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The Effect of Climate on the Variation of Pathogenic Bacteria in the Waters of the Manathira River

Samer H. Kadhem Al-Jashaami[1], Safaa M. Almudhafar [2], Basim A. Almayahi[3]

Abstract

This study investigates the impact of climate on the variation of pathogenic bacteria in the Manathira River. A spatial and temporal analysis of bacterial populations in relation to environmental factors was conducted. The results highlight substantial spatial differences in bacterial counts, with elevated levels near urban and agricultural areas. Bacterial counts decrease with distance from these sources. Furthermore, a clear seasonal trend is observed, with higher counts during the spring and fall, likely due to climatic conditions favoring bacterial growth. Importantly, all identified bacterial species present health risks to humans, animals, and plants. This study underscores the importance of monitoring and managing bacterial contamination in the Manathira River to safeguard public and environmental health.

Keywords*: Waterborne pathogen, Climate change, Manathira River, Pathogenic bacteria Public health*

Introduction

Waterborne pathogens pose a significant threat to human and environmental health, and understanding the factors influencing their distribution and prevalence is of paramount importance. Among the various factors, climate plays a pivotal role in shaping the dynamics of pathogenic bacteria in aquatic ecosystems. The Manathira River, as a representative waterbody, has been subject to the influences of changing climate patterns, leading to fluctuations in water quality and pathogenic bacteria concentrations. This study delves into the intricate relationship between climate variations and the presence of pathogenic bacteria in the waters of the Manathira River, shedding light on the potential health risks associated with these changes.

Climate change has been linked to alterations in precipitation patterns, temperature regimes, and hydrological processes, all of which impact the hydrological cycles of rivers and can affect bacterial populations [1]. Additionally, anthropogenic activities, such as agricultural runoff and urbanization, can exacerbate the introduction of pathogenic bacteria into the river system [2]. The health consequences of exposure to such waterborne pathogens can range from gastrointestinal diseases to respiratory infections, making this an urgent area of research [3].

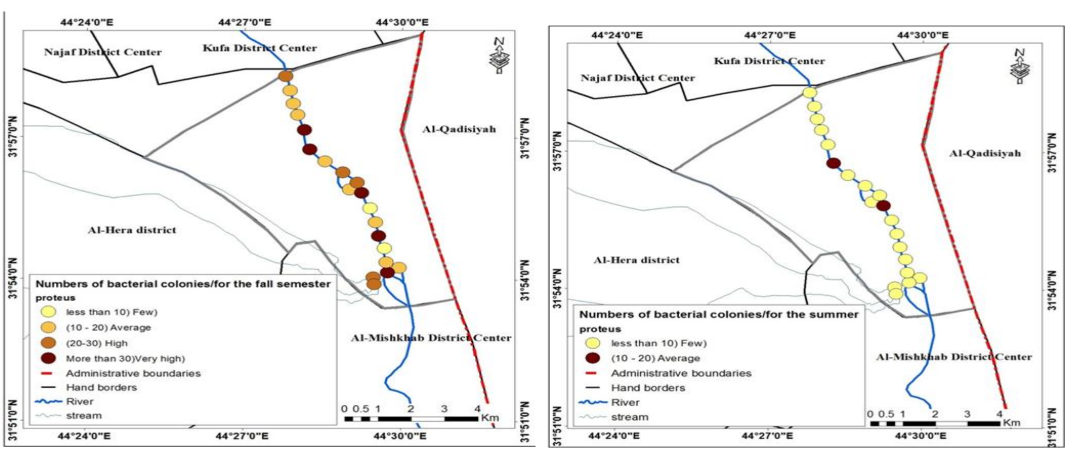
This study investigates the temporal and spatial distribution of pathogenic bacteria in the Manathira River under the influence of changing climatic conditions, with a focus on key factors contributing to their proliferation. The findings of this research will contribute to our understanding of the impact of climate on water quality and public health, with implications for policy and management strategies aimed at safeguarding the integrity of aquatic ecosystems and human well-being.

[1] Faculty of Physical Planning, Urban Planning Department, University of Kufa, Najaf, Iraq
[2] Department of Geography, Faculty of Arts, University of Kufa, Najaf, Iraq
[3] Department of Physics, Faculty of Science, University of Kufa, Najaf, Iraq, Corresponding Author: Email: basim.almayahi@uokufa.edu.iq

