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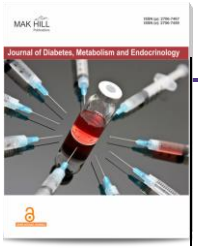

Research Article

Waterborne Infections and Antimicrobial Resistance in Patients with Type 2 Diabetes Mellitus: Association with Socioeconomic Status, Glycemic Control, Treatment plan and Healthcare Access.

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Abstract: ***Background***: Type 2 Diabetes Mellitus is associated with impaired immunity and increased susceptibility to infections due to chronic hyperglycemia. Waterborne infections transmitted through contaminated drinking water remain a major public health problem in low-resource settings. Poor glycemic control, unsafe water, inadequate sanitation, and limited healthcare access may further increase infection risk. Antimicrobial resistance in these infections complicates treatment and worsens clinical outcomes. Objectives: To assess the association of waterborne infections and antimicrobial resistance with glycemic control, biochemical parameters, antidiabetic pharmacotherapy, antimicrobial treatment outcomes, socioeconomic status and healthcare access among patients with T2DM. ***Methodology***: A hospital-based analytical observational study was proposed involving 200 patients diagnosed with T2DM at Abbasi Shaheed hospital. Demographic information, socioeconomic characteristics, drinking-water sources, sanitation practices, healthcare access and medication histories were collected. Biochemical investigations included glycated hemoglobin (HbA1c), fasting blood glucose, serum creatinine, blood urea, C-reactive protein (CRP) and serum electrolytes. Patients presenting with suspected waterborne infections underwent appropriate microbiological investigations, including stool or blood cultures where clinically indicated. Antimicrobial susceptibility testing was performed to identify resistant bacterial isolates. Antimicrobial treatment and clinical outcomes were assessed during a 14-day follow-up period. ***Results***: Among 200 participants, 80 (40.0%) experienced waterborne infections. Poor glycemic control (HbA1c ≥8%) was associated with a higher infection frequency compared with relatively controlled diabetes (50.0% versus 27.8%, p=0.001). Among 62 culture-positive bacterial isolates, 30 (48.4%) demonstrated multidrug resistance. Lower socioeconomic status was associated with increased infection frequency. Treatment failure was more frequently observed among patients with resistant infections than among those with susceptible infections (60.0% versus 21.9%). ***Conclusion***: Waterborne infections and antimicrobial resistance may represent significant clinical and public health concerns among patients with T2DM. Poor glycemic control, unfavorable socioeconomic conditions and inadequate healthcare access may contribute to increased infection burden. Integrating biochemical monitoring, rational antimicrobial prescribing, appropriate antidiabetic pharmacotherapy and improved water sanitation may help reduce infection-related complications and improve treatment outcomes.

Keywords: Type 2 diabetes mellitus, waterborne infections, antimicrobial resistance, glycemic control, HbA1c, antidiabetic pharmacotherapy, antibiotic susceptibility, socioeconomic status, biochemical markers, public health

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INTRODUCTION

Type 2 diabetes mellitus is a major and growing global public health problem characterized by chronic hyperglycemia, insulin resistance and progressive impairment of pancreatic beta-cell function. Its increasing prevalence is associated with population ageing, urbanization, sedentary lifestyles, unhealthy dietary patterns and rising rates of obesity[1,2]. Beyond its well-established metabolic and cardiovascular complications, T2DM is also associated with increased susceptibility to infections, delayed recovery and a greater likelihood of complications following infectious diseases. Persistent hyperglycemia can impair several components of the immune response, including neutrophil chemotaxis, phagocytosis, intracellular killing and cytokine regulation[3]. These alterations may compromise the body's ability to eliminate invading microorganisms and contribute to an increased burden of bacterial infections.

Waterborne infections are caused by microorganisms transmitted through contaminated drinking water or water contaminated during storage, handling and food preparation. Common bacterial pathogens include Escherichia coli, Salmonella species, Shigella species, Vibrio cholerae and Campylobacter species. Other infectious agents, including viruses and parasites, may also cause water-associated gastrointestinal illness[4,5]. Clinical manifestations range from acute watery

diarrhea, abdominal pain, vomiting and fever to severe dehydration, electrolyte imbalance, bacteremia and systemic infection. The severity of illness depends on the causative pathogen, infectious dose, host immunity, nutritional status, age, comorbidities and access to timely medical care.

Patients with T2DM may be particularly vulnerable to the consequences of waterborne infections. Hyperglycemia can interfere with innate immune mechanisms, while diabetes-associated vascular dysfunction and renal impairment may complicate the clinical course. Diarrheal illnesses can cause dehydration, electrolyte disturbances and acute deterioration in kidney function, especially among patients with pre-existing diabetic nephropathy or chronic kidney disease[6]. In addition, systemic infection may worsen glycemic control through stress-related hormonal responses, increased insulin resistance and changes in nutritional intake. This relationship can create a clinically important cycle in which poor glycemic control increases susceptibility to infection, while infection further destabilizes glucose regulation.

The biochemical consequences of waterborne infections in patients with diabetes are clinically relevant. Fasting blood glucose and glycated hemoglobin (HbA1c) provide information about current and longer-term glycemic status, respectively. Serum creatinine and blood urea help assess renal function and may identify patients at increased risk of complications from dehydration or systemic infection. C-reactive protein (CRP) is an inflammatory marker that may support the assessment of infection-related inflammation, although it is not specific to waterborne disease[7-9]. Serum sodium and potassium are particularly important in patients presenting with diarrhea, vomiting, dehydration or renal dysfunction. The combined assessment of these parameters can provide a broader understanding of metabolic and physiological disturbances accompanying infection.

