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Data-Driven Identification of Risk-Prone Zones and Wards in Ahmedabad Using Statistical Analysis of Water Quality and Waterborne Disease Data

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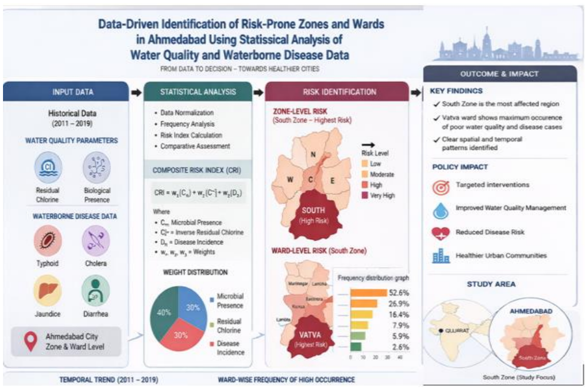
Abstract - Rapid urbanization in developing cities has significantly increased pressure on water supply systems, leading to deterioration in water quality and a rise in waterborne diseases. This study adopts a data-driven approach to identify vulnerable urban zones in Ahmedabad, Gujarat, India, through the analysis of historical water quality parameters and ward-level disease incidence data. The study identifies the south zone as a high-risk-prone zone and Vatva Ward in the south zone as a risk-prone ward.

GRAPHICAL ABSTRACT



Keywords: Waterborne diseases, water quality, risk zonation, statistical analysis, Ahmedabad

I. INTRODUCTION

A. General

Water is one of the basic requirements for the survival of human beings. Life cannot exist without water. Comprising 50–70% of body weight, water is the main component of the human body. Water is essential for the efficient operation of every system and cell of the human body. Inadequate water consumption can have an immediate negative impact on health and well-being.

B. Impact of water quality on society

The quality of the water is an important factor that has a significant influence in determining the health of individuals, communities, and the whole environment.

Poor water quality can significantly affect society in different ways, as follows:

- Public health: Dirty water can spread diseases such as cholera, typhoid, dysentery, and jaundice. Long-term exposure to polluted water with pollutants (such as heavy metals and pesticides) can cause long-term health problems like cancer, organ damage, and developmental problems.
- Economic Impact: Outbreaks of disease caused by contaminated water raise healthcare expenses. Sick people are less productive at work. Contaminated source water increases the burden on water treatment facilities.
- Social Well-being: Clean water access reduces societal inequalities and improves the overall quality of life. Poor communities often face the worst effects due to a lack of resources for proper water treatment.
- Agriculture & Food Security: Contaminated water used for irrigation purposes affects crop yield and quality. Bioaccumulation of harmful substances in food chains affects the health of both animals and humans.
- Environmental Impact: Degraded water bodies affect aquatic ecosystems and biodiversity.

C. Water supply system

To provide a reliable supply of safe and adequate water, a modern community must design and implement a water supply system that delivers potable water in line with the population's need and consumption pattern. This will help in supplying safe, wholesome water for domestic demand and also help in supplying water for public, commercial, industrial, and firefighting purposes. Water supply systems, therefore, help to promote the health, wealth, and welfare of all of humanity.

A typical water supply system is made up of several interconnected components that work together to guarantee that

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Vol. 15 Issue 04 , April - 2026

community members have access to water that is both safe and sufficient. For a water distribution system to work well, it needs to be well-designed, regularly maintained, and constantly monitored to ensure that the people who use it get water that is not just acceptable but also plentiful and reliable. Water treatment plants clean water so that it meets drinking water quality requirements.

As per Indian Standard IS 10500:2012, the water quality is defined based on the desirable and permissible limits of various physical, chemical, microbiological, and radiological parameters. These standards make sure that drinking water is safe and good for people to drink. The permitted limits only apply if there is no other supply of water that fulfills those levels. Table 1 shows the criteria and the acceptable and permitted levels for drinking water quality, as set out in IS 10500:2012.

Table** Error! No text of specified style in document.**: Drinking Water Quality Standards IS 10500-2012

Characteristic	Requirement (Acceptable limit)	Permissible limit in absence of alternate source (alternate
Physical Parameters		
Colour (Hazen units) max	5	15
Odour	Aggregable	Aggregable
Taste	Aggregable	Aggregable
Turbidity (NTU) max	1 NTU	5 NTU
pH	6.5–8.5	No relaxation
Chemical Parameters		
Total Dissolved Solids (TDS) mg/L max	500	2,000
Chloride (as Cl) mg/L, Max	250	1,000
Sulphate (as SO_4^{2-}) mg/L, Max	200	400
Nitrate (as NO_3^-) mg/L, Max	45	No relaxation
Fluoride (F^-) mg/L, Max	1.0	1.5
Iron (Fe) mg/L Max	0.3	No relaxation
Arsenic (As) mg/L, Max	0.01	0.05
Lead (Pb) mg/L, Max	0.01	No relaxation
Mercury (Hg) mg/L, Max	0.001	No relaxation
Cadmium (Cd) mg/L, Max	0.003	No relaxation
Microbiological Parameters		
E. coli (Thermotolerant coliforms)	Not detectable in 100 mL	N/A
Total Coliform Bacteria	Not detectable in 100 mL	N/A
Radiological parameters		
Gross Alpha Activity	$\leq$ 0.1 Bq/L	No relaxation
Gross Beta Activity	$\leq$ 1.0 Bq/L	No relaxation

Source: https://cpcb.nic.in/wqm/BIS_Drinking_Water_Specification.pdf

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 04 , April - 2026

This rule says that water should have a pH between 6.5 and 8.5, a turbidity that should not be more than 1 NTU, and a maximum TDS content that should be 500 mg/L. There is no relaxation for some harmful contaminants, like nitrates, iron, lead, and mercury. This means that their amounts must always stay within the acceptable ranges. Biological contaminants such as E.coli and total coliforms must not be detected in 100 mL water samples. There are also definite top limits for both alpha and beta operations, and radiological standards are also followed. It is common practice to treat raw water that is collected from the source up to the required standards and supply it to the end consumer via the drinking water distribution network. Sometimes certain biological, physical, and chemical impurities enter into the distribution network and make water unsafe to use.

Microbial infections are one of the biggest threats, and they often cause outbreaks of diseases that spread by water, such as cholera, typhoid, jaundice, and dysentery. Once infections get into the system, they can spread quickly and affect a lot of people. This is why early detection and risk assessment are so important. CAWST (2009) says that better water and sanitation are important for breaking the cycle of poverty because they immediately improve people's health, physical strength, and the capacity of students to attend school consistently. Poor water quality not only makes health concerns worse, but it also makes it harder to get an education and be productive at work.