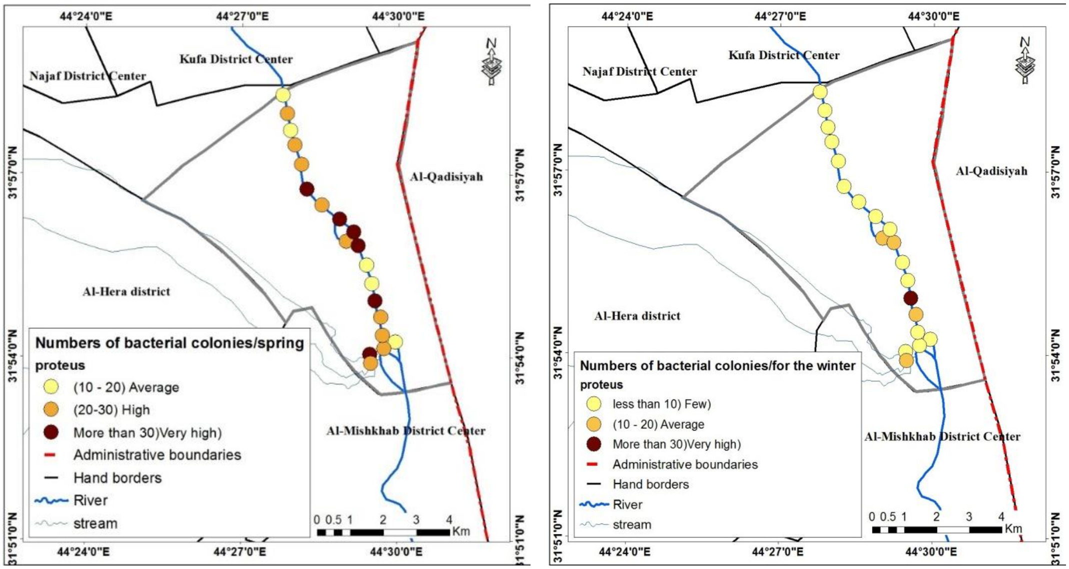
Bacteria Proteus

Proteus bacteria are Gram-negative rod-shaped bacteria that exist in various forms and are naturally present in the human intestine. They grow on solid surfaces in the form of thin membranous colonies with curled rings. They are known for their ability to break down proteins and release ammonia. Proteus bacteria are resistant to antibiotics and can cause several diseases in humans through contaminated food or direct contact with sources of pollution. These diseases include middle ear inflammation, wound infections, pressure sore ulcers, and urinary tract infections.

The data presented in Maps (1, 2) indicate spatial and temporal variations in the contamination of surface water with Proteus bacteria. This variation is observed both in different locations and throughout the seasons. For instance, in July, Maps (1, 2) reveals the distribution of this type of bacteria in two regions: "low" and "medium." The "low" region, shown in Maps (1, 2), includes the following locations: W1, W2, W3, W4, W5, W7, W8, W9, W10, W12, W13, W14, W15, W16, W17, W18, W19, and W20. The colony counts in these locations range from 2 to 9 colonies per 1 ml out of a total of 124 colonies in these sites. This lower count is attributed to high temperatures, increased evaporation rates, low humidity, and elevated salt concentrations, which create an environment unsuitable for bacterial growth. The spatial distribution of Proteus bacteria covers all parts of the study area, extending from the north to the south and from the east to the west. The "medium" region, represented in the eastern and western parts, includes two locations, W6 and W11. The colony counts in these locations range from 11 to 19 colonies per 1 ml. In the autumn season, the distribution of Proteus bacteria is categorized into four regions: "low," "medium," "high," and "very high." The "low" region includes two locations, W12 and W15, with nine colonies per 1 ml for each, out of a total of 246 colonies in these sites. This region is located in the southern part of the study area. The "medium" region encompasses six locations in the northern and southern parts, including W2, W3, W10, W13, W16, and W17, with colony counts ranging from 10 to 19 colonies per 1 ml. The "high" region appears in seven locations, including W1, W4, W7, W8, W9, W19, and W20, with colony counts ranging from 20 to 27 colonies per 1 ml. This region is spread across various parts of the area, including the north, west, and south. This analysis provides insights into the spatial and temporal variations in Proteus bacteria distribution in the waters of the Manathira River, offering valuable information for understanding water quality and potential health risks associated with these bacteria in the context of changing environmental conditions [4].



Map (1) for the Number of Colonies of Proteus for a. the Autumn Season, b. the Summer Season.

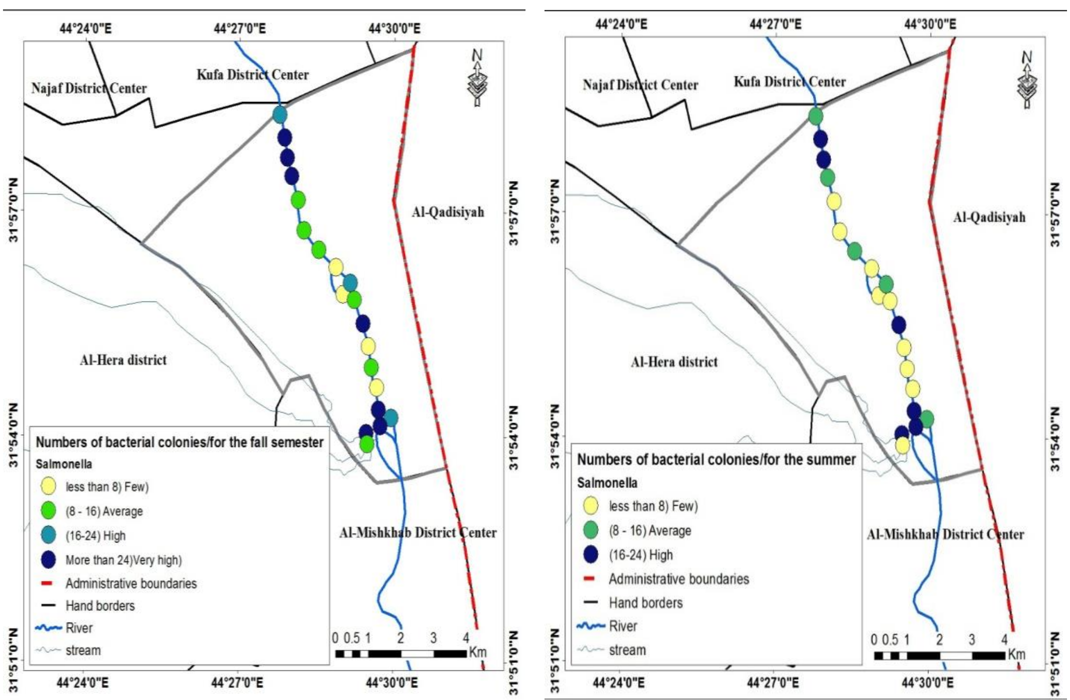


Map (2) For the Number of Colonies of Proteus for a. the Spring Season, b. the Winter Season.