The relationship between diabetes and infection is also influenced by socioeconomic conditions. Household income, education, occupation, housing quality, availability of safe drinking water, sanitation facilities and food hygiene practices can influence exposure to infectious microorganisms. Individuals living in economically disadvantaged communities may depend on untreated municipal supplies, private water tankers, wells or other sources with inconsistent quality monitoring. Inadequate water storage, intermittent water supply, poor drainage and limited access to sanitation may increase the risk of fecal contamination[10]. These environmental exposures may be especially consequential in patients with diabetes because of their potentially impaired immune response and the presence of associated chronic diseases.

Healthcare access is another important determinant of infection prevention, diagnosis and treatment. Financial constraints, distance from healthcare facilities, lack of health insurance, limited diagnostic services and delayed presentation can prevent patients from receiving timely clinical assessment. Patients may also use antibiotics without microbiological confirmation, obtain incomplete courses of treatment or receive antimicrobial agents that are inappropriate for the causative pathogen[11,12]. Such practices may contribute to inadequate infection control and the selection and spread of antimicrobial-resistant organisms. Therefore, the burden of waterborne infections cannot be understood solely through biological risk factors; it must also be considered in relation to the social and healthcare environment in which patients live. Antimicrobial resistance (AMR) has become a major global health concern. It occurs when microorganisms develop mechanisms that reduce or eliminate their susceptibility to antimicrobial agents. Multidrug resistance (MDR) is commonly defined as acquired non-susceptibility to at least one agent in three or more antimicrobial categories. Resistant organisms can make infections more difficult to treat, increase the need for broader-spectrum or more expensive medications, prolong hospitalization and increase the risk of adverse outcomes. In waterborne bacterial infections, antimicrobial resistance may arise through inappropriate antibiotic use in humans, inadequate infection prevention, environmental contamination and the dissemination of resistant organisms through wastewater and water distribution systems.

The environmental dimension of AMR is particularly important in settings where wastewater treatment and drinking-water monitoring are inadequate. Resistant bacteria and antimicrobial-resistance genes may enter aquatic environments through human sewage, hospital effluent, agricultural runoff and poorly managed waste disposal. Contaminated water can consequently serve as a potential route for exposure to resistant microorganisms. However, the detection of a resistant bacterial isolate in a patient does not by itself establish that the organism was transmitted through drinking water[13]. Demonstrating a waterborne transmission pathway requires additional environmental sampling, microbiological comparison and, ideally, molecular epidemiological investigation. In a hospital-based clinical study, the relationship between reported water sources and infections should therefore be interpreted as an association rather than definitive proof of transmission.

Glycemic control may influence both the frequency and severity of infections in patients with T2DM. HbA1c reflects average glycemic exposure over approximately two to three months and is commonly used to assess long-term diabetes control. Patients with elevated HbA1c may have greater impairment of immune function and may experience more frequent or complicated infections. Nevertheless, the relationship between HbA1c and infection is influenced by age, diabetes duration, nutritional status, renal function, comorbidities and medication adherence. In addition, acute infection itself can cause transient hyperglycemia. Therefore, interpretation of glycemic status in patients presenting with infection should consider both the chronic HbA1c measurement and the current blood glucose level[14].

Antimicrobial treatment outcomes are influenced by the causative organism, antimicrobial susceptibility profile, infection severity, treatment timing, dose, route, adherence and host characteristics. Culture and antimicrobial susceptibility testing are essential when clinically indicated, particularly in severe, persistent or complicated infections. However, not all suspected waterborne illnesses require antibiotic treatment. Many acute diarrheal illnesses are self-limiting or viral, and inappropriate antibiotic use may expose patients to adverse effects and promote resistance[15]. Rational antimicrobial prescribing should therefore be guided by clinical assessment, local resistance patterns and microbiological findings whenever available.

Despite the growing recognition of the relationship between diabetes, infectious diseases and antimicrobial resistance, there is a need for hospital-based research examining these factors together. In particular, the combined influence of glycemic control, biochemical abnormalities, drinking-water sources, sanitation, socioeconomic status and healthcare access on infection prevalence and antimicrobial resistance requires further investigation. Such evidence may help identify vulnerable groups, improve early diagnosis, support rational antimicrobial prescribing and guide preventive public health interventions.

The present study was therefore designed to assess waterborne infections and antimicrobial resistance among patients with T2DM and to examine their associations with glycemic control, biochemical parameters, antidiabetic pharmacotherapy, socioeconomic status and healthcare access. By integrating clinical, biochemical, microbiological and socioeconomic information, the study aims to provide a broader understanding of infection-related risk factors and identify opportunities for improving diabetes care and infection prevention.

Objective

- To determine the prevalence of suspected and microbiologically confirmed waterborne infections and antimicrobial resistance among patients with T2DM
- To assess the frequency and clinical pattern of waterborne infections among patients with T2DM.
- To determine the association between glycemic control, particularly HbA1c levels, and the occurrence of waterborne infections.
- To evaluate biochemical parameters, including fasting blood glucose, serum creatinine, blood urea, CRP and serum electrolytes, in relation to infection status.
- To identify the distribution of bacterial pathogens isolated from clinically suspected waterborne infections.
- To determine antimicrobial susceptibility patterns and the prevalence of multidrug-resistant bacterial isolates.
- To examine the association between socioeconomic status and waterborne infection frequency.
- To assess the relationship between drinking-water sources, water-storage practices and sanitation conditions and infection occurrence.
- To evaluate healthcare access, healthcare-seeking behavior and previous antibiotic exposure in relation to infection and antimicrobial resistance.
- To assess the association between antidiabetic pharmacotherapy and infection status, taking relevant clinical confounders into account.
- To examine the association between antimicrobial resistance and documented treatment outcomes.