This matter plays a key role in the United Nations Sustainable Development Goals (SDGs).

The UN approved the 2030 agenda for sustainable development in September 2015, which has 169 targets to achieve 17 sustainable development goals.

This research is related to SDG 3 and SDG 6, which specifically highlight the need for high water quality and good health.

As per The Water Gap—The State of the World's Water 2018 report by WaterAid, "just 10 countries account for 60% of the world population without access to clean water." India is one of these countries, as shown in Figure 1.

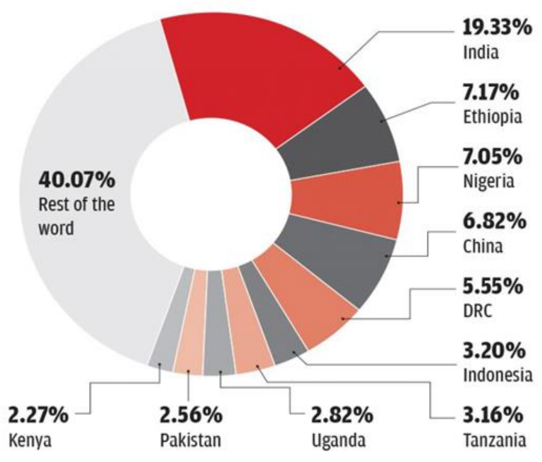

Figure 1: The Status of the World's Water

Source: https://www.downtoearth.org.in/water/19-of-world-s-people-without-access-to-clean-water-live-in-india-60011. (Report by WaterAid—2018)

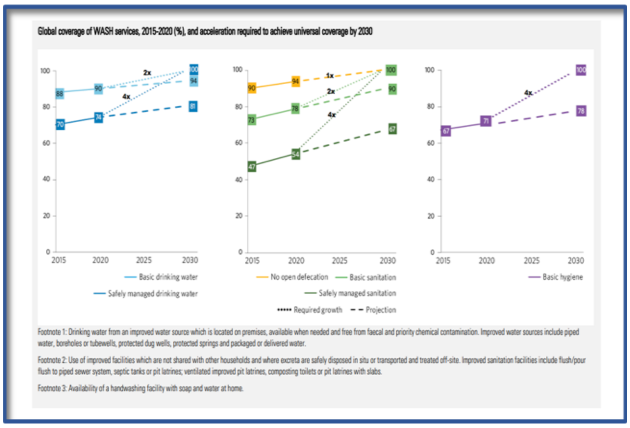

Figure 2: Worldwide coverage of WASH services

As per the Sustainable Development Goal extended report 2022, as shown in figure 2, the graph illustrates the worldwide coverage of WASH services, specifically focusing on drinking water, from 2015 to 2020 with projections to 2030.

It clearly highlights that while progress is being made in providing access to drinking water globally, the current pace is insufficient to achieve universal access by the 2030 deadline for the SDGs. Significant acceleration is required, especially for safely managed drinking water services.

D. Urban Challenges in Indian Cities

Rapid urbanization in India has led to significant pressure on urban infrastructure, particularly in water supply and public health systems. Cities like Ahmedabad are experiencing accelerated population growth, resulting in increased demand for safe drinking water and sanitation services. However, this growth is often unplanned, leading to disparities in infrastructure development across different wards.

One of the major challenges is the aging and inadequate water distribution network, which is prone to leakages and contamination. Intermittent water supply systems create negative pressure in pipelines, increasing the risk of intrusion of contaminants, including pathogens. This directly affects residual chlorine levels and promotes microbial contamination, making water unsafe for consumption.

Another critical issue is inefficient wastewater and sewage management. In many urban areas, sewage lines run parallel to water pipelines, and leakages or cross-connections can lead to contamination of drinking water sources. This significantly contributes to the spread of

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 04 , April - 2026

waterborne diseases such as diarrhea, typhoid, cholera, and jaundice.

Additionally, unequal service delivery across wards results in certain zones being more vulnerable than others. Informal settlements and densely populated areas often lack proper infrastructure, making them high-risk zones for disease outbreaks. Limited real-time monitoring and insufficient data integration further hinder effective decision-making.

Climate variability and seasonal factors, such as monsoon rainfall, exacerbate these challenges by increasing the likelihood of flooding and contamination events. Despite ongoing efforts by municipal authorities, there remains a need for data-driven approaches to identify vulnerable zones and prioritize interventions.

Addressing these challenges requires integrated urban planning, improved infrastructure, continuous water quality monitoring, and targeted public health strategies to ensure safe and equitable water access.

II. STUDY AREA

The present study is conducted in Ahmedabad, one of the largest metropolitan cities in western India and a major economic and industrial hub of Gujarat. The city is situated on the banks of the Sabarmati River and lies between approximately 22.97° N latitude and 72.57° E longitude. Ahmedabad has experienced rapid urban expansion over the past few decades, driven by industrial growth, migration, and infrastructure development, resulting in a substantial increase in population and spatial extent.

Administratively, the city is governed by the Ahmedabad Municipal Corporation (AMC) and is divided into multiple administrative zones and wards to facilitate urban management and service delivery. These wards exhibit considerable variation in terms of population density, socio-economic characteristics, and availability of basic infrastructure. Such heterogeneity makes Ahmedabad an appropriate case for studying spatial disparities in water quality and associated public health risks.

The primary sources of water supply in the city include surface water from the Narmada Canal and Sabarmati River, supplemented by groundwater in certain areas. The water is treated at centralized treatment plants and distributed through an extensive pipeline network. However, challenges such as aging infrastructure, intermittent supply, pipeline leakages, and unauthorized connections can compromise water quality at the consumer end. These issues are particularly prominent in densely populated and older parts of the city.

Climatically, Ahmedabad is characterized by a semi-arid climate with hot summers, moderate monsoon rainfall, and mild winters. Seasonal variations, especially during the monsoon period, can influence water quality by increasing the risk of contamination through surface runoff and sewer overflows. Such conditions often correlate with a rise in waterborne diseases, including diarrhea, typhoid, cholera, and jaundice.Given its diverse urban structure, varying infrastructure conditions, and documented public health concerns, Ahmedabad provides a suitable and representative setting for analyzing the relationship between water quality parameters—specifically residual chlorine and microbial presence—and the spatial distribution of waterborne diseases at the ward level.