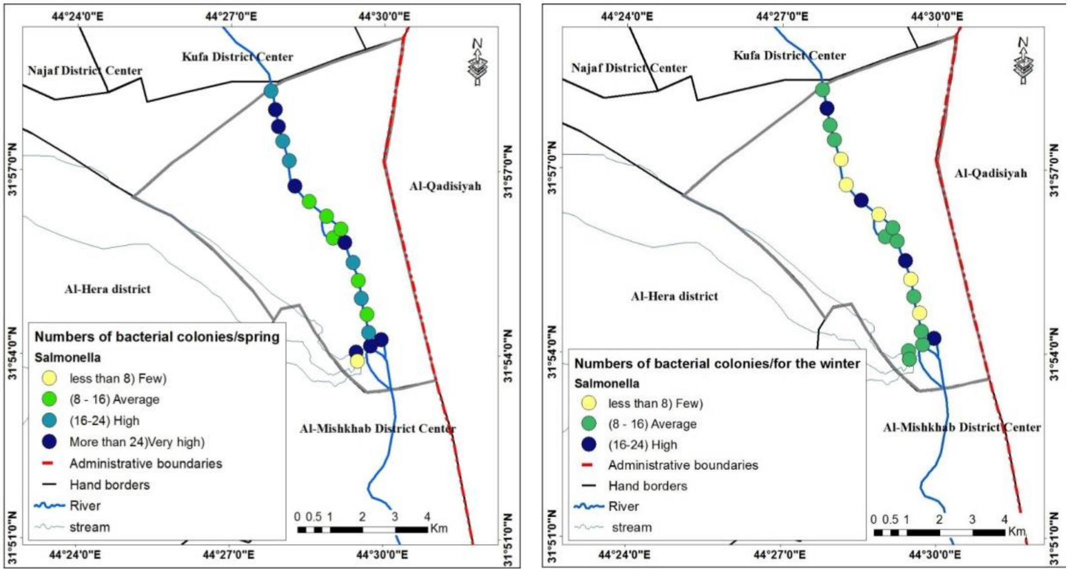
Region four (very high) for this type of bacteria appeared in (5) locations, namely (W5, W6, W11, W14, W18), with the number of colonies ranging from (33-54) colonies per 1 ml for each of them. Its spatial extension is shown in the eastern and western parts, extending to the southern part. During the winter season, from Map (1), it is evident that the distribution of this type of bacteria is in three regions (low, medium, high). The first region (low) for this type of bacteria appears in (15) locations, namely (W1, W2, W3, W4, W5, W6, W7, W8, W9, W12, W13, W16, W17, W18, W19). The number of colonies in these locations ranges from (2-9) colonies per 1 ml out of a total of (221) colonies. Its spatial extension is shown in all parts of the study area. The second region (medium) for this type of bacteria appears in (3) locations, namely (W10, W11, W15), with the number of colonies ranging from (10-19) colonies per 1 ml. Its spatial extension is in the central part of the study area, extending to the southern part. The third region (high) appears in one location, which is (W14), with the number of colonies reaching (85) colonies per 1 ml. Its spatial extension is in the southern part. During the spring season, from the data in Map (2), it is evident that the distribution of this type of bacteria is in three regions (medium, high, very high). The first region (medium) for this type of bacteria appears in (4) locations, namely (W1, W12, W13, W17), with the number of colonies ranging from (12-19) colonies per 1 ml for each of them. The total number of colonies in the spring season, which recorded the highest number of colonies for Proteus compared to other seasons due to the favorable environmental conditions of temperature and humidity, is (527) colonies. Its spatial extension is in various parts of the region, including the northern and southern parts. The second region (high) for this type of bacteria appears in (10) locations, namely (W2, W3, W4, W5, W7, W10, W15, W16, W18, W20), with the number of colonies ranging from (20-30) colonies per 1 ml. Its spatial extension is in all parts of the study area. The third region (very high) for this type of bacteria appears in (6) locations, namely (W6, W8, W9, W11, W14, W19), with the number of colonies ranging from (33-48) colonies per 1 ml. Its spatial extension is in the eastern part, extending to the southern part of the region. It is clear that this type of bacteria appears in all the studied locations of the study area. This aligns with the scientific reality of the area, and it records the highest number of colonies in the fall and spring seasons in the first place due to the suitable environmental conditions of temperature and humidity. This area is also affected by agricultural waste from the use of organic and chemical fertilizers, which reach the surface water, along with sewage water, which provides an integrated environment for the growth and reproduction of bacteria. In the second place is the summer season, which recorded the lowest number of colonies for this type of bacteria due to the high temperatures, low humidity, and high salt concentrations in the water that kill the bacteria. As for the winter season, which comes in the fourth place in terms of recording the lowest number of colonies for the bacteria, this is due to the limited impact of the region on the agricultural and civil waste in this season [5].

