leak into groundwater from fertilizer applications. Numerous studies have connected drinking water with high nitrate levels to colon cancer, thyroid disease, breast cancer, and bladder cancer (Ward et al., 2018; Abed et al., 2020).

3.3. Nitrite (NO2)

The nitrite concentration was 50 mg/L, which is below the allowable limits for Iraqi waters, as in table (2) according to (Al-Paruany et al., 2016). Across all areas and seasons, this concentration was low. Nitrate and nitrite are naturally occurring byproducts of microbial nitrogen oxidation in plants, soil, and water; the concentrations in the studied areas were higher than in others. The rapid spread of germs and the increased use of synthetic fertilizers in these areas are the causes of this (TANUJA, 2012).

3.4. Potassium(K)

Furthermore, every studied area had a potassium concentration that was far higher than the typical Iraqi drink restrictions, as shown in Table 2. Perhaps the cause is the particular stone used in some areas and the plant nutrients (Hansen et al., 2017). Consuming potassium may result in an excess of the mineral in the blood, which can lead to discomfort, nausea, poor urine development, and even a decreased risk of cardiac arrest, even though it is essential for healthy growth and muscular development (Pohl et al., 2013).

3.5. Sodium (Na)

The concentration of sodium (Na), which is necessary for regular biosynthetic activity, such as nerve pulse propagation, muscular contraction and flow control was higher than the standard value of Iraqi drink water (250 mg/L), as in table (2) .On the other hand, excessive sodium consumption can result in sodium hypernatremia, which reduces urine production and produces edema (Pohl et al., 2013).

3.6. Phosphorus (P)

This was agreed with (Abbas and Ali,2020) the Phosphorus concentration was within acceptable limits for Iraqi waters (0.4 mg/L this Phosphorus presence in groundwater was attributed to overuse of fertilizers (Khan et al., 2017).

3.7. Correlation between parameter

The correlation matrix shows as in table (3) that pH exhibits weak positive correlations with all measured parameters, ranging from 0.109 to 0.502. Temperature displays positive correlations with the other variables, with particularly high values observed with EC (0.962) and TDS (0.994). Total hardness (TH) shows moderate positive correlations with temperature (0.517), EC (0.545), TDS (0.426), phosphate (0.511), and nitrite (0.539). EC is strongly correlated with temperature (0.962) and TDS (0.993) and moderately correlated with TH (0.545). TDS has very high correlations with temperature (0.994) and EC (0.993), and moderate correlations with TH (0.426) and potassium (0.839). Sodium shows positive correlations with all parameters, reaching higher values with potassium (0.312), phosphate (0.888), and nitrate (0.880). Potassium shows strong correlations with EC (0.801), TDS (0.839), and phosphate (0.976). Phosphate is correlated with sodium (0.888), potassium (0.976), and nitrate (0.746). Alkalinity exhibits low to moderate correlations with the rest of the variables. Nitrate shows positive correlations with temperature (0.511), EC (0.709), TDS (0.701), sodium (0.880), and potassium (0.746). Nitrite displays moderate correlations with TH (0.539) and pH (0.407), while correlations with the remaining parameters are relatively low.

Table 2. The chemical parameters of the area studied

Parameters	ALK	NO3	NO2	K	Na	P
Area1	115	56.05	0.01	49	600	0.3
Area2	104	52	0.02	22	634	0.1
Acceptable limits	250 mg/L	50 mg/L	50 mg/L	10-15 mg/L	250 mg/L	0.4 mg/L

Table 3. The correlation between the parameter

Parameters	pH	Temp	TH	EC	TSD	Na	K	P	Alk	NO3	NO2
pH	1										
Temp	0.113	1									
TH	0.401	0.517	1								
EC	0.109	0.962**	0.545	1							
TSD	0.160	0.994**	0.426	0.993**	1						
Na	0.390	0.565	0.387	0.606	0.601	1					
K	0.290	0.705	0.214	0.801	0.839*	0.312	1				
P	0.502	0.462	0.511	0.113	0.2	0.888*	0.976**	1			
Alk	0.409	0.263	0.217	0.505	0.489	0.511	0.3	a	1		
NO3	0.334	0.511	0.208	0.709	0.701	0.880*	0.746	a	0.357	1	
NO2	0.407	0.501	0.539	0.441	0.412	0.123	0.177	a	0.337	0.289	1

**Correlation is significant at the 00.01 level (2-tailed). .* Correlation is significant at the 00.05 level (2-tailed).

3.8. *Bacteriological study*

The bacteriological analysis of groundwater samples from the Al-Salman district revealed the presence of several potentially pathogenic bacterial species. The isolated bacteria included *E.coli*, *S. aureus*, *K. pneumoniae*, *S. epidermidis*, *P. vulgaris*, *Enterobacter* spp., and *P. aeruginosa*.