III. OBJECTIVES

- To analyze historical water quality data
- To analyze waterborne disease trends
- To identify risk-prone zones/wards

IV. Methodology

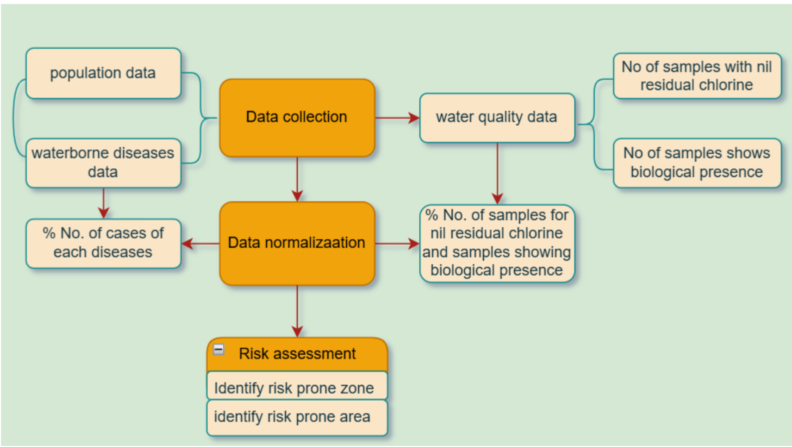

Figure 3: Methodology Chart

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 04 , April - 2026

V. DATA COLLECTION

Data collection is essential in research, directly influencing the accuracy of conclusions drawn from a study.

A. Water quality data

This document discusses the collection of water quality and waterborne disease data from Ahmedabad city between 2011 and 2019, focusing on illnesses such as typhoid, cholera, jaundice, and acute gastroenteritis across its administrative zones. The Ahmedabad Municipal Corporation oversees the collection and analysis of drinking water samples twice in a month to ensure quality, assessing parameters like residual chlorine and biological pollutants. Reports detailing the number of samples, instances of biological pollutants, and residual chlorine levels from each zone were compiled for this study, utilizing data from the water distribution network. Table 2 shows raw water quality data for January 2011.

Table 2: Water quality data for January 2011

Date	Zone	Distribution system			Municipal origin		
		Total number of samples (Res. Tap)	No. of samples with biological presence out of limit	No. of samples containing residual chlorine	Total number of samples (Res. Tap)	No. of samples with biological presence within limit	No. of samples containing residual chlorine
01-01-2011 to 15-01-11	East	221	02	194	280	280	280
	West	233	00	228	--	--	--
	New west	236	13	201	--	--	--
	North	425	01	395	--	--	--
	South	55	02	48	--	--	--
	Central	291	05	286	--	--	--
	Total	1461	23	1352	280	280	280
16-01-2011 to 31-01-11	East	267	01	237	280	280	280
	West	283	06	268	--	--	--
	New west	273	11	251	--	--	--
	North	452	04	422	--	--	--
	South	181	01	161	--	--	--
	Central	281	02	274	--	--	--
	Total	1737	25	1613	280	280	280

B. Waterborne disease data

For the purpose of this research, waterborne disease data were obtained from the Health Department of the AMC, covering the period from 2011 to 2019. The dataset includes the number of cases for four specific diseases—typhoid, cholera, jaundice, and acute gastroenteritis (AGE)—for each ward across all zones of the city.

International Journal of Engineering Research & Technology (IJERT)
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Vol. 15 Issue 04 , April - 2026

C. *Data on population*

The Ahmedabad Census Department provided the 2011 census statistics for the city. The website provided the population growth rate. Waterborne illness statistics were normalized using this demographic data. Ahmedabad's population growth trend from 1950 to 2034 is shown in Figure 4.

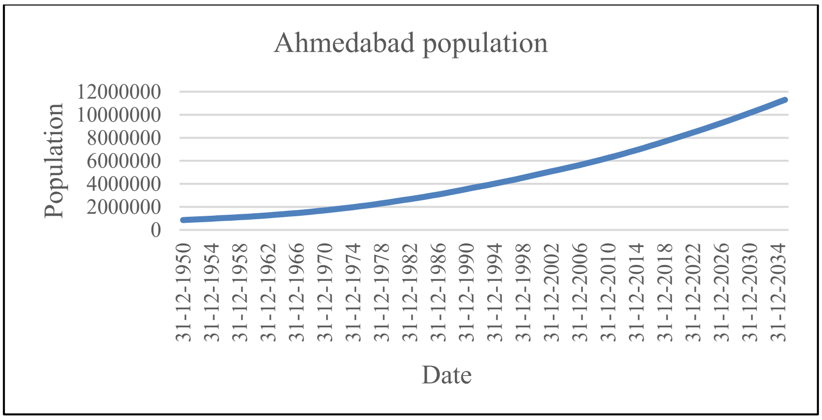
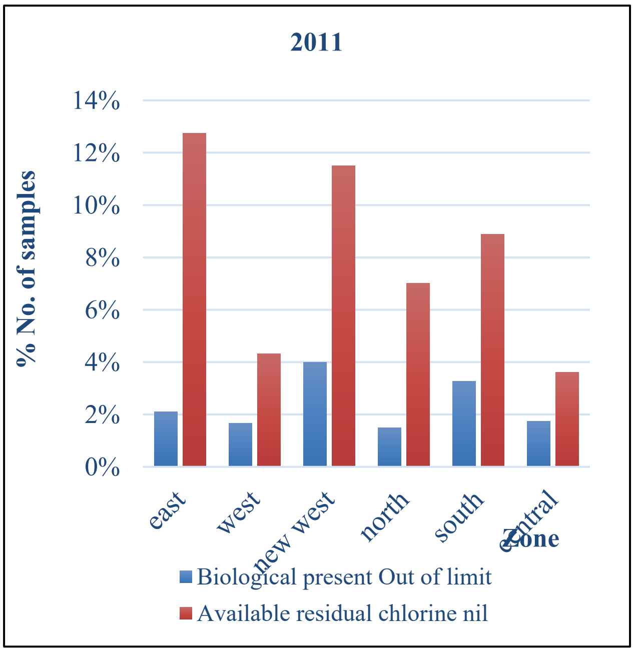