Salmonella Bacteria

Salmonella bacteria are Gram-negative, facultative anaerobic organisms that are often pathogenic. They are found in most warm-blooded and cold-blooded animals, mainly on the shells of raw eggs, in birds, poultry, and red meat. Human infection typically occurs through ingestion. These organisms are also commonly found in the feces of animals that contaminate food and water, and infections can be transmitted through direct contact, such as handling, raising, or slaughtering animals, especially poultry or ducks. They are also present in cattle, cats, and dogs and often reside in the intestines or gallbladders. Salmonella can cause various diseases in humans, including acute intestinal inflammation, blood poisoning, and typhoid fever. Maps (3, 4) reveal spatial and temporal variations in surface water contamination with Salmonella bacteria. The distribution of this type of bacteria differs from one place to another and varies throughout the seasons. Map (3) for the month of July illustrates that the distribution of these bacteria is divided into three regions (low, medium, high). The first region (low) is represented by (9) locations.



Map (3) For the Number of Colonies of a.salmonella During the Autumn, B.salmonella During the Summer.



Map (4) For the Number of Colonies of a. Salmonella During the Spring, B.salmonella During the Winter.

In these regions (W5, W6, W8, W10, W11, W13, W14, W15, W20), the number of colonies varied between (2-7) colonies/1 ml of the total number of colonies, which reached (210) colonies in these locations. This chapter represents the lowest number of colony growth for this type of bacteria due to high temperatures, increased evaporation rates, decreased humidity, and increased salt concentration. Consequently, it does not provide a suitable environment for growth. Its spatial distribution appears in the eastern part of the study area, extending to its center and the southern part.

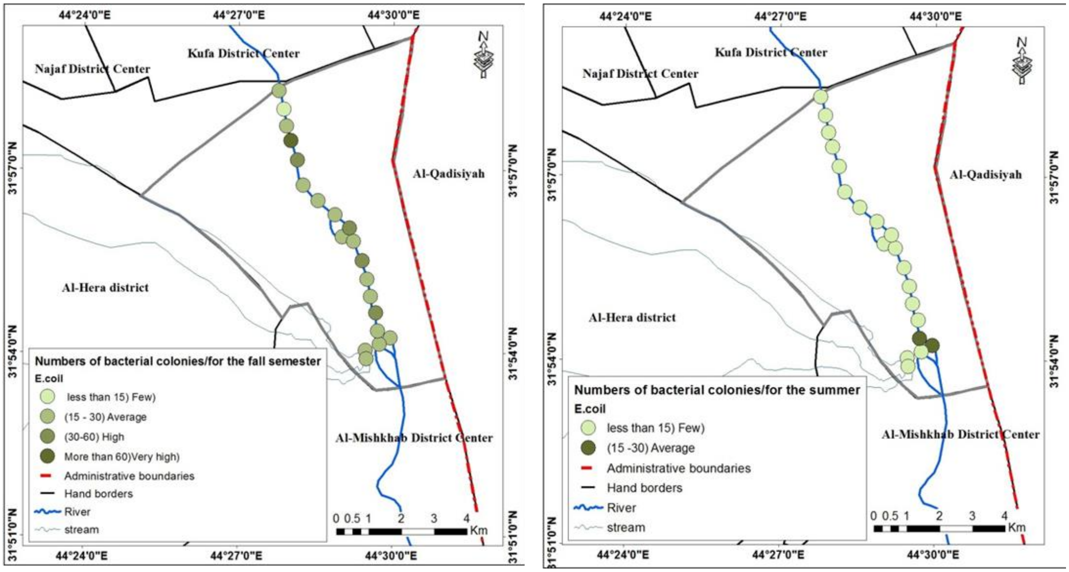
As for the second region (medium), for this type of bacteria, it appeared in (4) locations: W1, W4, W7, and W9, with the number of colonies ranging from (9-15) colonies/1 ml for each. Its spatial distribution appears in different parts of it, in the northern and southern parts. As for the third region (high) for this type of bacteria, it appeared in (7) locations: W2, W3, W7, W12, W16, W18, W19, with the number of colonies ranging from (17-22) colonies/1 ml for each. Its spatial distribution appears in different parts of it, in the northern and southern parts. As shown by the data in Map 4 for the autumn season, the distribution of this type of bacteria is represented in four regions: few, medium, high, and very high. The first region (few) for this type of bacteria appears in two locations, W10 and W13, with the number of colonies ranging from (4-6) colonies/1 ml out of a total of (213) colonies in these locations. Its spatial distribution appears in the southern part of the study area.