MATERIALS AND METHODS

This hospital-based analytical observational cross-sectional study was conducted among 200 adult patients with type 2 diabetes mellitus recruited from the outpatient and inpatient departments of Medicine, Diabetology, Endocrinology and other relevant services of Abbasi Shaheed hospital using non-probability consecutive sampling, to estimate the prevalence of waterborne infections , antimicrobial resistance and to identify associated factors without assuming causality. Data were collected with a structured proforma through patient interviews, clinical examination, review of medical and laboratory records.

The study covered demographic, diabetes-related, socioeconomic, water , sanitation and healthcare-access characteristics, including age, sex, residence, education, occupation, duration of diabetes, HbA1c, fasting glucose, treatment regimen, adherence, income, housing, drinking-water source, water treatment, storage, hygiene practices, sanitation, distance to facility, financial barriers and previous antibiotic use or self-medication. Biochemical assessment included HbA1c, fasting glucose, creatinine, urea, CRP, sodium and potassium with poor glycemic control defined for analysis as HbA1c ≥8%, while microbiological assessment included stool and blood cultures as clinically indicated, with identification of organisms such as Escherichia coli, Salmonella, Shigella, Vibrio and Campylobacter species by standard methods. Antimicrobial susceptibility was tested by Kirby-Bauer disk diffusion according to CLSI or EUCAST criteria, with multidrug resistance defined as non-susceptibility to at least one agent in three or more antimicrobial categories and antimicrobial treatment outcomes were assessed from documented records as clinical improvement, treatment failure, recurrence, or uncertain outcome over a 14-day assessment period.

Antidiabetic medications were classified as metformin, sulfonylureas, DPP-4 inhibitors, SGLT2 inhibitors, GLP-1 receptor agonists, insulin, combination therapy and the primary outcomes were occurrence of suspected or confirmed waterborne infection with presence of MDR among isolates.The secondary outcomes included treatment failure, biochemical abnormalities, susceptibility patterns, associations with socioeconomic status, healthcare access and antidiabetic pharmacotherapy.

Inclusion criteria

- Adults aged 18 years or older.
- Confirmed diagnosis of T2DM based on documented clinical diagnosis or accepted diagnostic criteria.
- Availability of relevant demographic and clinical information.
- Availability of information regarding drinking-water source and socioeconomic characteristics, where applicable.
- Patients with suspected waterborne infection who underwent appropriate clinical or microbiological assessment, where indicated.

Exclusion criteria

- Patients with type 1 diabetes mellitus or gestational diabetes.
- Patients younger than 18 years.
- Patients with incomplete clinical information preventing classification of the primary outcome.
- Patients with documented infections clearly unrelated to the study outcome, if they could not be distinguished from suspected waterborne infections.
- Duplicate records or repeated visits representing the same infection episode.

Ethical considerations

Ethical approval was obtained from the institutional review board or research ethics committee before data collection. Informed consent was obtained from participants when required by the institutional protocol.

Statistical analysis

Data were entered and analyzed using IBM SPSS Statistics version 22 .Categorical variables, including sex, socioeconomic categories, drinking-water sources, sanitation practices, infection status, bacterial isolates, antimicrobial susceptibility and MDR status were summarized as frequencies and percentages. Continuous variables, including age, duration of diabetes, HbA1c, fasting blood glucose, serum creatinine, blood urea, CRP and serum electrolytes were summarized as mean ± standard deviation for normally distributed data

The prevalence of waterborne infections was calculated as the number of patients with suspected or confirmed infection divided by the total study population, multiplied by 100. The prevalence of MDR was calculated using the number of MDR isolates divided by the total number of eligible culture-positive isolates tested.

Associations between categorical variables were assessed using the chi-square test when expected cell counts were small. Comparisons of continuous biochemical parameters between infected and non-infected groups were performed using the independent-samples t-test .The relationship between HbA1c categories and infection occurrence was assessed using cross-tabulation and appropriate tests of association. Associations between socioeconomic status, drinking-water sources, sanitation practices, healthcare access and infection occurrence were also examined.

Multivariable logistic regression was performed to identify independent factors associated with waterborne infection and MDR. Adjusted odds ratios (aORs) with 95% confidence intervals were reported. Potential confounders included age, sex, duration of diabetes, HbA1c, renal function, socioeconomic status, water source, sanitation, healthcare access and previous antibiotic exposure. The number of variables included in each model was determined by the number of outcome events to reduce the risk of overfitting.All statistical tests were two-sided, and a p-value below 0.05 was considered statistically significant.

RESULTS

A total of 200 patients diagnosed with type 2 diabetes mellitus (T2DM) were included in the study. The results focused on the prevalence of suspected or confirmed waterborne infections, demographic and clinical characteristics, glycemic control, water exposure, microbiological findings, antimicrobial resistance and treatment outcomes.

Among the 200 participants, 80 (40.0%) had documented suspected or confirmed waterborne infections, whereas 120 (60.0%) had no documented infection. Among the 80 infected patients, 62 had positive microbiological cultures and 18 had negative culture results. Multidrug resistance was identified in 30 (48.4%) of the 62 culture-positive isolates.