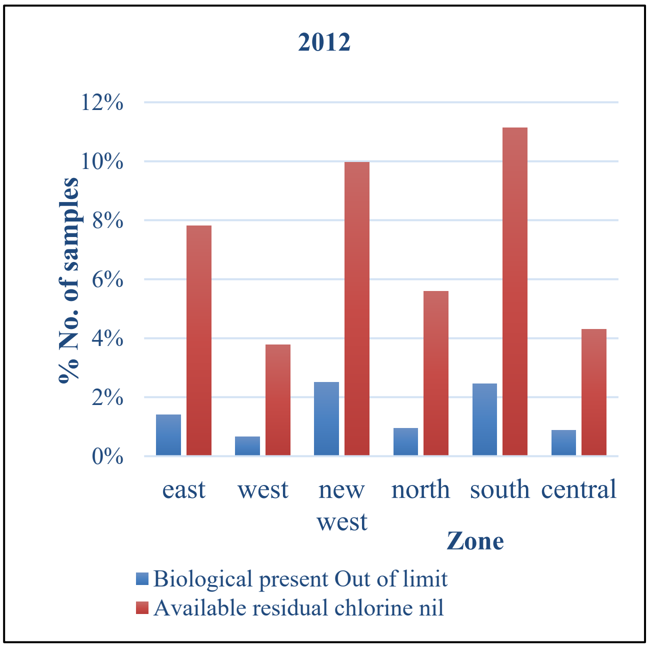
Figure 4: Population data of Ahmedabad

VI. DATA NORMALIZATION

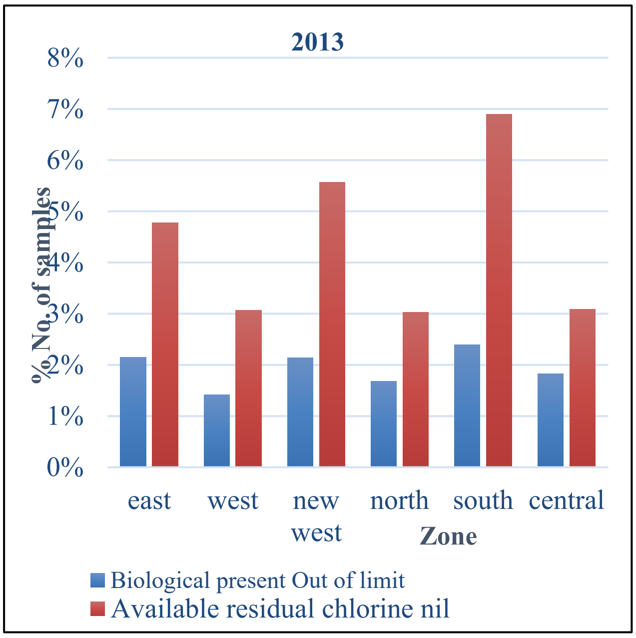
A. *Water quality*

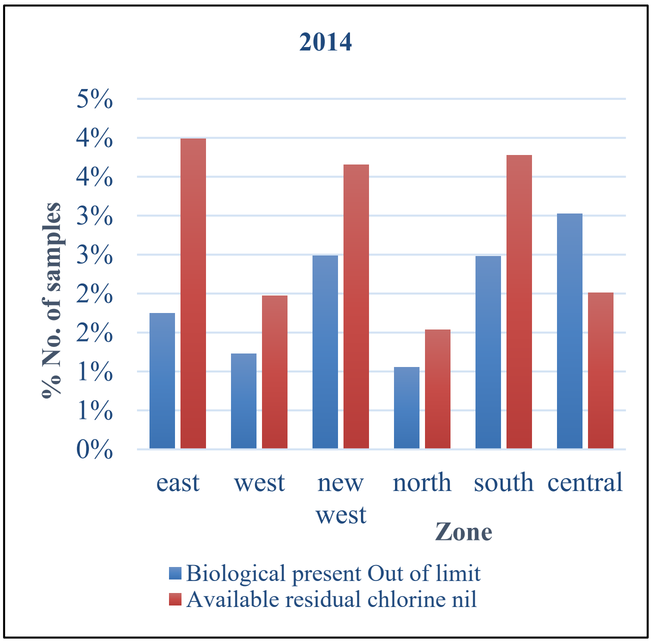
The data on water quality in Ahmedabad showed varying sample counts across different zones. To achieve uniformity for effective comparison, the data were normalized into percentages reflecting samples with nil residual chlorine and biological contamination. This involved calculating total samples per year for each zone as a base (100%). The proportions of biologically contaminated samples and those with residual chlorine were determined using specific formulae, ensuring consistent analysis across zones. Graphs were then created to compare water quality status across various years.

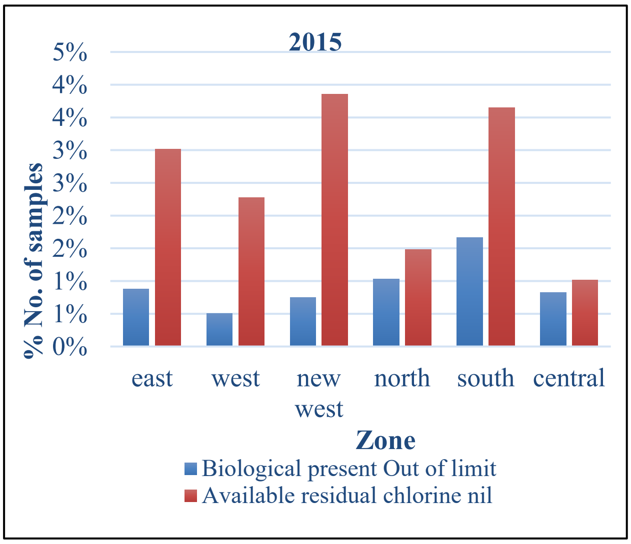


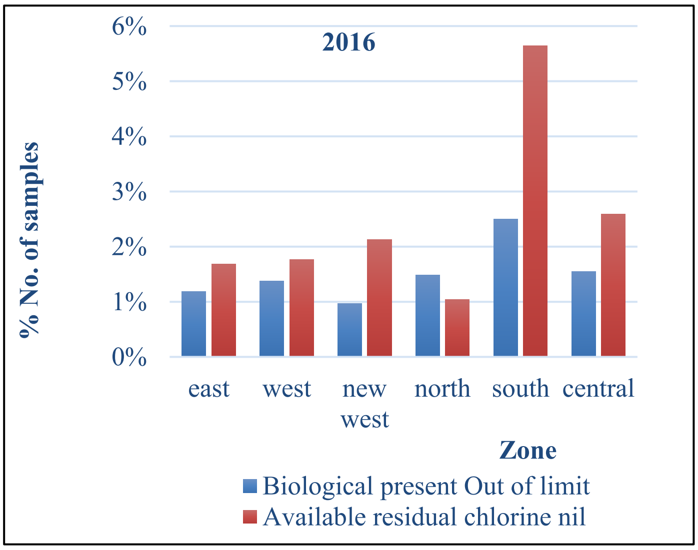


International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 04 , April - 2026