The second region (medium) for this type of bacteria appears in (8) locations: W5, W6, W7, W8, W11, W14, W15, and W20, with the number of colonies ranging from (8-14) colonies/1 ml. Its spatial distribution appears in the eastern and southern parts. The third region (high) for this type of bacteria appears in (3) locations: W1, W9, and W17, with the number of colonies ranging from (18-24) colonies/1 ml. Its spatial distribution appears in various parts, in the northern, central, and southern parts. As for the fourth region (very high) for this type of bacteria, it appeared in (7) locations: W2, W3, W4, W12, W16, W18, and W19, with the number of colonies ranging from (26-35) colonies/1 ml for each. Its spatial distribution covers the northern and southern parts of the region. During the winter season, as shown in Map 4, the distribution of this type of bacteria is represented in three regions: few, medium, and high. The first region (few) for this type of bacteria appears in 5 locations: W5, W6, W8, W13, and W15, with the number of colonies ranging from (1-7) colonies/1 ml out of a total of (321) colonies. Its spatial distribution appears in the eastern and southern parts [6].

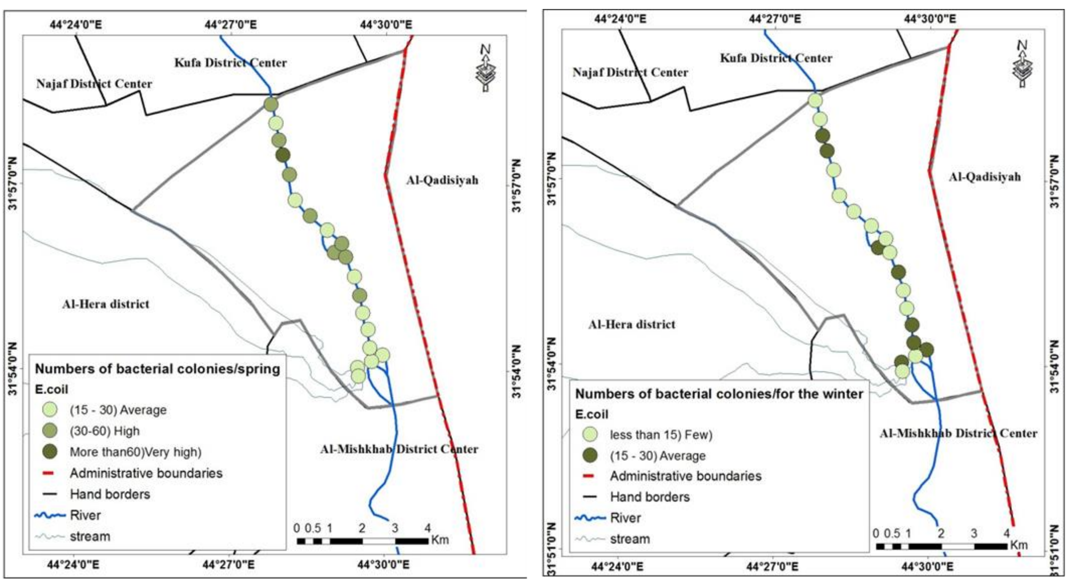
The second region (medium) for this type of bacteria appears in 9 locations: W1, W3, W4, W9, W10, W11, W14, W16, and W19, with the number of colonies ranging from (10-31) colonies/1 ml. Its spatial distribution covers various parts of the study area, including the northern and eastern parts, extending to the southern part. The third region (high) appears in 4 locations: W2, W7, W12, and W17, with the number of colonies ranging from (17-18) colonies/1 ml. Its spatial distribution covers different parts of the study area, including the northern, western, and southern parts. Meanwhile, during the spring season, data from Map 4 show that the distribution of this type of bacteria is represented in four regions: few, medium, high, and very high. The first region (few) for this type of bacteria appears in one location, W20, with the number of colonies reaching (5) colonies/1 ml out of a total of (407) colonies in the spring season, which recorded the highest number of colonies for Salmonella bacteria compared to other seasons. This is due to the favorable environmental conditions, including moderate temperatures and high humidity. Its spatial distribution appears in the southern part.

The second region (medium) for this type of bacteria appears in 5 locations: W8, W9, W10, W13, and W15, with the number of colonies ranging from (10-13) colonies/1 ml. Its spatial distribution covers the central part of the study area, extending to the southern part. The third region (high) for this type of bacteria appears in 7 locations: W1, W4, W5, W7, W12, W14, and W16, with the number of colonies ranging from (16-23) colonies/1 ml. Its spatial distribution covers the northern and southern parts of the region. The fourth region (very high) for this type of bacteria appears in 7 locations: W2, W3, W6, W11, W17, W18, and W19, with the number of colonies ranging from (27-39) colonies/1 ml. Its spatial distribution covers different parts of the region, including the northern and eastern parts, extending to the south. It is clear that this type of bacteria appears in all the studied locations in the study area. This is consistent with the global reality of the region, with autumn and spring seasons ranking highest in terms of the number of bacteria colonies. This is due to moderate temperatures, high humidity rates, and increased environmental waste, such as sewage and agricultural waste, which directly contain these bacteria. This exposes the region's residents, including farmers, to the risk of ear infections, urinary tract infections, and wound infections. In contrast, during the winter season, which ranks second in terms of the number of bacteria colonies, the reduced agricultural areas and organic fertilizers lead to fewer colonies of this type of bacteria. In the summer season, the lowest number of colonies is recorded due to climatic characteristics and increased salt concentrations, which kill the bacteria. Escherichia coli (E. coli) bacteria belong to the Enterobacteriaceae family. They are rod-shaped bacteria that do not retain the Gram stain and can be divided into two types. The first type is found in the human colon, as well as in the intestines of birds, insects, reptiles, and aquatic creatures. While they are not typically pathogenic, they can become disease-causing when they exit the body with feces, contaminating water, soil, and air.