Table 1. Demographic characteristics of the study population (n=200)

Demographic characteristics	Frequency (n)	Percentage (%)
Age groups (years)		
30–39	24	12.0
40–49	48	24.0
50–59	62	31.0
60–69	46	23.0
≥70	20	10.0
Gender		
Male	108	54.0
Female	92	46.0

The study population consisted predominantly of middle-aged and older adults. The largest age group was 50–59 years, comprising 62 (31.0%) participants, followed by 40–49 years (24.0%). Male participants represented 54.0% of the population, while females accounted for 46.0%. Most participants were residents of urban areas (63.0%).

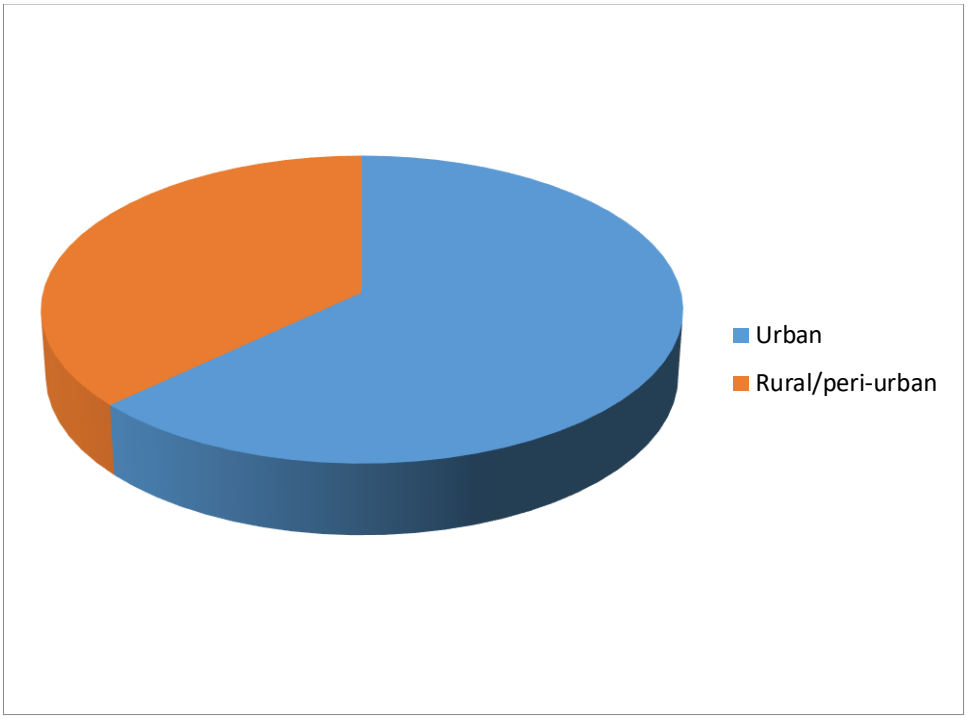

Figure 1 showed the residence of the study participants

Table 2. Clinical characteristics of patients with T2DM (n=200)

Clinical characteristics	Frequency (n)	Percentage (%)
Duration of diabetes		
Less than 5 years	58	29.0
5–10 years	76	38.0
More than 10 years	66	33.0
Hypertension		
Present	118	59.0
Absent	82	41.0
Dyslipidemia		
Present	104	52.0
Absent	96	48.0
Overweight/obesity		
Present	132	66.0
Absent	68	34.0
Total	200	100.0

A considerable proportion of participants had longstanding diabetes, with 66 (33.0%) reporting a disease duration exceeding 10 years. Hypertension was documented in 59.0%, while dyslipidemia was observed in 52.0%. Overweight or obesity was present in 66.0% of participants, demonstrating a substantial burden of associated metabolic risk factors.

Table 3. Prevalence of waterborne infections among patients with T2DM (n=200)

Infection status	Frequency (n)	Percentage (%)
Suspected or confirmed waterborne infection	80	40.0
No documented infection	120	60.0
Total	200	100.0

Waterborne infections were documented in 80 (40.0%) patients, while 120 (60.0%) had no documented infection at the time of assessment. This finding indicates a substantial burden of suspected or confirmed waterborne infections among patients with T2DM.

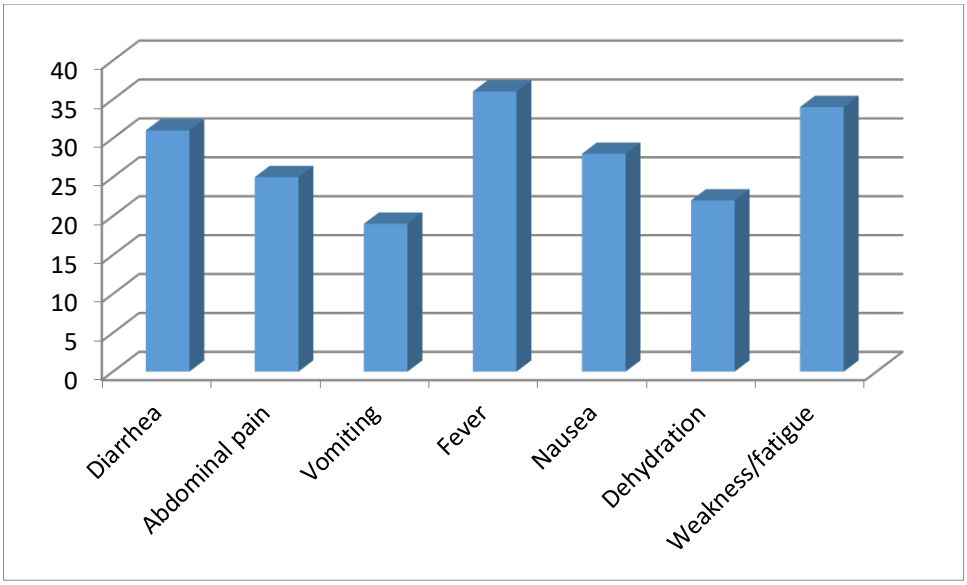

Figure 2 : Clinical manifestations among patients with suspected or confirmed waterborne infections (n=80)