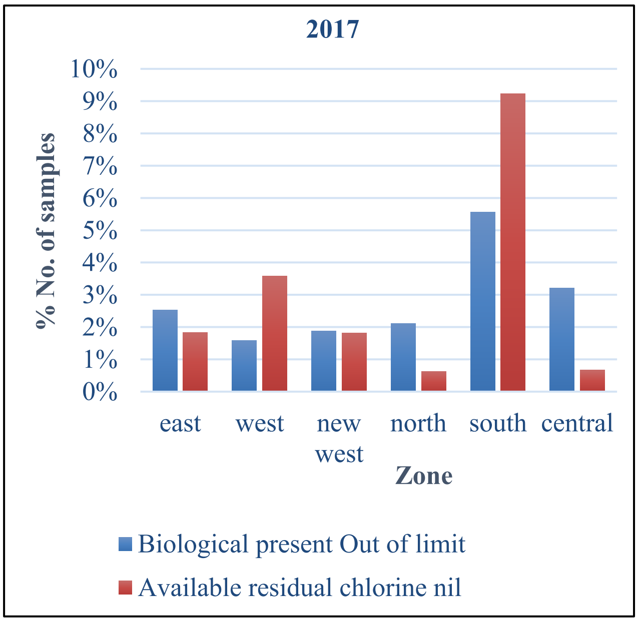


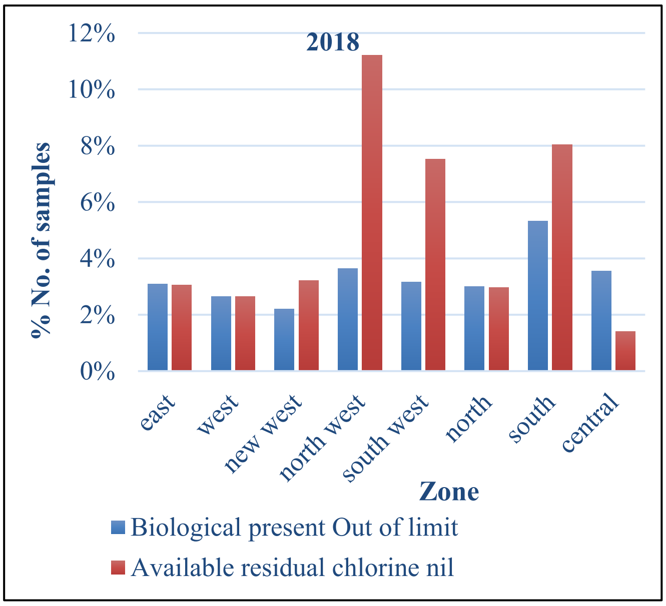






International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 04 , April - 2026





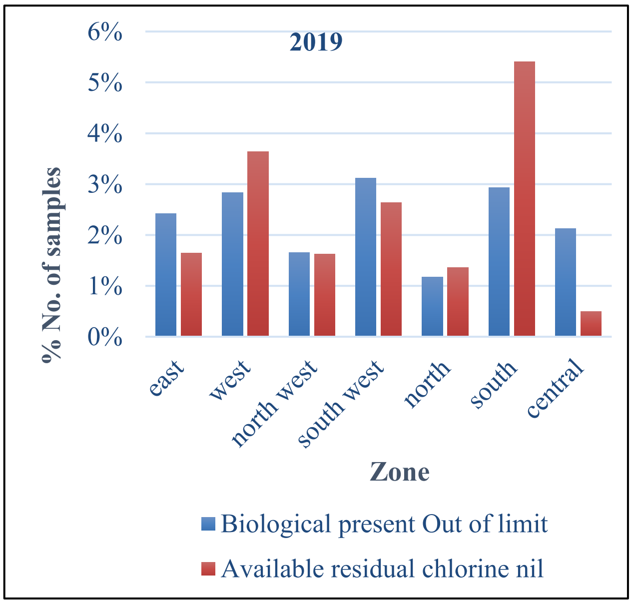


Figure 5: Graph showing water quality data for the years 2011 to 2019

B. Normalization of disease data

Step 1: Determination of Ward Population Proportion

Demographic data were utilized to obtain the total population of individual wards (P_w)and the overall population of Ahmedabad city (P_c). The proportional contribution of each ward to the city's total population was computed using the following expression:

$$\%P_w = (P_w/P_c) \times 100$$

This calculation provides a relative measure of population distribution across different wards.

Step 2: Projection of Annual Ward Population

To estimate population changes over time, the ward population for subsequent years was projected using the city's average annual growth rate (r). Starting from the base year population (P_{w0}), future population values were calculated using a compound growth model:

- $P_{wt} = P_{w0} \times (1+r)^t$

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 04 , April - 2026

This approach accounts for continuous population growth over time.

Step 3: Standardization of Disease Incidence

The reported number of disease cases in each ward (D_{wt})was standardized with respect to the corresponding projected population (P_{wt}). This was done to eliminate the influence of varying population sizes across wards. The normalized disease incidence was calculated as:

Normalized Disease Incidence =

$$(D_{wt} / P_{wt}) \times 100$$

This transformation ensures comparability of disease prevalence across different wards and years.

Step 4: Statistical Evaluation and Visualization

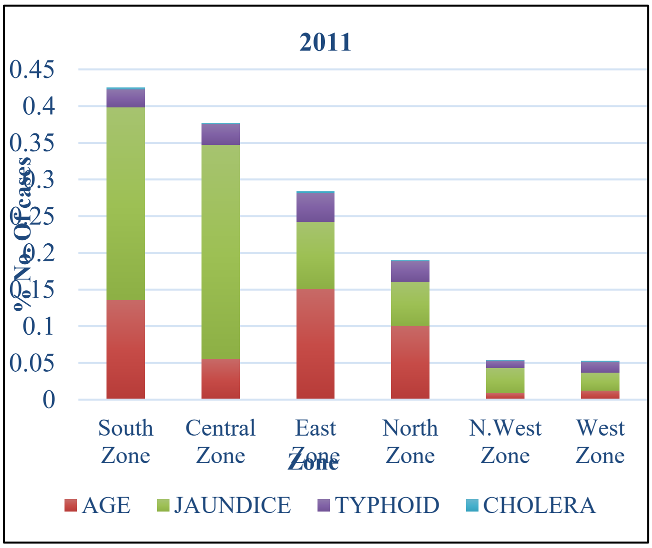
The normalized datasets for the period 2011–2019 were systematically compiled and analyzed. Graphical representations were developed by plotting ward-wise (or zonal) data along the X-axis and the corresponding percentage of disease incidence along the Y-axis. Separate graphs were prepared for each category of waterborne disease.