The second type of E. coli can cause a range of diseases, including acute diarrhea, which is especially prevalent in children and can lead to dehydration. Additionally, this type can infect the urinary tract, causing conditions such as bladder inflammation and kidney inflammation, and it is considered a major source of bloodstream infections [7].



Map (4): For the Number of Colonies of A.E. Coli for the Autumn, B.E. Coli for the Summer.



Map (5): For the Number of Colonies of A. E. Coli for the Spring, E. Coli for the Winter.

It is evident from Maps (4, 5) that there is spatial and temporal variation in the contamination of surface water with E. coli bacteria. This variation occurs from one place to another and varies throughout the seasons. Map (4) for the month of July shows that the distribution of this type of bacteria is represented in two regions, which are (Low, Medium). The first region (Low) is present in (18) locations (W1, W2, W3, W4, W5, W6, W7, W8, W9, W10, W11, W12, W13, W14, W15, W18, W19, W20). The number of colonies in these locations ranges from (5-13) colonies/1ml out of a total of (186) colonies in these locations. This season has the lowest number of colonies due to high temperatures, increased evaporation rates, low humidity, and high salt concentrations, which do not provide a suitable environment for their growth. The spatial distribution extends across all parts of the study area, ranging from the northern to the southern part and from the eastern to the western part. The second region (Medium) for this type of bacteria is present in two locations (W16, W17) with colony counts ranging from (17-19) colonies/1ml in each location, and its spatial distribution is in the southern part.

In Map (5) for the autumn season, it is evident that the distribution of this type of bacteria is represented in four regions (Low, Medium, High, Very High). The first region (Low) for this type of bacteria is present in one location (W1) with a colony count of (10) colonies/1ml out of a total of (568) colonies in these locations. The spatial distribution extends to the northern part of the region. The second region (Medium) for this type of bacteria is present in 14 locations (W1, W3, W6, W7, W8, W10, W11, W13, W14, W16, W17, W18, W19, W20) with colony counts ranging from (20-28) colonies/1ml, and its spatial distribution is spread across various parts of the region, including the northern, eastern, and southern parts. The third region (High) for this type of bacteria is present in four locations (W5, W9, W12, W15) with colony counts ranging from (31-37) colonies/1ml, and its spatial distribution is in the western and southern parts. The fourth region (Very High) for this type of bacteria is present in one location (W4) with a colony count of (91) colonies/1ml, and its spatial distribution is in the northern part. During the winter season, as shown in Map (4), this type of bacteria is distributed in two regions (Low, Medium). The first region (Low) is present in 12 locations (W1, W2, W5, W6, W7, W8, W9, W11, W13, W14, W18, W20) with colony counts ranging from (6-12) colonies/1ml out of a total of (264) colonies in these locations. The spatial distribution extends to the northern and southern parts.

The second region (Medium) for this type of bacteria is present in 8 locations (W2, W4, W10, W12, W15, W16, W17, W19) with colony counts ranging from (17-21) colonies/1ml, and its spatial distribution extends across all parts of the study area, ranging from the northern to the southern part and from the eastern to the western part.

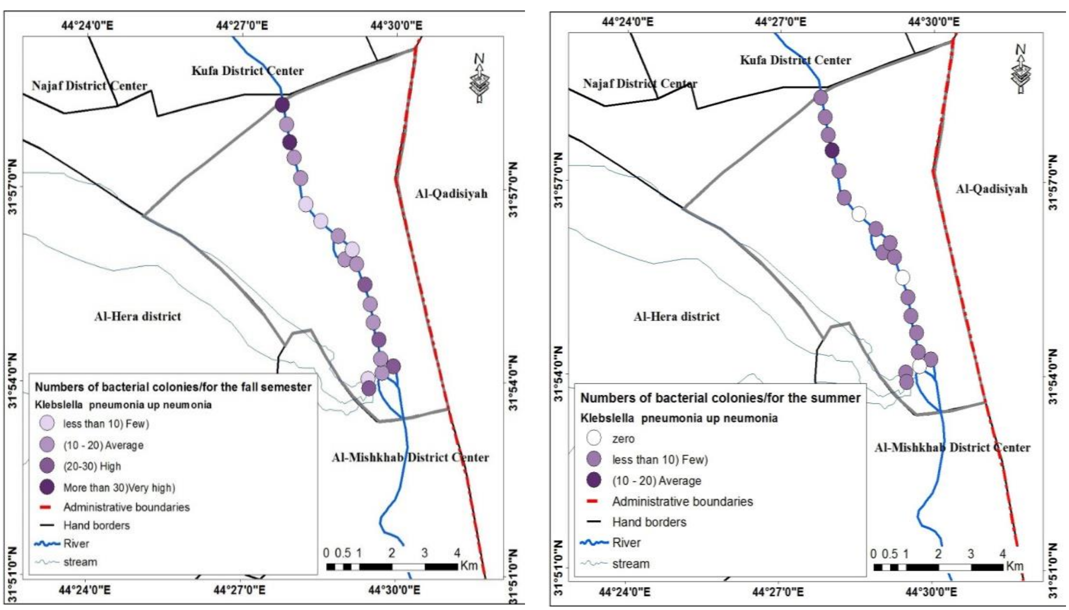
During the spring season, according to Map (5), this type of bacteria is represented in three regions (Medium, High, Very High). The first region (Medium) for this type of bacteria is present in 9 locations (W2, W12, W14, W15, W16, W17, W18, W19, W20) with colony counts ranging from (20-29) colonies/1ml, out of a total of (638) colonies in the spring, which recorded the highest number of colonies of E. coli compared to other seasons due to favorable environmental conditions such as moderate temperatures and high humidity. Its spatial distribution extends across all parts of the study area, ranging from the north to the south and from the east to the west. The second region (High) for this type of bacteria is present in 10 locations (W1, W3, W5, W6, W7, W8, W9, W10, W11, W13) with colony counts ranging from (30-42) colonies/1ml, and its spatial distribution is in the northern and western parts of the region.The third region (Very High) for this type of bacteria is present in one location (W4) with a colony count of (87) colonies/1ml, and its spatial distribution is in the northern part.