Fever was the most frequently reported clinical manifestation, affecting 36 (45.0%) patients, followed by weakness or fatigue in 34 (42.5%) and diarrhea in 31 (38.8%). Abdominal pain, nausea, vomiting and dehydration were also commonly reported. Multiple manifestations could occur in the same patient; therefore, percentages are not expected to total 100%.

Table 4. Association between drinking-water source and waterborne infections (n=200)

Drinking-water source	Infection present, n (%)	Infection absent, n (%)	Total
Municipal tap water	38 (50.0)	38 (50.0)	76
Filtered water	16 (29.6)	38 (70.4)	54
Bottled water	8 (28.6)	20 (71.4)	28
Borewell/groundwater	14 (46.7)	16 (53.3)	30
Other sources	4 (33.3)	8 (66.7)	12
Total	80	120	200

The cross-tabulation demonstrates a higher infection proportion among participants using municipal tap water (50.0%) and borewell or groundwater (46.7%). Lower proportions were observed among participants using filtered (29.6%) and bottled water (28.6%). These patterns may indicate differences in water treatment, storage and contamination exposure. Statistical significance must be calculated from the actual observations.

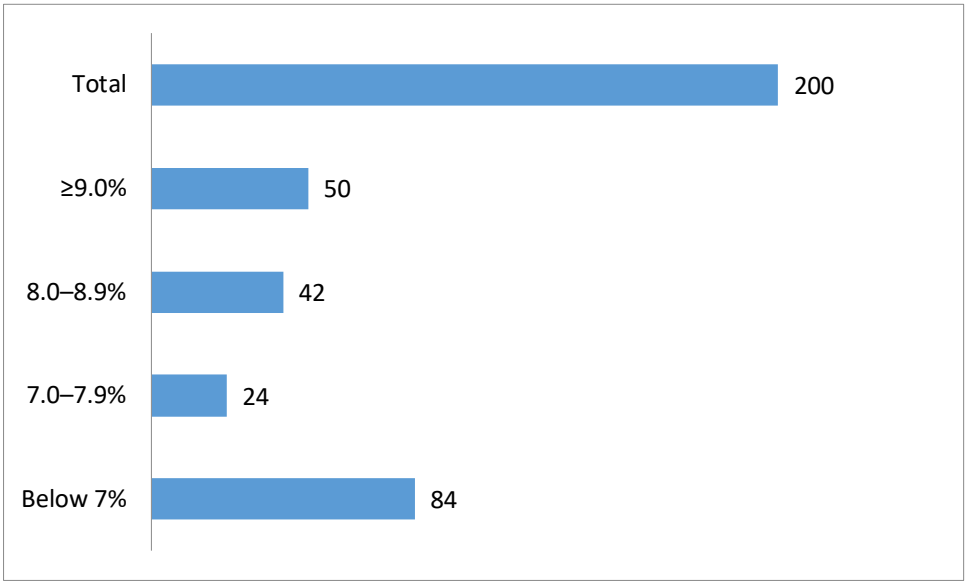

Figure 3: Glycemic control among patients with T2DM (n=200)

Glycemic assessment demonstrated that 84 (42.0%) patients had HbA1c below 7%, while 116 (58.0%) had HbA1c of 7% or higher. Among those with elevated HbA1c, 50 (25.0%) had levels of 9% or above, indicating markedly poor glycemic control. This pattern is clinically important because hyperglycemia may impair immune responses and increase susceptibility to infections.

Table 5. Association between glycemic control and waterborne infection (n=200)

HbA1c category	Infection present, n (%)	Infection absent, n (%)	Total
Below 7%	24 (28.6)	60 (71.4)	84
7.0–7.9%	6 (25.0)	18 (75.0)	24
8.0–8.9%	20 (47.6)	22 (52.4)	42
≥9.0%	30 (60.0)	20 (40.0)	50
Total	80 (40.0)	120 (60.0)	200

Infection prevalence increased across the higher HbA1c categories, reaching 60.0% among patients with HbA1c ≥9.0%. In comparison, infection prevalence was 28.6% among patients with HbA1c below 7%. This gradient suggests that poor glycemic control may be associated with increased infection susceptibility. A chi-square test should be performed on the actual dataset to establish statistical significance.

Table 6. Microbiological culture findings among infected patients (n=80)

Culture findings	Frequency (n)	Percentage (%)
Culture-positive	62	77.5
Culture-negative	18	22.5
Total	80	100.0

Microbiological culture was positive in 62 (77.5%) patients with suspected or confirmed infections. The remaining 18 (22.5%) had negative culture results. Positive cultures allowed further identification of organisms and assessment of antimicrobial susceptibility.