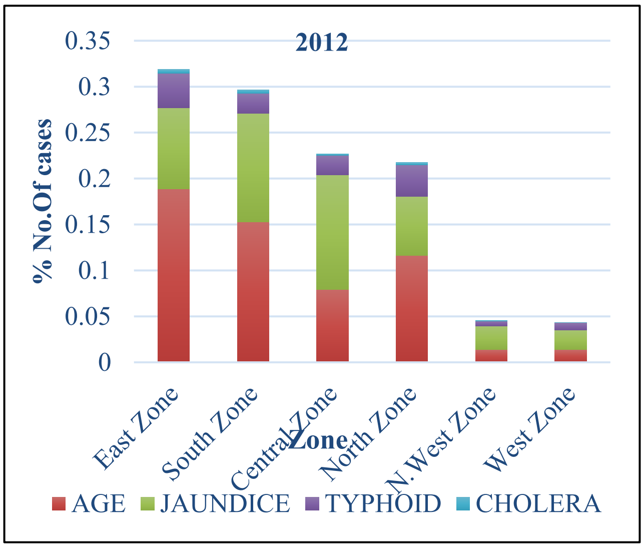
This analysis facilitated:

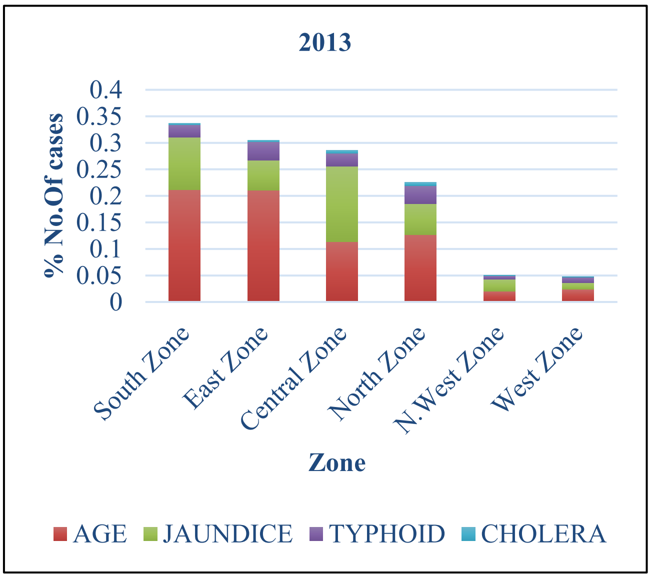
Identification of spatial differences in disease distribution across wards,

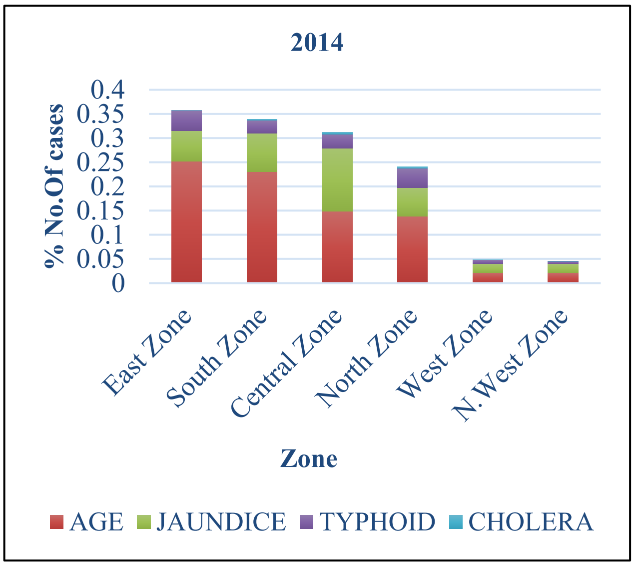
Examination of temporal variations over the study period, and

Recognition of high-risk zones that require prioritized intervention.









International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 04 , April - 2026

Figure 6: Graph showing normalized waterborne diseases Data for the year 2011-2019

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 04 , April - 2026

VII. RISK ASSESSMENT AND IDENTIFICATION OF RISK-PRONE ZONES:

Following the normalization and statistical analysis of water quality and disease data, a risk assessment procedure was undertaken to delineate vulnerable zones and to identify high-risk wards within those zones.

A. Identification of Risk-Prone Zones:

An integrated analysis of normalized water quality parameters (residual chlorine and microbial presence) and waterborne disease incidence was performed to determine spatial risk patterns across the study area. Based on this assessment, zones exhibiting the highest and second-highest levels of disease incidence, coupled with deteriorated water quality conditions, were identified for each year within the study period.

B. Frequency-Based Zone Analysis

To evaluate the consistency of risk across different zones, a frequency analysis was conducted using data from 2011 to 2019. For each zone, the number of occurrences representing high disease incidence and poor water quality was counted across all study years. This frequency was then expressed as a percentage of the total number of years considered, providing a measure of relative vulnerability as shown in figure 7.

The results of this analysis indicate that the **South Zone** (S) consistently recorded the highest frequency of occurrence, suggesting a persistent pattern of elevated risk. This highlights the South Zone as the most vulnerable region in comparison to other zones within Ahmedabad.