It is evident that this type of bacteria appears in all the studied locations of the study area, which aligns with the global situation of the region. It records the highest number of colonies in the autumn and spring seasons, due to favorable environmental conditions such as moderate temperatures and high humidity. However, it records the lowest number in the summer season due to the impact of natural factors such as high temperatures and increased evaporation, resulting in increased salt concentrations, which kill the bacteria. These bacteria are a source of diseases for the region's farmers, including urinary tract infections and blood contamination, transmitted through surface water contaminated with sewage and through soil contaminated with feces. Klebsiella pneumonia is a non-motile, Gram-negative, rod-shaped bacterium enclosed in a capsule. It falls under facultative anaerobes within the class of Enterobacteriales and the order Eubacteriales, and it belongs to the Klebsiella genus, specifically Klebsiella pneumoniae. This type of bacteria is found naturally in the oral, skin, and intestinal flora and is also present in the soil, making up around 30% of nitrogen-fixing strains in anaerobic conditions. Despite its presence in the natural flora of the mouth, skin, and intestines, it can lead to devastating changes in the lungs of both humans and animals when inhaled, particularly affecting the pulmonary alveoli. Symptoms include the formation of a gelatinous substance, brown or yellow in color, resembling phlegm. It affects the respiratory system, primarily impacting the elderly, alcoholics, individuals with diabetes, and those with liver diseases due to weakened respiratory systems. Furthermore, it can cause urinary tract infections, lower biliary tract infections, pneumonia, and various diseases, such as venous thrombotic inflammation, gallbladder inflammation, diarrhea, nephritis, and meningitis. Pneumonia is one of the most dangerous and common conditions caused by Klebsiella bacteria. It can manifest as bronchopneumonia or bronchial inflammation. In the context of the data presented, there seems to be spatial and temporal variation in the contamination of surface water with Klebsiella pneumoniae. The data in maps (6, 7) illustrate this variation. The distribution of this bacterium varies spatially, from one location to another, and temporally, across seasons. For instance, Map (29) for the month of July shows that the distribution of this bacterium can be represented in two regions: "Low" and "Medium" contamination areas [8].

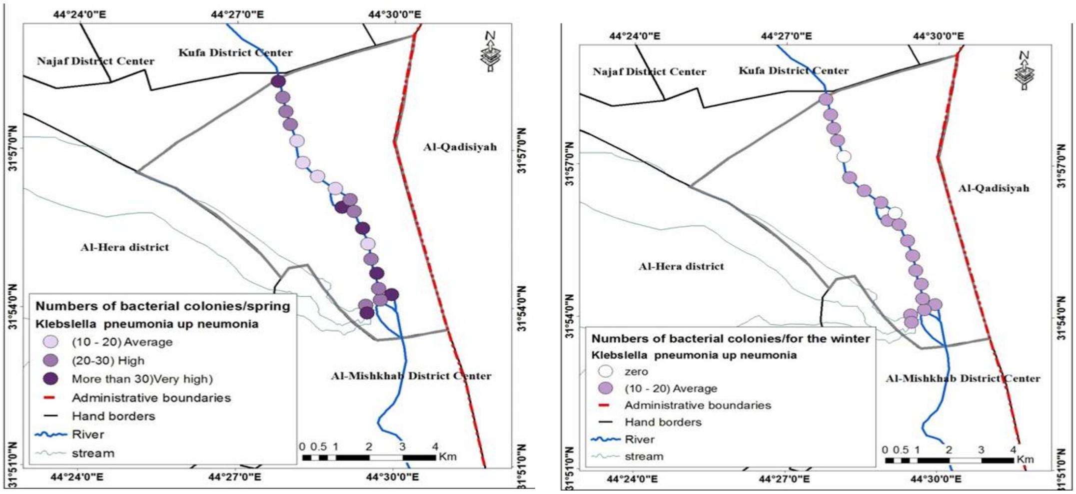
In the "Low" region, which includes locations W1, W2, W3, and so on, the number of colonies ranges from 0 to 9 colonies per milliliter among a total of 88 colonies in these areas. This chapter represents the lowest number of colonies for this type of bacteria, and its spatial extension covers all parts of the study area, extending from north to south and from east to west. In the "Medium" region, which includes only one location, W4, there are 10 colonies per milliliter, and its spatial extension is mainly in the northern part. However, in the fall season, according to Map (6), the distribution of this bacterium is observed in four regions: "Low," "Medium," "High," and "Very High." The "Low" region, with locations W6, W7, W10, and W19, contains 9 colonies per milliliter in each location, with a total of 372 colonies in these areas. The spatial extension of this region is primarily in the eastern part.