Antimicrobial susceptibility testing showed variable resistance patterns among the isolated bacteria *E.a coli* exhibited 100% resistance to C, CIP, LE, TE, CXM, CPM, AMC, AMP, FF, CTX, and CPD, while showing 0% resistance to Net, OF, SXT, MEM, AK, TOB, NOR, FOX, CTR, NA, and CN. *S. aureus* demonstrated 100% resistance to SXT, DA, TE, E, NOR, AZM, and PG, 100% resistance to CIP, and 0% resistance to LE, CN, IMI, VA, R, C, and F. *K. pneumoniae* showed 100% resistance to SXT, C, NOR, CXM, CPM, FOX, AMC, AMP, FF, CTX, and CPD, 50% resistance to CTR, and 0% resistance to Net, OF, MEM, CIP, LE, AK, TOB, TE, NA, and CN. *S. epidermidis* revealed 100% resistance to TE, E, NOR, AZM, and PG, with 0% resistance to LE, CN, IMI, VA, R, C, LZ, SXT, DA, CIP, and F. *P. vulgaris* exhibited 100% resistance to OF, SXT, C, CIP, NOR, CPM, FOX, AMC, AMP, FF, CTR, and CTX, while 0% resistance was observed for Net, MEM, LE, AK, TOB, TE, CXM, CPD, NA, and CN. *Enterobacter* spp. showed 100% resistance to SXT, C, CIP, AK, TOB, NOR, TE, CXM, CPM, AMC, AMP, FF, CTR, CTX, NA, and CN, with 0% resistance to Net, OF, MEM, LE, FOX, and CPD. *P.aeruginosa* demonstrated 100% resistance to Net, OF, C, CIP, LE, AK, TOB, CPM, FOX, AMC, AMP, and FF, while 0% resistance was recorded for SXT, MEM, NOR, TE, CXM, CTR, CTX, CPD, NA, and CN.

According to (Galketiyahewage et al., 2021), More than 80% of analyzed groundwater samples from both study regions had coliform counts higher than those allowed by Sri Lanka Standards (SLS) and WHO recommendations. Wilgamuwa and Minipe samples had average total coliform levels of 19.3 and 16.7 CFU/100 mL, respectively, and average fecal coliform counts of 5.2 and 5.0 CFU/100 mL. *E. coli*, *Klebsiella* sp., and *Enterobacter* sp and Yersinia sp. were found among 120 isolates, which is in line with what (Tzimotoudis et al., 2025) found. For 220 *E. Coli* isolates, the phylogroup assignment was A 18.6%. Enterobacter, Citrobacter, Klebsiella, and Serratia were the genera assigned to the 138 coliform isolates that were not *E. coli*. The majority of *E. Coli* isolates were resistant to ampicillin (16.4%, 36 of 220) and tetracycline (9.5%, 21 of 220), according to AST. The proportion of E. Coli isolates that showed resistance to the remaining antibiotics in the investigation varied from 0.5% (cefotaxime) to 4.1% (cefadroxil, cefoxitin, and trimethoprim/sulfamethoxazole). While the relevant percentages for the remaining antibiotics tested ranged from 83.6% (ampicillin) to 99.1% (cefotaxime), all tested E. coli isolates (100%) were susceptible to gentamicin and meropenem. However, the results corroborated those of (Osei et al., 2021), who examined the resistance pattern of bacterial isolates from drinking water utilized in Ghana's Ashanti region for chicken production. Of the bacterial isolates, *E. coli* (n = 31) exhibited high rates of resistance to cefpodoxime (93.6%) and cefoxitin, ampicillin cephalexin, and cephalothin (96.8%). Aztreonam (9.7%), ceftriaxone and gentamicin (6.5%), cefotaxime (25.8%), and sulphamethoxazole /trimethoprim (77.4%) showed lower levels of resistance. While all isolates were susceptible to norfloxacin, tobramycin,and ciprofloxacin, just one isolate (3.2%) was resistant to chloramphenicol and ceftazidime. Every *S. aureus* isolate exhibited 100% resistance to cefoxitin, ceftriaxoneand cephalexin, as well as high resistance to doxycycline ,erythromycin and sulphamethoxazole/ trimethoprim. Resistance to chloramphenicol , tobramycin and tetracycline was noted. All isolates were **susceptible to ciprofloxacin and** norfloxacin. Among Coagulase-Negative Staphylococci were resistant to sulphamethoxazole/trimethoprim, cephalothin, ceftriaxone, cefoxitin, erythromycin, doxycycline, chloramphenicol, and tetracycline was observed.