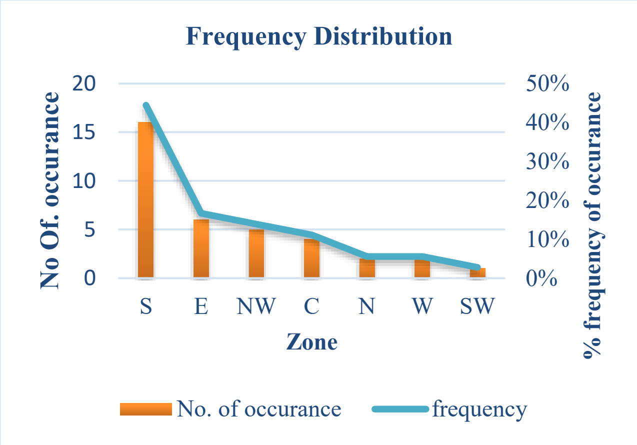
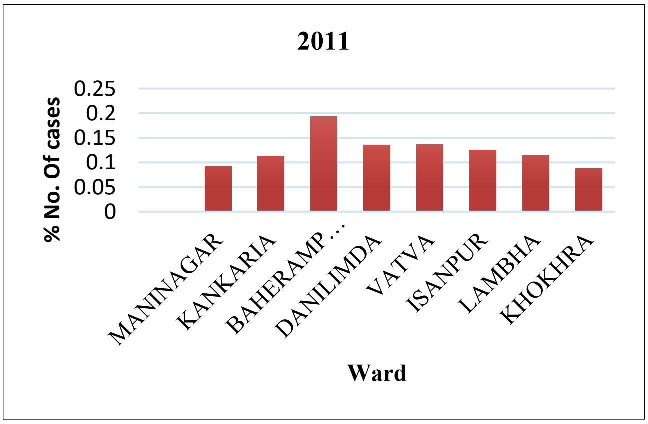
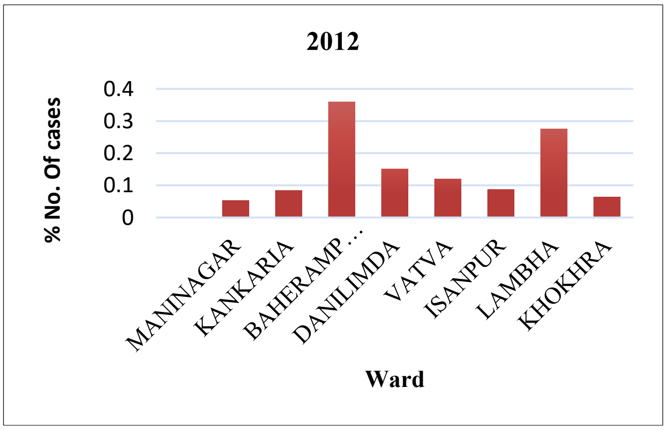


Figure 7: Frequency distribution for zone identification

The South Zone of Ahmedabad consists of multiple wards, including Maninagar, Kankaria, Baherampura, Danilimda, Vatva, Isanpur, Lambha, and Khokhra. To identify vulnerable locations within this zone, the analytical approach used for zone-level assessment was further applied at the ward level. For each year of the study period, graphical representations were developed to evaluate and compare ward-wise variations in water quality conditions and the incidence of waterborne diseases.





International Journal of Engineering Research & Technology (IJERT)
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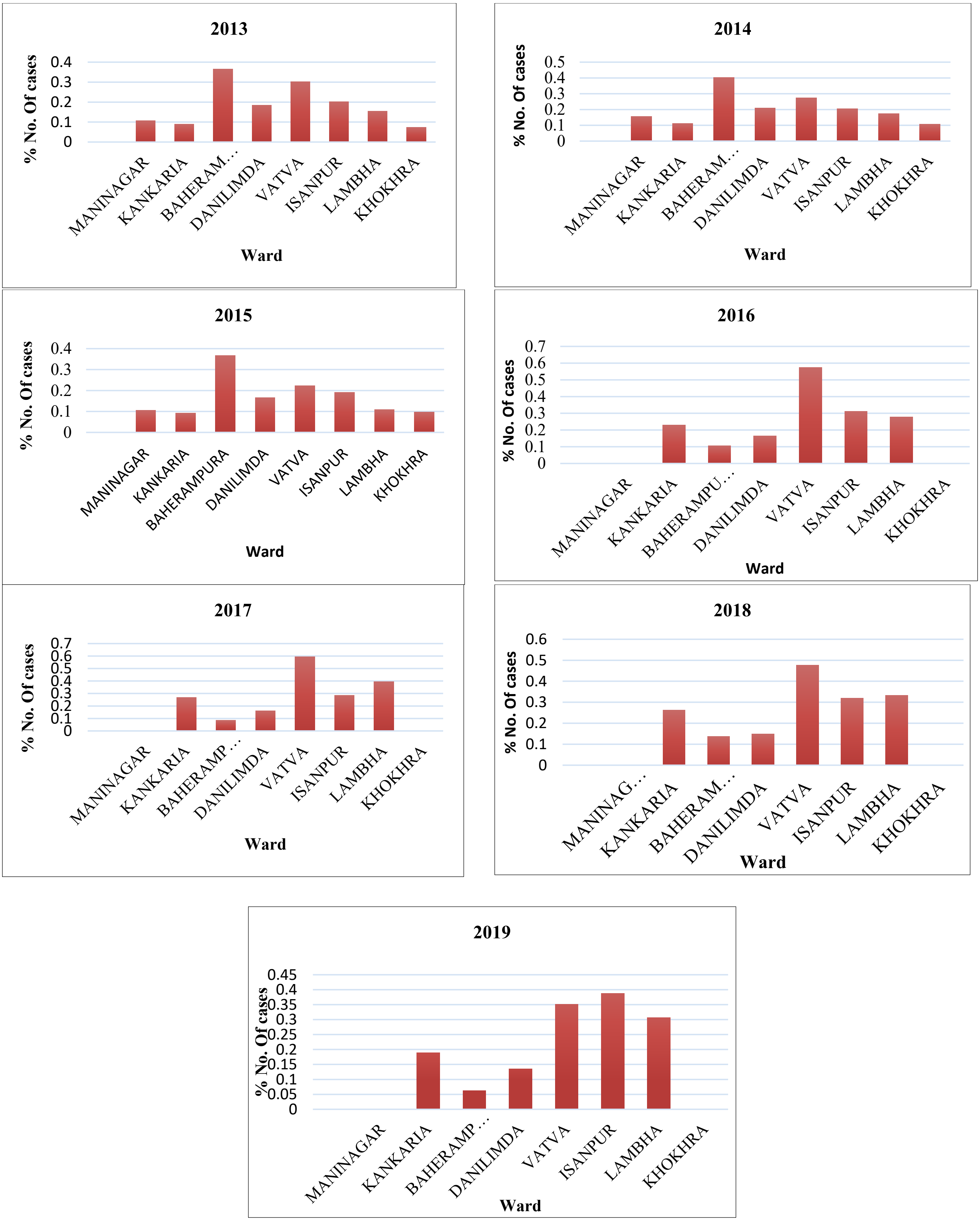

Figure 8: Graphs showing % no. of cases for different wards of the south zone

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 04 , April - 2026

The annual observations were further analyzed using a frequency distribution approach. For each year within the study period, the wards reporting the highest and second-highest number of waterborne disease cases were identified. Subsequently, the number of occurrences of each ward within these categories was computed over the entire study duration. The resulting frequencies were then expressed as percentages relative to the total number of years considered. A graphical illustration of this distribution is provided in Figure 9.