The information provided indicates variations in the spatial and temporal distribution of Klebsiella pneumoniae in surface water, with different contamination levels observed in different locations and seasons. The second region (medium) for this type of bacteria appears in 8 locations, including W4, W5, W8, W11, W13, W14, W16, W18. The number of colonies in these locations ranges from 11 to 18 colonies per milliliter. Its spatial distribution covers various parts of the area, particularly in the northern and eastern parts. As for the third region (high) for this type of bacteria, it is found in 6 locations, namely W2, W10, W12, W15, W17, W20. The number of colonies in these locations ranges from 20 to 23 colonies per milliliter. Its spatial extension is mainly in the southern part. The fourth region (very high) for this type of bacteria is found in two locations, W3 and W1, with a number of colonies ranging from 36 to 47 colonies per milliliter in each location. Its spatial extension is primarily in the northern part. During the winter season, the data in Map (6) show that this type of bacteria is distributed in one region (low). The low region is found in 20 locations, such as W1, W2, W3, W4, W5, W6, W7, W8, W9, W10, W11, W12, W13, W14, W15, W16, W17, W18, W19, W20. The number of colonies in these locations ranges from 0 to 6 colonies per milliliter, with a total of 59 colonies in these locations. The spatial extension covers all parts of the study area.

During the spring season, based on the data in Map (7), the distribution of this type of bacteria is observed in three regions: medium, high, and very high. The medium region is found in 3 locations, including W5, W7, and W8, with a number of colonies ranging from 16 to 19 colonies per milliliter. The total number of colonies in the spring season reaches 513 colonies, the highest among all seasons. This is likely due to the favorable environmental conditions, high humidity, and increased organic fertilizers from agricultural activities carried by runoff water and soil washing into surface water. Additionally, the growth of aquatic plants provides a fertile environment for this type of bacteria, along with industrial and civil activities in the area. The high region for this type of bacteria in the spring season appears in 11 locations, including W2, W3, W4, W6, W9, W11, W13, W14, W16, W18, and W19. The number of colonies ranges from 20 to 29 colonies per milliliter, and its spatial distribution covers various parts, including the northern, western, and southern areas of the region. The very high region for this type of bacteria in the spring season is found in 6 locations: W1, W10, W12, W15, W17, and W20, with the number of colonies ranging from 31 to 37 colonies per milliliter. Its spatial extension covers various parts, including the northern, western, and southern areas. In summary, this type of bacteria is not found in all studied locations within the research area, which is consistent with the global pattern. It tends to thrive during the autumn and spring seasons when temperature conditions are ideal and humidity is high. This is also due to the increased organic fertilizer runoff from agricultural activities and soil washing into surface waters, as well as the growth of aquatic plants, creating a fertile environment for the bacteria. Conversely, during the winter season, there is the least growth of these bacteria due to limited agricultural areas, minimal organic waste, and reduced industrial and civil activities. During the summer season, high temperatures and increased salt concentrations in surface waters lead to decreased growth and multiplication of these bacteria, which are among the most dangerous types of bacteria, exposing the local population, particularly farmers, to respiratory diseases, liver diseases, urinary tract infections, and pneumonia, especially those with weakened immune systems and diabetes. In essence, the results and discussion sections work in tandem to showcase the outcomes of a study, from raw data to their broader significance, facilitating a robust scientific conversation and contributing to the advancement of knowledge in a particular field [9].



Map (6): For the Number of Colonies of a. Klebsiella for the Autumn Season, B.Klebsiella for the Summer Season.



Map (7): For the Number of A.Klebsiella Colonies for the Spring Season, B.Klebsiella Colonies for the Winter Season.

Results and discussions are crucial components of any scientific study or research project. These sections provide a comprehensive overview of the findings, their significance, and the implications they hold. In the results section, the researcher presents the data collected, often using tables, graphs, or charts, to illustrate patterns, trends, or relationships between variables. This section is objective and factual, providing readers with a clear understanding of what the study revealed. Conversely, the discussion section offers an in-depth analysis of the results, interpreting their meaning and placing them within the context of the existing body of knowledge. Researchers discuss the implications of their findings, the potential applications, and whether their results support or contradict existing theories. This section allows for critical thinking, hypothesis testing, and presenting new insights. It's a space for researchers to explain the "why" and "how" behind their findings, fostering a deeper understanding of the subject matter.

Conclusions

This study provides valuable insights into the variation of pathogenic bacteria in the waters of the Manathira River and their relationship with climatic factors. The research reveals a significant spatial and temporal heterogeneity in bacterial populations, influenced by urban and agricultural activities. It is evident that bacterial counts increase in areas impacted by urban and agricultural runoff, whereas they decrease further from these sources. Moreover, there is a clear temporal pattern, with bacterial counts peaking during the spring and fall seasons, likely due to favorable climatic conditions. Notably, all identified bacterial species pose a risk to human, animal, and plant health, emphasizing the importance of monitoring and controlling bacterial contamination in the river.

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