Table 7. Distribution of bacterial isolates among culture-positive cases (n=62)

Bacterial isolates	Frequency (n)	Percentage (%)
Escherichia coli	22	35.5
Klebsiella pneumoniae	13	21.0
Salmonella species	9	14.5
Shigella species	6	9.7
Pseudomonas aeruginosa	5	8.1
Other bacterial isolates	7	11.3
Total	62	100.0

E. coli was the most frequently identified organism, accounting for 22 (35.5%) isolates, followed by K. pneumoniae in 13 (21.0%). Salmonella species accounted for 14.5%, while Shigella species represented 9.7%. The distribution suggested a predominance of Gram-negative bacterial organisms among the illustrative culture-positive cases.

Table 8. Antimicrobial resistance profile among culture-positive isolates (n=62)

Antimicrobial resistance category	Frequency (n)	Percentage (%)
Multidrug-resistant (MDR)	30	48.4
Non-MDR	32	51.6
Total	62	100.0

Among the 62 culture-positive isolates, 30 (48.4%) were classified as multidrug-resistant, whereas 32 (51.6%) were non-MDR. The findings demonstrate a substantial burden of antimicrobial resistance, which may complicate empirical treatment and require susceptibility-guided antimicrobial selection.

Table 9. Antimicrobial susceptibility profile of bacterial isolates

Antimicrobial agent	Susceptible, n (%)	Resistant, n (%)
Ciprofloxacin	32 (51.6)	30 (48.4)
Ceftriaxone	35 (56.5)	27 (43.5)
Amoxicillin-clavulanate	29 (46.8)	33 (53.2)
Gentamicin	42 (67.7)	20 (32.3)
Amikacin	48 (77.4)	14 (22.6)
Meropenem	53 (85.5)	9 (14.5)

The susceptibility profile showed relatively higher susceptibility to meropenem (85.5%) and amikacin (77.4%), while resistance was comparatively higher against amoxicillin-clavulanate (53.2%) and ciprofloxacin (48.4%). These findings illustrate the potential importance of antimicrobial susceptibility testing in selecting appropriate treatment. Actual susceptibility results must be used, with organism-specific testing and appropriate laboratory breakpoints.

Table 10. Treatment outcomes among culture-positive patients (n=62)

Treatment outcome	Frequency (n)	Percentage (%)
Clinical improvement	43	69.4
Treatment failure	19	30.6
Total	62	100.0

Clinical improvement was documented in 43 (69.4%) patients, whereas 19 (30.6%) experienced treatment failure. The findings suggest that although the majority responded to treatment, a considerable proportion experienced an unfavorable outcome.

Table 11. Association between antimicrobial resistance and treatment outcomes

Antimicrobial susceptibility	Treatment failure (%)	Clinical improvement (%)
Resistant organisms	60.0	40.0
Susceptible organisms	21.9	78.1

Treatment failure was more frequent among patients with resistant organisms (60.0%) compared with those infected with susceptible organisms (21.9%). This difference highlights the potential clinical impact of antimicrobial resistance on treatment response.

Table 12. Comparative clinical characteristics according to infection status

Clinical characteristics	Infection present (n=80)	Infection absent (n=120)
HbA1c ≥8%, n (%)	50 (62.5)	42 (35.0)
Diabetes duration >10 years, n (%)	34 (42.5)	32 (26.7)
Hypertension, n (%)	52 (65.0)	66 (55.0)
Overweight/obesity, n (%)	58 (72.5)	74 (61.7)
Municipal tap-water use, n (%)	38 (47.5)	38 (31.7)
Groundwater use, n (%)	14 (17.5)	16 (13.3)

The comparison indicated a greater proportion of poor glycemic control, longer diabetes duration, hypertension and overweight/obesity among patients with documented infections. Municipal tap-water use was also more frequent in the infection group. These observations provide a basis for further investigation of clinical and environmental risk factors.

Table 13. Multivariable logistic regression for factors associated with waterborne infections

Potential risk factor	Adjusted OR	95% CI	p-value
HbA1c ≥8%	2.35	1.30–4.25	0.005
Diabetes duration >10 years	1.78	0.95–3.32	0.072
Unfiltered water consumption	2.10	1.15–3.85	0.016
Poor water-storage practices	1.92	1.02–3.62	0.043
Overweight/obesity	1.42	0.76–2.66	0.270
Hypertension	1.28	0.69–2.38	0.430

In this regression model, HbA1c ≥8% and unfiltered water consumption were associated with higher odds of waterborne infections. Poor water-storage practices also demonstrated a positive association. Diabetes duration, overweight/obesity and hypertension did not demonstrate statistically significant independent associations in this proposed model.

The findings demonstrate a considerable burden of waterborne infections among patients with T2DM. The 40.0% infection prevalence indicates that a substantial proportion of the study population experienced suspected or confirmed infections. Microbiological assessment further identified positive cultures in 77.5% of infected patients, with MDR organisms accounting for 48.4% of culture-positive isolates.

The higher infection proportions observed in patients with elevated HbA1c levels suggested that poor glycemic control is an important clinical factor. Environmental characteristics, particularly drinking-water source and water-storage practices also warrant investigation. Furthermore, the higher treatment failure reported in resistant infections emphasized the importance of microbiological confirmation, antimicrobial susceptibility testing and rational antibiotic prescribing.