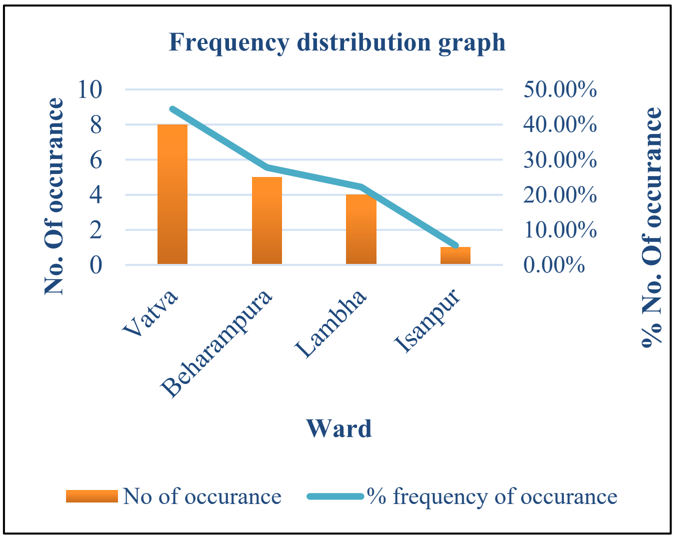

Figure 9: Frequency distribution graph for ward identification

The analysis indicates that Vatva Ward exhibits the highest frequency of occurrence, thereby identifying it as the most vulnerable ward within the South Zone. This finding highlights the need for prioritized interventions in this area. It is recommended that targeted measures be implemented to improve water quality conditions in Vatva, which would contribute to reducing the prevalence of waterborne diseases and enhancing overall public health outcomes.

VIII. RESULTS AND DISCUSSION

A. *Water Quality and Disease Relationship*

The analysis revealed a strong association between water quality deterioration and the prevalence of waterborne diseases. Wards exhibiting **low residual chlorine levels** and **high microbial contamination** consistently reported higher incidences of diarrhea, jaundice, typhoid, and cholera. This confirms that inadequate disinfection and contamination within the distribution system are major contributing factors to disease outbreaks.

B. *Spatial Distribution of Risk*

The zonal analysis identified the **South Zone** as the most vulnerable region, with the highest frequency of poor water quality and disease occurrence during the study period (2011–2019). Within this zone, several wards repeatedly exhibited elevated risk index values, indicating persistent infrastructure and sanitation challenges.

C. *Ward-Level Risk Assessment*

Application of the Composite Risk Index enabled clear differentiation of wards into risk categories. A small proportion of wards fell under the high-risk category, characterized by the following:

Consistently low residual chlorine levels

- High coliform contamination
- Elevated disease incidence rates

These wards represent critical hotspots requiring immediate attention.

D. Temporal Trends

Over the study period, fluctuations in disease incidence were observed, with peaks often corresponding to periods of compromised water quality. Seasonal influences, particularly during monsoon months, likely contributed to increased contamination and subsequent disease outbreaks.

E. *Policy-Oriented Recommendations*

Based on the identification of high-risk zones and wards, particularly Vatva in the South Zone of Ahmedabad, the following policy measures are recommended to improve water quality and reduce the burden of waterborne diseases:

1. Strengthening Water Quality Monitoring Systems

- Establish real-time monitoring mechanisms for key parameters such as residual chlorine and microbial contamination at the ward level. Increase the frequency of sampling and testing in high-risk wards.
- Develop a centralized data management system for continuous surveillance and quick decision-making.

2. Improvement of Disinfection Practices

- Ensure adequate and consistent chlorination throughout the distribution. Install automated chlorination systems at critical nodes to maintain required residual chlorine levels.
- Conduct periodic audits of treatment plants and distribution points.

3. Rehabilitation of Water Distribution Infrastructure

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 04 , April - 2026

- Identify and repair leakages and cross-connections in pipelines, especially in older and densely populated wards.
- Replace aging pipelines with durable materials to prevent contamination ingress.

4. Targeted Public Health Interventions

- Focus healthcare resources and awareness programs in high-risk wards such as Vatva.
- Conduct regular health camps and disease surveillance programs.
- Promote community awareness on safe water handling, storage, and hygiene practices.

IX. CONCLUSION

This study presents a comprehensive data-driven framework for identifying risk-prone zones and wards in Ahmedabad city through the integrated analysis of historical water quality parameters and waterborne disease data. By focusing on key indicators such as residual chlorine and microbial contamination, along with disease incidence data for diarrhea, typhoid, cholera, and jaundice, the study establishes a clear linkage between water quality conditions and public health outcomes.

The application of statistical techniques, including normalization, frequency analysis, and composite risk index development, enabled systematic assessment of spatial and temporal variations in risk. The results identified the South Zone of Ahmedabad as the most vulnerable region, exhibiting the highest frequency of poor water quality and disease occurrence over the study period. Further ward-level analysis revealed Vatva as the most risk-prone ward within this zone, indicating persistent challenges related to water distribution infrastructure and contamination.

The proposed Composite Risk Index (CRI) proved to be an effective tool for quantifying and comparing risk levels across different spatial units. By integrating multiple indicators into a single framework, it facilitates objective classification of areas into high-, moderate-, and low-risk categories. This approach enhances the ability of urban managers to prioritize interventions and allocate resources efficiently.

The findings emphasize the importance of maintaining adequate residual chlorine levels and controlling microbial contamination within water distribution systems to minimize disease outbreaks. Additionally, the study highlights the need for continuous monitoring, infrastructure improvement, and coordinated efforts between water supply and public health agencies.

Overall, this research demonstrates that the integration of environmental and health data through a structured analytical framework can significantly improve the identification of vulnerable urban areas. The methodology developed in this study is scalable and can be applied to other cities facing similar challenges, thereby contributing to sustainable urban water management and improved public health planning.

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