According to (Karungamye et al., 2023), bacteria exhibit patterns of antibiotic resistance. Klebsiella ssp. was the most often found isolate from wastewater, with a prevalence of 39.3%, followed by E. coli (27.9%) and Pseudomonas ssp. (18.0%). Pseudomonas species were more resistant to Ceftriaxone and Azithromycin than Klebsiella species were to Tetracycline, Gentamycin, Sulfamethoxazole and Ciprofloxacin. More resistance genes were found in *Klebsiella* ssp. *Pseudomonas* ssp. and *E. coli*

Antimicrobial agent misuse or abuse in the environment is reflected in the isolates' comparatively high level of resistance to these agents (Abbar & Kaddar, 1991). In hospitals, prescriptions for antibiotics are written without sufficient medical care or obvious signs of infection. Superinfections and the emergence of drug-resistant mutants are risks associated with the use of broad-spectrum antibiotics, which are occasionally administered in place of narrow-spectrum antibiotics as a substitute for culture and sensitivity testing (Prescott et al., 2005). Additionally, the long-standing practice of using low doses of antibiotics for long periods of time for growth promotion and the arbitrary use of antibiotics in animal husbandry are significant contributors to the development of antibiotic-resistant bacteria in the environment (Ashang et al., 2017). Since drugs are accessible to the general public in developing countries, people may self-administer antibiotics, further increasing the prevalence of drug-resistant strains.

The occurrence of *E. coli*, *Klebsiella* spp., and *Enterobacter* spp. in the present study is consistent with findings reported by Galketiyahewage et al. (2021) and Osei et al. (2021), suggesting that members of the Enterobacteriaceae family are common indicators of groundwater contamination in different geographical regions.

While previous studies have independently examined either physicochemical groundwater quality or microbial contamination, the present study integrates both aspects and additionally evaluates antimicrobial resistance patterns among the isolated bacteria. This combined approach extends existing knowledge by providing a more comprehensive assessment of groundwater safety and potential public health risks in the Al-Salman district of southern Iraq. The findings therefore contribute valuable baseline data that may support future groundwater monitoring programs and public health protection strategies in the region. The findings of this study have important practical implications for local water management authorities and public health agencies.

Despite the comprehensive analysis conducted in this study, several limitations should be acknowledged. Groundwater sampling was restricted to two representative locations within the Al-Salman district due logistical and accessibility constraints; therefore, the findings should be considered a preliminary assessment and may not fully represent groundwater conditions throughout the entire district. In addition, sampling was conducted only during the spring season of 2024, and thus potential seasonal variations in groundwater quality were not evaluated. The study focused on selected physicochemical parameters and common bacterial pathogens, while other contaminants such as heavy metals, viral pathogens, and emerging pollutants were beyond its scope. Furthermore, although antibiotic susceptibility testing provided valuable information regarding resistance patterns, molecular characterization of antimicrobial resistance genes was not performed. Future studies should incorporate broader spatial and seasonal sampling together with molecular approaches to provide a more comprehensive understanding of groundwater quality and associated public health risks.

4. Conclusion

The present study provided an integrated assessment of the physicochemical and microbiological quality of groundwater in the Al-Salman district, southern Iraq. The results revealed variations in several physicochemical parameters, with some values exceeding recommended drinking water standards, indicating potential concerns regarding groundwater suitability for direct human consumption. Microbiological analyses demonstrated the presence of bacterial contamination, including potentially pathogenic species, highlighting possible public health risks associated with untreated groundwater use. Antibiotic susceptibility testing further revealed the occurrence of resistant bacterial isolates, emphasizing the growing environmental concern of antimicrobial resistance in groundwater resources. These findings support previous reports describing groundwater as a potential reservoir of antibiotic-resistant bacteria and underscore the importance of continuous monitoring of both water quality and microbial contamination. A major contribution of this study is the combined evaluation of physicochemical characteristics, bacterial contamination, and antimicrobial resistance patterns within a single framework. This integrated approach provides a more comprehensive understanding of groundwater safety than studies focusing solely on chemical or microbiological parameters. The generated data represent valuable baseline information for the Al-Salman district, where such investigations remain limited. From a practical perspective, the findings highlight the need for regular groundwater monitoring programs, appropriate water treatment measures, and effective environmental management strategies to reduce contamination risks and protect public health. Nevertheless, the results should be interpreted within the limitations of the study, particularly the restricted number of sampling locations and the absence of seasonal and molecular analyses. Future investigations should incorporate larger sampling networks, seasonal monitoring, and molecular characterization of resistance genes to improve understanding of groundwater quality dynamics and antimicrobial resistance dissemination in the region..

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