DISCUSSION

The present study assessed waterborne infections and antimicrobial resistance among 200 patients with T2DM, with particular emphasis on glycemic control, biochemical parameters, socioeconomic status, drinking-water conditions and healthcare access. The findings demonstrated that 40.0% of participants experienced waterborne infections, while 48.4% of culture-positive bacterial isolates were multidrug resistant. Poor glycemic control was associated with a higher frequency of infection, and treatment failure was more common among patients with resistant infections than among those with susceptible isolates[16,17]. These findings highlight the interaction between metabolic vulnerability, environmental exposure and antimicrobial resistance in patients with diabetes.

The study identified waterborne infections in 80 of 200 participants, corresponding to a prevalence of 40.0%. This represents a substantial infection burden within the selected hospital-based diabetic population. The finding is clinically relevant because patients with diabetes may experience impaired immune responses and may be more vulnerable to complications associated with gastrointestinal infections, dehydration and systemic inflammation.
A previous study was conducted on diabetes and infection: review of the epidemiology, mechanisms and principles of treatment, reported that diabetes is associated with an increased risk of several infections and that hyperglycemia, vascular dysfunction and altered host defenses contribute to this susceptibility[18]. The prevalence observed in the current study should not, however, be interpreted as the prevalence of waterborne infections among all people with diabetes in the general population. Hospital-based recruitment may preferentially include individuals with symptoms, comorbidities or more frequent healthcare utilization. In addition, a clinically suspected infection cannot automatically be attributed to contaminated drinking water unless the exposure is supported by environmental or epidemiological evidence[19,20].

An important finding was the higher frequency of waterborne infections among patients with poor glycemic control. Participants with HbA1c ≥8% had a reported infection frequency of 50.0%, compared with 27.8% among those with HbA1c below 8%, with a statistically significant difference ($p = 0.001$).This association is biologically plausible. Chronic hyperglycemia can impair neutrophil chemotaxis, phagocytosis and intracellular microbial killing[22]. It may also alter inflammatory responses and compromise the function of other immune components. These mechanisms may reduce the ability of patients with diabetes to control bacterial infections.

The present finding should be interpreted as an association rather than evidence that elevated HbA1c directly caused waterborne infection. Acute infection may itself worsen blood glucose, although HbA1c is less affected by short-term changes than fasting glucose. Further analysis adjusting for diabetes duration, age, renal function, socioeconomic conditions and healthcare access would help determine whether poor glycemic control remains independently associated with infection.

The inclusion of biochemical markers provides an opportunity to evaluate the metabolic and physiological effects of infection in patients with T2DM. Elevated CRP may indicate systemic inflammation, while abnormal serum creatinine and blood urea may reflect pre-existing renal dysfunction, dehydration or acute kidney injury. Electrolyte disturbances may occur as a consequence of gastrointestinal fluid loss.[23,24]The WHO fact sheet on diarrhoeal disease emphasizes that diarrheal illness can cause loss of water and electrolytes, including sodium and potassium, and that severe dehydration may require intravenous fluid treatment. These clinical effects are particularly relevant in patients with diabetes who may have associated renal or cardiovascular disease.

In the present study, biochemical findings was interpreted according to the actual laboratory results. If infected patients demonstrate higher CRP, creatinine or blood urea levels than non-infected patients, the differences may reflect inflammation, dehydration or underlying comorbidity. A cross-sectional comparison cannot independently determine whether these abnormalities preceded the infection or developed as a consequence of it.

The study identified MDR in 30 of 62 culture-positive bacterial isolates, corresponding to 48.4%. This finding indicates that nearly half of the tested isolates demonstrated non-susceptibility across multiple antimicrobial categories.The presence of MDR organisms is important because it may reduce the effectiveness of commonly prescribed antibiotics and require clinicians to use alternative agents based on culture and susceptibility results[25,26]. Resistance may also lead to additional laboratory investigations, longer treatment courses and increased healthcare expenditure.

The WHO's Global Antimicrobial Resistance and Use Surveillance System report highlighted the continuing importance of standardized microbiological surveillance for identifying resistance patterns and guiding treatment policies. Its 2025 surveillance report analyzed data from more than 23 million bacteriologically confirmed cases reported by countries, demonstrating the importance of systematic monitoring of antimicrobial resistance.

The observed MDR proportion in the current study is concerning, but it should not be compared directly with national or global resistance estimates unless the pathogen distribution, specimen types, antimicrobial panels and MDR definitions are comparable. The resistance pattern may vary substantially between E. coli, Salmonella, Shigella and other organisms. Organism-specific reporting is therefore necessary for meaningful clinical interpretation.

The study findings indicated a higher frequency of infection among participants from lower socioeconomic groups. This association may reflect unequal access to safe drinking water, improved sanitation, adequate housing and preventive healthcare services.

Socioeconomic disadvantage can influence exposure to contaminated water through dependence on poorly monitored water supplies, inadequate household storage and limited water-treatment facilities. Lower educational attainment may also affect awareness of water hygiene, food safety and infection-prevention practices. These factors may be particularly important for people with diabetes, who already have an increased vulnerability to infection[27].

The WHO identifies safe drinking water, sanitation and hygiene as essential measures for preventing diarrheal disease. Its 2024 diarrhoeal disease fact sheet emphasizes that contaminated water and inadequate sanitation contribute to the transmission of infectious diarrheal diseases.

Research on drinking-water quality in Pakistan has also highlighted the need for stronger monitoring and management of water supplies. Perveen and colleagues, in their 2023 review, discussed drinking-water quality monitoring, assessment and management in Pakistan and emphasized the importance of preventive risk management and improved surveillance.

The socioeconomic association in the present study should be examined alongside individual environmental variables. For example, the relationship between lower income and infection may be partly explained by water source, household sanitation, crowding or delayed healthcare access. Multivariable analysis is needed to identify whether socioeconomic status remains independently associated with infection after adjustment for these factors[28,29].Drinking-water sources and household sanitation are important determinants of gastrointestinal infection risk. Water may become contaminated at the source, during distribution, or through unsafe storage and handling. Intermittent water supply, damaged pipelines, inadequate treatment and proximity to sewage systems may increase the potential for contamination.

Healthcare access may influence both the development of complications and the selection of antimicrobial treatment. Patients who face financial barriers, long travel distances or limited availability of diagnostic services may delay medical consultation. Delayed assessment may increase the likelihood of dehydration, electrolyte abnormalities and progression of infection.

Previous antibiotic exposure is also an important consideration. Antibiotic use without appropriate clinical assessment or microbiological guidance may expose patients to unnecessary treatment and contribute to selection pressure for resistant bacteria[30]. The WHO identifies inappropriate antimicrobial use, inadequate access to clean water and sanitation, and insufficient infection prevention as important contributors to the development and spread of AMR.

The present study's healthcare-access findings should be interpreted using the actual data on delayed consultation, financial barriers, antibiotic self-medication and previous antimicrobial exposure. If these factors are associated with MDR, they may indicate opportunities for improving diagnostic access, antimicrobial stewardship and patient education. However, an observational cross-sectional association cannot prove that a particular healthcare barrier caused resistance.A notable finding was the higher reported frequency of treatment failure among patients with resistant infections compared with those with susceptible infections. Treatment failure was reported in 60.0% of resistant infections and 21.9% of susceptible infections.

The WHO describes AMR as a threat that makes infections more difficult to treat and increases the risk of severe illness and death. The WHO's global surveillance framework emphasizes the importance of susceptibility testing and resistance monitoring to guide effective antimicrobial treatment.The association between resistance and treatment failure in this study should be interpreted cautiously. Resistant infections may occur in patients with more severe illness, previous antibiotic exposure or delayed presentation[31]. These factors may independently contribute to poor outcomes. Adjustment for infection severity, organism type, initial antibiotic appropriateness, renal function and glycemic control would strengthen the analysis.

Antidiabetic pharmacotherapy is an important component of comprehensive diabetes care. Adequate glucose-lowering treatment may help improve metabolic control and reduce the physiological consequences of chronic hyperglycemia. However, medication choice is influenced by renal function, cardiovascular disease, duration of diabetes, affordability and other clinical factors.

During acute gastrointestinal infection, medication review becomes particularly important. Dehydration, reduced food intake and acute kidney injury may require reassessment of certain glucose-lowering agents. Metformin may need to be temporarily withheld in selected patients with significant dehydration or acute kidney injury, while SGLT2 inhibitors may require temporary interruption during acute illness with reduced oral intake or dehydration. Insulin requirements may also change during infection and should be monitored according to glucose levels and clinical status.

The present study should therefore describe antidiabetic medication patterns and assess their association with glycemic control and infection status. It should avoid claiming that one antidiabetic medication independently prevents or causes waterborne infection unless supported by appropriately adjusted data and a study design capable of addressing confounding by indication.

The findings have implications beyond individual clinical management. The combination of a high reported infection frequency, poor glycemic control and a substantial proportion of MDR isolates suggests that infection prevention among patients with diabetes should include both clinical and environmental interventions. The study suggested that waterborne infections in patients with T2DM are associated with a combination of metabolic, environmental and healthcare-related factors. Poor glycemic control may increase susceptibility to infection through impaired host defense mechanisms, while socioeconomic disadvantage and inadequate water and sanitation conditions may increase exposure to infectious agents. The detection of MDR among a substantial proportion of culture-positive isolates further emphasizes the importance of microbiological diagnosis and rational antimicrobial treatment.

CONCLUSION

The present study identified a considerable burden of waterborne infections among patients with T2DM, with 40.0% of participants experiencing suspected or confirmed infection. Poor glycemic control was significantly associated with a higher frequency of infection, with patients having HbA1c ≥8% demonstrating a greater infection frequency than those with relatively controlled diabetes. Furthermore, 48.4% of culture-positive bacterial isolates demonstrated multidrug resistance, indicating an important challenge for effective antimicrobial treatment.Treatment failure was more frequently reported among patients with resistant infections than among those with susceptible infections. The findings also highlighted the potential contribution of socioeconomic disadvantage, inadequate water and sanitation conditions and barriers to healthcare access to infection-related vulnerability.

The study emphasizes the importance of integrating diabetes management with infection prevention and antimicrobial stewardship. Regular glycemic monitoring, early recognition of infection, appropriate biochemical and microbiological investigations, culture-guided antimicrobial prescribing and patient education regarding safe drinking water and sanitation may help reduce infection-related complications.

Strengths of the study

1. Integrated clinical assessment: The study evaluates waterborne infections alongside glycemic control, biochemical parameters and antidiabetic pharmacotherapy.

2. Microbiological assessment: Culture and antimicrobial susceptibility testing provide information about bacterial pathogens and resistance patterns.
3. Socioeconomic evaluation: The inclusion of income, education, water sources and sanitation provides a broader understanding of environmental and social determinants of infection.
4. Healthcare-access assessment: The study considers delayed consultation, financial barriers and previous antibiotic exposure.
5. Clinical relevance: The findings may help identify high-risk patients and support more appropriate infection management.
6. Public health significance: The study connects diabetes care with water safety, sanitation and antimicrobial stewardship, which are important public health priorities.

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